Indigenous Knowledge and Ecology of Subterranean Termites on Grazing Lands in Semi-arid Ecosystems of Central Uganda

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A PhD Thesis Submitted to the University of Nairobi, Department of Land Resource Management and Agricultural Technology in Partial Fulfillment for the Award of a Doctorate of Philosophy in Dryland Resource Management.

Declaration

This thesis is my original work and has not been presented for a degree in any other University.

Signed ______________________ Date 09/08/11

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This thesis has been submitted with our approval as University supervisors

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DEDICATION

To my family

To my father (Musoke Erias), who worked tirelessly sometimes under difficult circumstances to secure an education for me. To my wife (Namutebi Shamilah), for the overwhelming encouragement and emotional support during the study and thesis development.

ACKNOWLEDGEMENTS

I am so grateful to my supervisors Dr. Moses Nyangito, Dr. Denis Mpairwe and Prof. John Nderitu for the technical guidance and encouragement rendered to me during the course of the study. Dr. Moses Nyangito is particularly appreciated for ensuring all the necessary logistical and institutional support which ensured the successful completion of the study. I am also grateful to Dr. Denis Mpairwe for the overwhelming assistance in designing experimental trials, sampling procedures, field supervision and data analysis. Prof. John Nderitu is also applauded for the guidance rendered to me during proposal development and conceptualization of the entire study. I also extend my appreciation to RUFORUM (Regional Universities Forum for Capacity Building in Agriculture) and NaLIRRI (National Livestock Resources Research Institute, Uganda) for partially funding the study. The Association of African Universities (AAU) is commended for availing funds that aided in thesis development. Finally, I extend my sincere gratitude to the farmers and Production department of Nakasongola District for their dedicated participation in the study.

Abstract

Development of sustainable termite management interventions in any ecosystem requires adequate knowledge of the ecological interactions between termites and other ecosystem components. diversity and composition of termite assemblages and proper understanding of farmers' ethno-ecological knowledge of the termite problem. To this effect, a study was conducted in the rangeland ecosystem in semi-arid Nakasongola of Uganda with intention to generate information to aid in the formulation of sustainable termite management practices in the area. The objectives of the study were: (1) to investigate farmers' ethno-ecological knowledge of the termite problem; (2) to examine the termite assemblage structure and (3) to analyze the effect of ecological factors on composition and foraging intensity of subterranean termites on the grazing lands.

The study involved administration of pre-tested semi-structured questionnaires on 120 randomly selected respondents to capture information on farmers' perceptions of the genesis and prevalence of the termite problem, factors enhancing termite damage on vegetation, temporal and spatial variability of damage, diversity of termite species and potential termite control strategies. The termite assemblage structure was established by collecting termite samples following a standardized direct search sampling protocol. The standardized sampling protocol that involved sampling for termite species and selected soil and vegetation variables in selected sections of the belt transects was used to analyze the effect of ecological factors on composition and foraging intensity of subterranean termites. The factor-effect relationships were analyzed using principal component and canonical correspondence analysis, and modeled by non-linear regression.

Kruskal–Wallis test showed that there was a significant difference (X^2= 451.5, P>0.0001) among farmers' ranking of factors responsible for the destructive behaviour of termites on rangeland vegetation. Overgrazing and deforestation were significantly (X^2= 156, P>0.0001) ranked higher than other factors. Use of chemical insecticides and removal of the queen from mounds were reported as the most common control methods attempted by 74% and 30% of the farmers respectively. However, use of cattle manure and heaps of organic materials were noted as potential ecologically sustainable termite control strategies that require further evaluation and improvement. The termite assemblage in the study area constituted of 16 termite species from eight genera, three sub-families and one family. Species from the sub-family *Macrotermitinae* and genus *Macrotermes* constituted 69 and 38% of the total number of species sampled respectively. The assemblages comprised of Group II (wood, litter, dung and grass feeders) and Group IV (true soil feeders) feeding groups, with most of the species belonging to Group II. Most of the species were noted to nest in epigeal and hypogeal nests with a few species nesting in wood.

Results from nonlinear regression of percentage of bait consumed with basal cover indicated that highest consumption of baits (95%) occurred within a range of 55-60% basal cover beyond which the amount of bait consumed reduced. Litter and biomass quantity, pH and bulk density were noted as the most influential environmental variables driving the variability in termite composition while basal cover was the major determinant of foraging intensity. The results from the study implied that rangeland management techniques that enhance accumulation of adequate litter and maintenance of adequate basal cover are critical in mitigating termite damage on rangeland vegetation.

Thesis Layout

Chapter 1

This chapter covers the description of the destructive behaviour of termites on ecosystem functioning in termite infested semi-arid ecosystems. The chapter also identifies the key knowledge gaps that are critical in development of coherent as well as sustainable termite management strategies aimed at mitigating termite damage on rangeland vegetation. Further, the chapter gives a review of work on farmers' ethno-ecological knowledge of the termite problem, termite assemblage structure of savanna ecosystems and the effect of ecological factors on termite dynamics. The general description of the study area is also provided in the same chapter.

Chapter 2

The chapter documents farmers' ethno-ecological knowledge of the termite problem in semi-arid Nakasongola, Uganda. The farmers' perceptions on severity and causes of the termite problem, diversity of termite species in the ecosystem, temporal and spatial variations in termite damage levels, and existing termite control strategies are described.

Chapter 3

The chapter covers a detailed analysis of the termite assemblage structure on grazing lands in semi-arid Nakasongola. The section describes the composition and diversity of the families, sub-families, genera and species that constitute the termite assemblages. The diversity of functional groups and nesting sites is also described.

Chapter 4

In this chapter, the effects of selected ecological factors (both biotic and abiotic) on composition and foraging intensity of subterranean termites are analyzed and discussed. The key factors driving spatial variations in composition of termites and their resultant effects on vegetation are discussed. The ecological factors enhancing the destructive behaviour (foraging intensity) of termites on rangeland vegetation are also highlighted.

Chapter 5

This chapter covers a synthesis of the entire study and provides general recommendations for management of termite infested rangelands as well as for further research in the area.

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Chapter 1

General Introduction

1.1 Introduction

Uganda's rangelands, also known as the "cattle corridor" cover about 43% of the total land area stretching from the north-east, through the central to the south-east of the country (NEMA, 1996). They are of immense social, ecological and economic importance as they support over 40% of the human population, 55% and 42% of indigenous and exotic cattle respectively, 42% of sheep and goats, 36% of pigs and about 38% of the national poultry flock. Approximately 60% of the households in these rangelands are livestock keepers which signify the importance of livestock production in these areas (Livestock Development Program, 2002). About 85% of the total milk and beef production in Uganda is derived from these rangelands (Mpairwe, 1999).

Unfortunately, the rangeland ecosystem productivity for grazing is steadily deteriorating owing to overgrazing, deforestation, bush/weed encroachment, uncontrolled fires, and extension of cropping to marginal lands among other factors (NEMA, 2007). In many parts of the cattle corridor, particularly on the rangelands of Nakasongola District, the situation is exacerbated by surges in termite activity resulting into enormous destruction of grazing lands by termites and hence driving the ecosystem to extreme degradation (Sekamatte, 2001). The dominant termite species belong to the genus *Macrotermes* and the species have constructed numerous mounds on the grasslands ranging between 8-525 mounds per hectare which has greatly reduced the amount of land available for grazing. This has resulted in concentration of livestock in small areas hence exacerbating the problem of ecosystem degradation.

Termites have also been observed to forage on various species of both herbaceous and woody species in the ecosystem. However, grass species have been reported to be more susceptible to termite damage leading to denudation of grass cover which translates into high levels of feed scarcity. Consequently, sustaining animal nutrition of 184, 111 heads of cattle, 36, 944 goats and 22, 164 sheep that are estimated to depend on native rangeland vegetation in Nakasongola is a major challenge and hence the lives of 127,067 farmers who are reported to derive their livelihood from livestock production are threatened (Byenkya and Mpairwe, 2007).

The diminishing grass cover is also associated with the disruption of the ecological interactions between grasses and woody species, upon which the structure of savanna vegetation depends. Further, the combined effect of overgrazing and termite damage on basal herbaceous vegetation have contributed to emergence of extensive bare surfaces that enhance extra-ordinarily high rates of surface run-off, erosion, surface evaporation and silting of downstream water reservoirs that exacerbates the water scarcity problem in the area. Farmers in the area have reported that termites demonstrate strong preference for particular grass species and pointed out *Hyparrhenia* species as one of the most preferred grass by termites. This tendency of termites to prefer particular species to others poses a great threat to rangeland biodiversity with subsequent reduction in resilience of the rangeland ecosystem. Other than damages on pasture and fodder trees, termites cause serious damage to crops resulting in losses between 10%-30% in maize (Sekamatte, 2001). Wooden fences are also destroyed making grazing management extremely difficult.

Control of termites on grazing lands in semi-arid ecosystems is largely based on use of various kinds of chemical insecticides (Sekamatte and Okwakol, 2007). However, the high cost of chemical insecticides renders the method unaffordable by majority of farmers. Further, chemical control is ecologically un-sustainable since it poses a great threat to rangeland arthropod diversity with a consequence that populations of termite insect-predators may reduce resulting in escalation of the current termite problem (Sekamatte, 2001). This calls for dedicated efforts to develop termite management interventions that are ecologically sound as well as socially acceptable by the farmers. Okwakol and Sekamatte (2007) reported that development of sustainable macro-faunal management practices for any ecosystem should be premised upon an explicit understanding of the structure and ecology of the concerned macro-faunal communities. The authors further demonstrated that understanding the assemblage structure (species composition, species and functional group diversity) of soil macro-fauna is critical in generating coherent principals upon which sustainable management of the concerned macro-fauna communities would be based. Dawes-gromadzki (2008) also noted that detailed knowledge of local species diversity as well as the diversity of functional groups of termites (different groups of species that have different ecological strategies, e.g. different feeding habits) is critical in development of sound termite management practices, e.g. agricultural, grazing and fire management.

Dauber (2005) however reported that the structure, behaviour and the subsequent impact of soil macro-fauna communities is dependent on the influence of other ecological factors. In this regard, Mitchell (2002) and Wood (1991) noted that foraging intensity of subterranean termites on vegetation was higher in highly disturbed grasslands than on intact grasslands suggesting that level of disturbance was a major driver of foraging intensity. Such findings imply that adequate understanding of how variations in ecological factors drive variability in structure and behaviour of termites is necessary to generate strategies that aim at favourable manipulation of ecological factors to reduce the destructive behaviour of termites. In addition to generation of knowledge on termite assemblage structure and the complex interactions between termites and ecological factors, Altieri (1993). Morse and Buhler (1997) emphasized the importance of farmers' ethno-ecological knowledge in aiding the development of socially acceptable termite (pest) management interventions. The authors further noted that the current philosophy in pest management is that if scientists have to work with farmers to improve crop protection and production, they should value farmers' indigenous technical knowledge systems (ethno-science) and recognise farmers' constraints. The concept of indigenous pest (such as termites) management knowledge relates to the way in which local people view and understand their environment and how they structure, code, classify, interpret and apply meaning to their experience (Altieri, 1993; Nkunika, 2002; Price, 2001). The strong point of farmers' indigenous knowledge systems is that it is the product of frequent observation of crops, pasture and trees during the whole cropping, grazing and production cycles, and it comprehends continuities within the diverse landscape and vegetation.

Practices and principles grounded in the theory of ethno-ecology are often used for capturing farmers' pest management knowledge and practices (Bjo¨rnsen Gurung, 2003; Price and Bjo¨rnsen Gurung, 2006). Ethno-ecological knowledge may be understood as spontaneous knowledge, culturally referenced, learned and transmitted through social interactions and is targeted at resolution of daily routine situations (Toledo, 1992). A growing body of literature suggests that many farming communities have a thorough knowledge of the history, biology and bionomics of pests that affect their crops, pasture or trees (Altieri, 1993; Bjo¨rnsen Gurung, 2003; Nyeko *et al.*, 2002; Nyeko and Olubayo, 2005; Price 2001; Price and Bjo¨rnsen Gurung, 2006). Understanding the potentials and drawbacks of farmers' indigenous pest management knowledge may form the basis for constructive generation of appropriate termite management strategies on grazing lands in semi-arid Nakasongola.

1.2 Farmers' ethno-ecological knowledge of subterranean termites

1.2.1 Farmers' knowledge of termite taxonomy

Local communities are able to identify major genera and species using simple community based taxonomic skills (Sileshi *et al.*, 2009). Nyeko and Olubayo (2005) reported that farmers in Tororo district of Uganda identified 14 species with distinct vernacular names. The farmers were able to use simple features such as shape and size of mounds, size, colour and shape of workers, soldiers and alates. Other features used by farmers to aid identification were flight periods of alates, presence or absence of vents on mounds and types of nests among others. Sekamatte and Okwakol (2007) also reported that 70–100% of the farmers interviewed across five districts of Uganda were able to identify various termites in their area using simple taxonomic features. Farmers were also able to identify termites using vernacular names in Kenya (Malaret and Ngoru, 1989), Somalia (Glover, 1967), Zambia, and Malawi (Nkunika, 1998, Sileshi *et al.*, 2008).

1.2.2 Farmers' knowledge of termite abundance and distribution

Farmers were also noted to possess good understanding of the abundance and distribution of termites in their area. For example, most farmers in Tororo district of Uganda rated *Macrotermes bellicosus* and *M. subhyallinus* as the most abundant termite species (Nyeko and Olubayo, 2005), which was in agreement with Pomeroy (1978) who noted that the two species dominated most termite assemblages in Uganda. However, farmers' rating of *M. bellicosus* and *M. subhyallinus* as being more abundant on upland and lower altitudes respectively, disagreed with Pomeroy (1978) who stated that the two species had similar distributions. Farmers in Machakos district of Kenya associated *Macrotermes* and *Odontotermes* species with farmland more than bushland. They could also identify the humus feeders from those that attack crops or trees (Malaret and Ngoru, 1989).

1.2.3 Farmers' perceptions of termites as pests

Studies evaluating farmers' perceptions of termites (Nkunika, 1998; Nyeko and Olubayo, 2005; Sekamatte and Okwakol, 2007; Sileshi *et al.*, 2008) have demonstrated that farmers have good knowledge of those species that are pests. In Tororo district of Uganda, farmers rated *M. bellicosus* and *M. subhyallinus* as most serious pests to trees, crops and rangelands (Nyeko and Olubayo, 2005). Although *Pseudacanthotermes spriniger* was reported to damage some crops, farmers perceived it as a minor pest that does not merit control (Nyeko and Olubayo 2005). Out of the six genera identified by farmers in southern Zambia, *M. falciger* was at the top of the pest list (Nkunika, 1998). In eastern Zambia, farmers ascribed most of the crop damage to *M. falciger* and *M. subhyallinus*. *Microtermes* species are considered major pests in Africa (Wood *et al.*, 1980) were not rated as serious pests by most farmers (Malaret and Ngoru, 1989, Nyeko and Olubayo, 2005, Sileshi *et al.*, 2008). This is probably because *Microtermes* species do not build termitaria. Damage to plants by *Microtermes*, *Allodontermes*, and *Ancistrotermes* spp. is often internal or subterranean. This probably makes these species less apparent to farmers.

1.2.4 Farmers' knowledge of causes and seasonal variations in termite damage

Most farmers in eastern Zambia believe that crops become susceptible to termite attack at maturity (Wood *et al.*, 1980). According to these farmers, termite damage to crops, trees and rangeland is more severe during dry spells or drought periods. Similarly, Ugandan and Kenyan farmers considered termite damage to be more severe in the dry months compared with the wet months (Malaret and Ngoru, 1989; Nyeko and Olubayo, 2005). Damage by termites is greater during dry periods or droughts than periods of regular rainfall (Logan *et al.*, 1990; Black and Okwakol, 1997; Sileshi *et al.*, 2005). The increases in termite damage could also be associated with climate change-induced drought. In recent decades, drought linked to El Niño episodes has become more intense and widespread in southern Africa (Fauchereau *et al.*, 2003). Farmers in Uganda and Zambia also mentioned that termite problems are more serious now than in the past (Sekamatte and Okwakol 2007; Sileshi *et al.*, 2008; Tenywa 2008). In a termite survey conducted in eastern Uganda, elders linked the increasing termite problem to the low abundance of predatory ant species attributed to aerial sprays intended to control tsetse flies (*Glossina* species) during the 1960s and 1970s (Sekamatte and Okwakol, 2007). However, Tenywa (2008) reported that termite damage on trees, crops and rangelands could have increased as a result of the depletion of the usual termite food due to deforestation and overgrazing. Deforestation may have also resulted in loss of the natural enemies of termites such as the aardvark (*Orycteropus afer*), pangolin (*Manis* species), aardwolf (*Proteles cristatus*), and hedgehog (Pomeroy *et al.*, 1991; Peveling *et al.*, 2003). Habitat loss has led to the disappearance of the aardvark in countries such as Ethiopia (Jiru, 2006). Continuous cultivation and overstocking reduce the diversity of termites (Glover, 1967, Black and Okwakol, 1997; Eggleton *et al.*, 2002) followed by outbreak of those species that tolerate disturbances (Wood *et al.*, 1980).

1.3 Farmers' Termite Management Practices

1.3.1 Destruction of termitaria (mounds) and the colony

Farmers practice different methods of destroying the colony. These include digging the nest and removing the queen; burning wood, grass, or cow dung; pouring hot water, insecticides, rodenticides, or paraffin into the nest; and flooding the nest with rainwater to kill the colony (Malaret and Ngoru, 1989; Nyeko and Olubayo, 2005). Although destruction of the colony has been advocated by researchers (Logan *et al.*, 1990), success has been limited because of various constraints including labour requirements and lack of knowledge about termite biology. These practices are directed toward mature colonies of the mound building species, and species that do not build mounds (e.g., many *Odontotermes* and *Microtermes* spp.) are often overlooked. Those species that build mounds are subterranean for the first few years. Even if mature colonies are killed, the immature colonies could spread to take over the area (Logan *et al.*, 1990). In addition, many farmers resist destroying the mounds (Nkunika, 1998) even when they are live or very easy to flatten. Mound destruction may not be acceptable, probably because termitaria are sacred places among many communities in Africa (Copeland, 2007).

1.3.2 Use of plant materials

Many plant species have been used by farmers across Sub-Saharan Africa to control termites (Logan *et al.*, 1990; Nkunika, 1998). Among the plant species mentioned frequently by farmers, *Euphorbia tirucalli* ranks first. Farmers in Malawi and Zambia believe that planting *E. tirucalli* in crop fields or applying its branches in planting holes deters termites (Sileshi *et al.*, 2008). In Tanzania, the leaves and roots of *E. tirucalli* are soaked in water and the solution is sprayed to protect seedlings from termites (Logan *et al.*, 1990). In Zambia, farmers apply crushed pods of *Bobgunnia* (*Swartzia*) *madagascareinsis* in planting holes (Nkunika, 1998; Sileshi *et al.*, 2008). Extracts from leaves of *Tephrosia vogelii* are also used to protect tree seedlings in Malawi and Zambia (Nkunika, 1998; Sileshi *et al.*, 2008). The limitation of plant materials is that farmers' recipes vary widely. Most plant materials also break down rapidly in the soil and do not give prolonged protection from termite attack (Logan *et al.*, 1990). In addition, the hazard they present to humans and the environment is often unknown. Therefore, greater care is required in their use. Rigorous toxicological, safety, and environmental evaluation are also needed for their wider application.

1.3.3 Wood ash

Wood ash has been widely mentioned as one of the control practices in eastern and southern Zambia (Nkunika, 1998; Sileshi *et al.*, 2008) and Nigeria (Banjo *et al.*, 2003). However, the mechanism by which ash provides protection against termites is unclear. Variations also exist on the effectiveness of ash (Nkunika, 1998). This information gap demands better evaluation of wood ash against the most serious termites for the particular area.

1.3.4 Protein- or sugar-based products

In Uganda, farmers use dead animals, meat, and sugarcane husks to "poison" *Macrotermes* mounds (Sekamatte *et al.*, 2001). Farmers in Tsangano district of Mozambique mentioned that they used leftover pork or beef to control termites (Sileshi *et al*., 2008). Similarly, Nigerian farmers bury dead animals or fish viscera to reduce termite attack on crops (Logan *et al*., 1990). In South Africa, Riekert and van den Berg (2003) experimentally demonstrated significant reduction in termite damage on maize using fish meal. Until recently, the rationale behind this practice had not been clear (Logan *et al*., 1990). Sekamatte *et al*. (2001) demonstrated that the reduction in termite damage in plots that received fish meal is due to increased activity of ants. The protein-based baits resulted in greater ant nesting near maize plants and reduction in termite damage (Logan *et al*., 1990).

1.3.5 Cow dung and urine

Cow dung and urine have been used for termite control by farmers (Malaret and Ngoru, 1989; Nkunika, 1998) In Machakos district of Kenya, farmers smear cow dung on posts to protect them from termite attack (Malaret and Ngoru, 1989). In Monze district of Zambia, farmers used fresh cow dung to reduce termite damage to maize (Nkunika, 1998). Similarly, farmers in southwestern Nigeria believe that goat and cow dung reduce termite damage (Banjo *et al*., 2003). Reduction in termite damage to rangeland using cow dung has been demonstrated in an experiment conducted in the "Cattle Corridor" of Uganda (Mugerwa *et al*., 2008). Further research should establish the effectiveness and the mechanism by which cow dung reduces termite damage to crops or trees.

1.4 Termite assemblage structure of African savanna ecosystems

Termites are a large and diverse group of insects consisting of over 2600 species worldwide. With over 660 species, Africa is by far the richest continent in termite diversity (Wood, 1991). While comparing the termite assemblages of South Africa, Senegal, Ivory Coast and Nigerian savannas, Ferrar (1982) reported that the species belonged to three families: *Kalotermitidae* (3 genera), *Rhinotermitidae* (2 genera) and *Termitidae* (28 genera). However, the author noted that majority of the species belonged to one family (*Termitidae*) and two sub-families (*Termitinae* and *Macrotermitinae*). Ferrar (1982) further noted that *Macrotermes*, *Micrototermes* and *Odontotermes* species were the dominant termite species and where encountered on all sampled sites of the savannas. Members of the sub-families *Apicotermitinae* and *Nasutitermitinae* were reported as most rare species among members of the *Termitidae* family. In fact, *Trinervitermes* species were the only species of the sub-family *Nasutitermitinae* encountered on all sampled sites. Other species (*Nasutitermes*, *Mimeutermes*, *Eulleritermes* and *Eutermellus*) were limited to particular ecosystems. In the Darfur region of Sudan, Pearce *et al.* (1995) reported that the termite assemblages comprised of species from two families namely *Kalotermitidae* and *Termitidae*. The family *Kalotermitidae* consisted of only three genera (*Neotermes*, *Psammotermes* and *Coptoterme*) while the family *Termitidae* consisted of two sub-families namely *Termitinae* (3 genera) and *Macrotermitinae* (9 genera) and majority of the species belonged to the sub-family *Macrotermitinae* (Pearce *et al.*, 1995). In the rangelands of Uganda, Sekamatte (2001) reported that the termite assemblages consisted of species from two families (*Hodontotermitidae* and *Termitidae*). *Hodotermes* and *Microhodotermes* were the only genera encountered from the family *Hodontotermitidae* and the species were extremely rare. He however reported that species from two sub-families (*Macrotermitinae* and *Termitinae*) constituted majority of the species in the ecosystem. Review of such literature indicate that termites from the family *Termitinae* and sub-families *Macrotermitinae* and *Termitinae* dominate the termite assemblages in most of African savannas but there is a necessity to clearly describe the termite assemblages in terms of species, nesting groups and functional group diversity so as to develop coherent and sustainable termite management interventions.

1.5 Effect of ecological factors on structure and behavior of subterranean termites

Some studies (Bandeira *et al.*, 2003; Jones *et al.*, 2003) have reported that termite assemblages were affected by the level of habitat disturbance and trampling, with a reduction in termite diversity and abundance from the best preserved site to the most disturbed site. Removal of vegetation was noted to affect the micro-climate and quantity and quality of feeding and nesting sites. Vegetation loss due to grazing and tree cutting was reported to result in simplification of termite assemblages, both in diversity and feeding groups. Chopping down trees was also noted to increase the input of dead plant matter to the soil, which may increase populations of some termites, especially wood-and leaf-feeders. With time, the reduction of food resources, lack of soil cover, and microclimatic changes may cause population reduction and local extinction (Bandeira *et al.*, 2003). The density of conspicuous nests and the number of nest building species were also reported to decrease with level of disturbance, and no nest was present in cleared sites. Vasconcellos *et al.*, (2010) noted that termite assemblages were sensitive to habitat disturbance and seasonal climatic variations. The authors further noted that all feeding groups were affected by the gradient of anthropogenic disturbance, but the wood-feeders were the most affected. However, the authors noted that some termite species are able to tolerate the negative effects of disturbance and may even increase in abundance with increased disturbance. This is especially true for species that can resist desiccation and food depletion by nesting deep underground or in large epigeal mounds (Jones *et al.*, 2003). The effects of the dry season on the apparent structure of the termite assemblages were noted to be more evident in the cleared area than in vegetated areas. The lack of soil cover has a negative effect on the microclimate, which may force termites to seek protection deeper into the soil, under stones near trees, and to reduce foraging activity near the surface. The population and biomass of termites are apparently higher in the rainy season in most ecosystems.

Mathieu *et al.* (2009) noted that samples taken from below herb tufts or woody branches hosted a much higher abundance and diversity of soil macro-fauna than the bare ground, showing a striking local limitation by habitat and /or food availability. For instance, a dead trunk on the ground was seen to be a specific resource that favoured termite activity, especially the soil and wood feeding genus *Amitermes* (*Termitinae*). *Brachiaria brizantha* tussocks were observed to offer both specific environmental and feeding resources for soil macro-fauna and thus their size and shape influenced soil macro-fauna biodiversity. Grass tussocks are therefore regarded as biodiversity hotspots for soil macro-fauna in many pastures. In this regard, soil macro-fauna biodiversity was noted to (i) decrease with increasing distance to the nearest grass tuft (ii) increase with increasing vegetation cover and (iii) be influenced by size of the largest herb tuft in the micro-landscape. Plants are known to change their micro-environments by intercepting sun rays and rain and absorbing soil water (Geiger and Aron, 2003). In addition, they modify the chemical properties of the soil near roots by adsorbing mineral nutrients and releasing organic-C exudates, lowering pH, activating micro-flora, and deposting litter. This process known as "ecological engineering" creates a gradient of specific physical and chemical properties which are beneficial to soil macro-flora and also probably to soil macro-fauna, mainly through bottom-up processes such as increasing organic matter. *B. brizantha* grasses were noted to influence the soil environment by cooling down and reducing soil temperature variations beneath and around them, in the upper 15 cm of soil, where soil macro-fauna are most abundant.

1.6 Research questions and objectives

The overall aim of the study was to contribute to generation of knowledge to aid in the development of coherent termite management strategies on grazing lands in semi-arid Nakasongola. The three specific objectives were aligned with the following specific research questions.

1. What were farmers' perceptions on the causes of the termite problem, spatial and temporal variation of the problem and potential control strategies?
2. What were the diversity (composition and abundances), functional groups and nesting sites of species that constituted the termite assemblage on grazing lands of Nakasongola rangelands?
3. What was the effect of ecological factors (biotic and abiotic factors) on the composition and foraging intensity of subterranean termites on grazing lands of Nakasongola rangelands?

The specific objectives of this study were:

1) To investigate farmers' ethno-ecological knowledge of the termite problem on grazing lands in semi-arid ecosystem of Nakasongola.
2) To establish the termite assemblage structure on grazing lands in semi-arid Nakasongola.
3) To analyze the effect of biotic and abiotic factors on composition and foraging intensity of subterranean termites on the grazing lands.

1.7 Study area

The study was conducted in Nakasongola District ($55^0$140'N, 32^0 50'E), which forms part of Uganda's cattle corridor that stretches diagonally from the Uganda-Tanzania border in the South through the plains of Lake Kyoga region, to Karamoja in the North East. Nakasongola District is located in the central region of Uganda on Bombo – Gulu road 114 Km north of capital Kampala (Figure 1.1). The mean daily maximum temperature is 30^0C. Night heat surges are very common. The average humidity ranges from 80% in the morning to 56% in the afternoon. Rainfall range between 500-1000mm per annum and there are two rain seasons (Figure 1.2). The main rain season occurs from March to June while the second rain season follows from August to October/November. A long dry season occurs from December to February while a short spell comes around July/August. Very often the second rain season in the district is unreliable and at times the dry season extends from August to February. The minimum and maximum evaporation rates range from 1500mm to 1700mm during wet and dry seasons respectively.

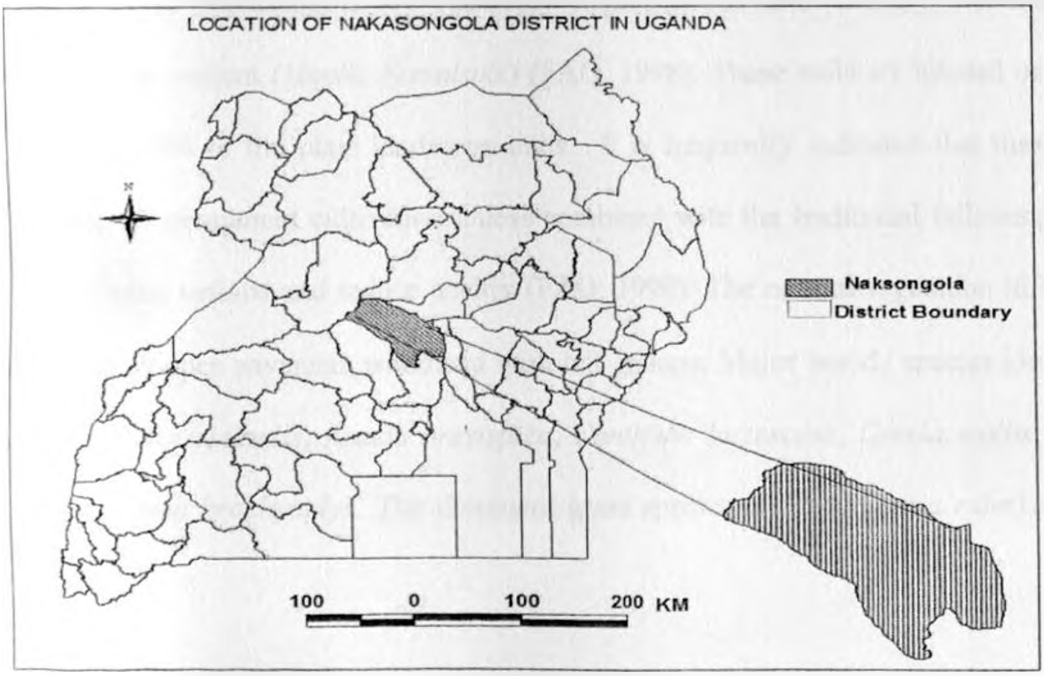
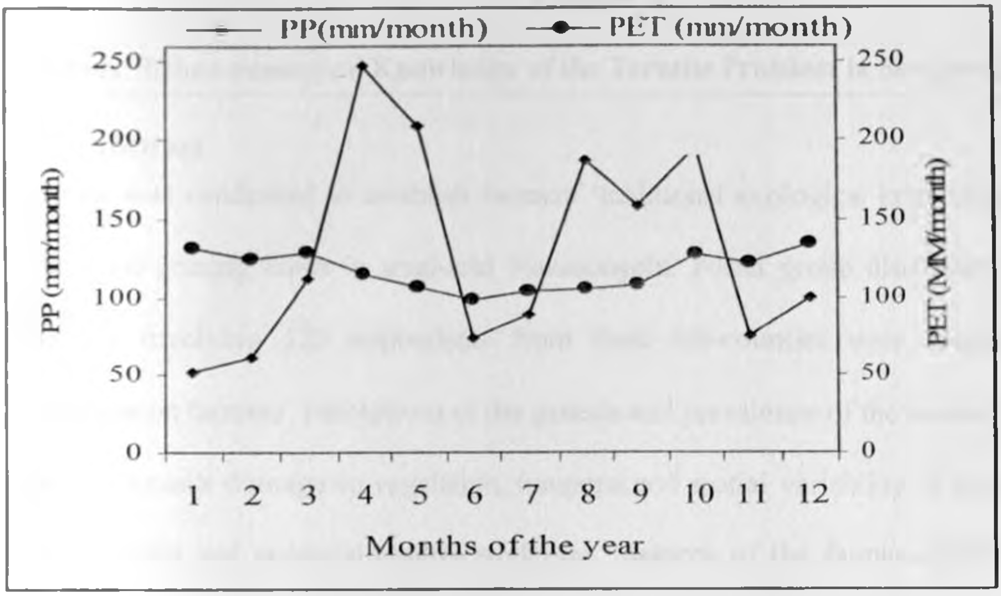


Figure 1.1: Map of Uganda showing the location of Nakasongola District



Source: Mugerwa, 2009

Figure 1.2: Precipitation and potential evapotraspiration for Nakasongola District. PET is for Potential Evapotranspiration and PP is for precipitation.

The soils of Nakasongola are relatively homogeneous and strongly weathered with high sesquioxide content (*Haplic Ferralsols*) (FAO, 1998). These soils are located on slope ranging between 5-8% of the plain landscape units. It is frequently indicated that these soils are not suitable for permanent cultivation unless combined with the traditional fallowing techniques to restore basic cations and reduce acidity (FAO, 1998). The natural vegetation in Nakasongola is dominantly open savannah woodland with tall grasses. Major woody species identified include: *Combretum terminalis*, *Acacia brevispica*, *Canthium lactescens*, *Grevia mollis*, *Teclea nobilis* and *Vernonia brachycalyx*. The dominant grass species is *Hyparrhenia rufa*(Langdale-Brown, 1970).

Chapter 2

Farmers' Ethno-ecological Knowledge of the Termite Problem in Semi-arid Nakasongola

2.1 Abstract

A survey was conducted to establish farmers' traditional ecological knowledge of the termite problem on grazing lands in semi-arid Nakasongola. Focus group discussions and individual interviews involving 120 respondents from three sub-counties were conducted to capture information on farmers' perceptions of the genesis and prevalence of the termite problem, factors enhancing termite damage on vegetation, temporal and spatial variability of damage, diversity of termite species and potential control strategies. Majority of the farmers (60% of respondents) rated severity of termite damage on vegetation as high with only 33% rating it as low. Kruskal–Wallis test showed that there was a significant difference (X^2= 451.5, P>0.0001) among farmers' ranking of factors responsible for the destructive behaviour of termites on rangeland vegetation. Farmers' ranking of overgrazing and deforestation was significantly higher (X^2= 156, P>0.0001) than for other factors. Eight termite species were identified and the species belonged to one family (*Termitidae*), two sub-families (*Macrotermitinae* and *Termitinae*) and four genera (*Macrotermes*, *Odontotermes*, *Cubitermes* and *Pseudocanthotermes*). Use of chemicals and removal of the queen from mounds were reported as the most common control methods attempted by 74% and 30% of the farmers respectively. Overgrazing and deforestation were identified as the major factors favouring the destructive behaviour of termites on vegetation while use of cattle manure and heaps of organic fertilizers were potential termite control strategies that require evaluation. Therefore, proper grazing management and application of organic techniques (manures and organic fertilizers) may have potential to restore the ecological integrity of termite infested grazing lands.

2.2 Introduction

Devastation of rangeland vegetation by subterranean termites is a major constraint to animal production in the rangelands of Uganda, particularly, in semi-arid Nakasongola (NEMA, 2007; Sekamatte and Okwakol, 2007; Tenywa, 2008). Although termites' attack severely damages all components of rangeland vegetation, grasses are more susceptible to termite damage. Consequently, there is a remarkable decline in the grass component of the ecosystem which translates into reduced feed availability, poor livestock performance and increased susceptibility of livestock to feed scarcity-induced mortalities. Termites have not only denuded the grass vegetation but have also frustrated several attempts to restore pasture vegetation on degraded bare surfaces by destroying reseeded pasture (Mugerwa *et al.*, 2008; Mpairwe *et al.*, 2008). Studies have noted that termites of the sub-family *Macrotermitinae*, the most dominant species in Nakasongola, collect up to 60% of the grass, woody material and annual leaf fall to construct fungus gardens in their nests (Lepage *et al.*, 1993). Mitchell (2002) noted that populations of destructive termite species build up during dry seasons and increase over successive dry years to a level where they remove substantial amounts of the standing grass biomass and all the litter, posing severe competition to livestock for feeds. During such times, the combined effect of livestock grazing and termite damage is to virtually denude considerable tracts of grassland, exposing soils to erosion by both wind and water.

Termites have also constructed numerous mounds (ranging between 80 – 350 mounds ha^{-1}) on the grasslands which has considerably reduced the size of land available for livestock grazing (Plate 2.1). This has resulted in restriction of livestock to smaller areas leading to overgrazing and further driving the ecosystem to extreme deterioration (Nakasongola District State of

Environment Report, 2004). The escalating number of mounds over time is also associated with proliferation of termite resistant shrubs which gradually become the major component of the woody vegetation.

Plate 2.1: Mounds of *Macrotermes* species in a grazing paddock in Nakasongola

In relation to grazing management, termites have equally constrained interventions aimed at sustainable utilization of pasture through enormous destruction of wooden fencing posts used to partition ranches into grazing paddocks. Increased costs of livestock production due to frequent replacement of damaged posts and continuous purchase of expensive chemicals to treat fence posts are other associated termite-induced constraints to livestock production.

The need to mitigate termite damage as well as termite-induced rangeland degradation cannot be overemphasized. This calls for dedicated efforts to develop ecologically sustainable as well as socially acceptable termite management strategies. However, development of such strategies requires an explicit understanding of the genesis of the termite problem in the area, temporal and spatial variability of termite damage; existing termite control strategies and the various types/species of termites damaging the ecosystem (Cowie *et al*., 1989). Such useful information could be constructively obtained from farmers faced with the problem. Sileshi *et al*. (2009) noted that communities have a clear understanding of termite associated problems and practice mitigation measures based on indigenous knowledge of termite ecology and taxonomy. Involving communities in the research cycle would enhance proper understanding of the problem situation as well as focusing research to the actual issues of interest to the concerned communities (Norton *et al*., 1999). Further, this would result in generation of interventions that are responsive to peoples' challenges which is critical to adoption of generated interventions (Chitere and Omolo, 1993). Berkes (2008) also noted that resource-poor farmers look for practices that best fit their biophysical, economic, and socio-cultural conditions. Ethno-ecological knowledge or traditional ecological knowledge (Okwakol and Sekamatte, 2007) is thus important for formulation of sustainable termite management in Africa. Ethno-ecological knowledge is defined as " a cumulative body of knowledge, practices and beliefs evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings with one another and with their environment" (Berkes, 2008). Despite its importance in sustainable termite management, there continues to be little information on farmers' traditional ecological knowledge about termite ecology and management. This study was thus conceived to investigate farmers' traditional ecological knowledge of the termite problem with the intent to build more coherent principles required in the development of appropriate termite management strategies on grazing lands in semi-arid Nakasongola, Uganda.

2.3 Materials and Methods

2.3.1 Location and sampling procedures

The study was conducted in Nabiswera, Nakitoma and Wabinyonyi sub-counties located in the eastern and central parts of the district respectively (Figure 2.1). The sub-counties were purposively selected based on the severity of the termite problem on grazing lands. The District Production Department provided a sampling frame which contained all livestock keeping households from the three selected sub-counties. After consultations with the district extension staff, forty households were selected from the sampling frame of each sub-county following systematic random sampling procedure. The total number of livestock keeping households in each sub-county was divided by 40 to obtain the n^{th} value. The first household was then selected randomly from the frame and the subsequent households were selected every after the n^{th} value until when forty households were obtained per sub-county. Qualitative and quantitative data was obtained using semi-structured pre-tested questionnaires administered by way of one-on-one direct interviews.

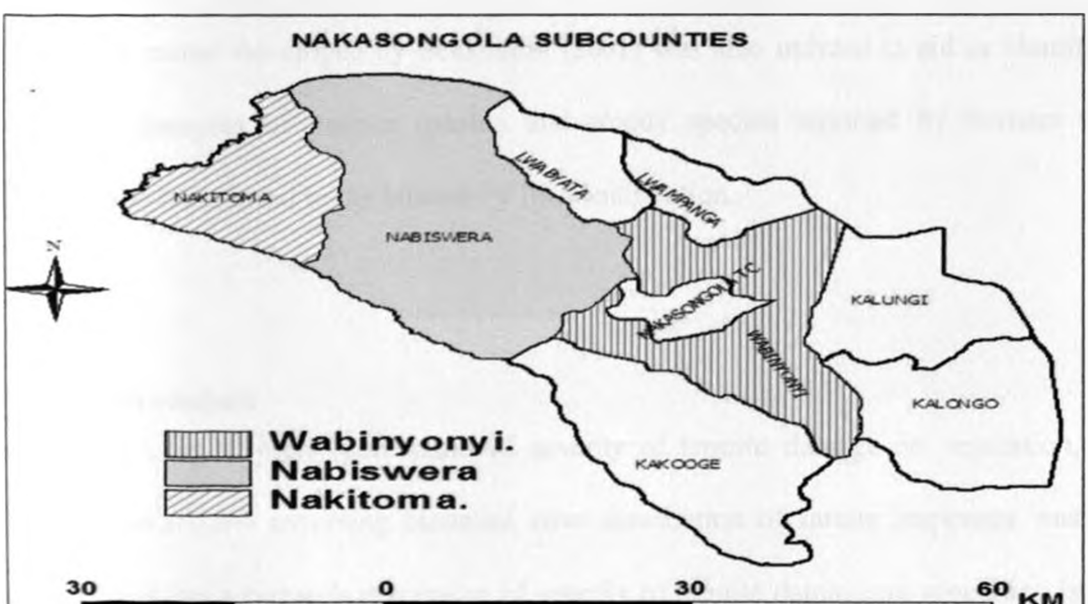


Figure 2.1: Map of Nakasongola District showing the location of Wabinyonyi, Nabiswera and Nakitoma sub-counties.

Focus group discussions (one per sub-county) were also held to corroborate the information gathered in direct interviews. The questionnaires and focus group discussions were intended to capture information such as:

- Genesis of the termite problem in the area
- Severity of termite damage on grazing lands
- Factors favouring the destructive behaviour of termites on rangeland vegetation
- Diversity and distribution of termite species on grazing lands
- Spatial and temporal variability in termite damage levels
- Existing termite control strategies

Samples of all termite species identified by farmers were collected, preserved in 80% alcohol and transported to the laboratory for identification. In the laboratory, the specimens were identified to genus or species level following the standard determination keys by Webb (1961). The termite record developed by Sekamatte (2001) was also utilized to aid in identification of specimens. Samples of various grasses and woody species reported by farmers were also collected and transferred to the laboratory for identification.

2.3.2 *Data analysis*

In characterizing farmers' perception of severity of termite damage on vegetation, a general linear model (GLM) assuming binomial error distribution of farmer responses was used. We hypothesized that a farmer's perception of severity of termite damage on vegetation is a function of farmer specific explanatory variables such as dominant termite species, dominant pasture species and level of termite infestation on grazing lands. Farmers' responses on the severity of termite damage on vegetation were used as dependent variables and the dominant termite species, dominant pasture species and level of termite infestation on farmers' grazing lands as explanatory variables. The data was then subjected to logistic regression following the requirements of probit model in XLSTAT (2011). Farmers' responses on factors favouring the destructive behaviour of termites on vegetation were subjected to nonparametric test (Kruskal–Wallis one-way analysis of variance) to establish whether differences existed between the different factors. The factors were ranked by farmers using a nominal scale of 1-5, with 5 being the most important factor favouring termite damage and 1 the least important factor. The computed sums of ranks were compared using multiple pair wise comparisons to establish the significance differences among different factors (Dunn, 1964). XLSTAT (2011) was used to generate summary statistics (frequencies, percentages and means) for most variables and later tabulated. The information characterizing the different termite species identified by farmers and the various termite control strategies was summarized and tabulated.

2.4 Results

2.4.1 Genesis and prevalence of the termite problem

Most of the farmers (45%) indicated that the problem was first recognized as far as ten to twenty years back (Table 2.1). It was also reported that severe termite damage on rangeland vegetation among sites was noticed at different times depending on the management techniques undertaken on various management units (ranches) but generally, the problem seem to have intensified 20 years ago.

Table 2.1: Farmers' profile, damage levels and year of recognition of the termite problem

	Frequency	% of respondents
Sex of respondents (N=120)		
Male	116	96.7
Female	4	3.3
Age group (N=120)		
20-29	2	1.7
30-39	14	11.7
40-49	65	54.2
50-59	17	14.2
>60	22	18.3
Main occupation (N=120)		
Livestock production	91	75.8
Crop production	27	22.5
Charcoal making	2	1.7
Major animal enterprise (N=120)		
Cattle	107	89.2
Goats	9	7.5
Pigs	2	1.7
Chicken	2	1.7
Severity of damage on vegetation (N=120)		
Low	40	33
Moderate	8	7
High	72	60
Year of recognition (N=118)		
1-10 years ago	34	28.8
11-20 years ago	53	44.9
21-30 years ago	24	20.3
31-40 years ago	7	5.9

Majority of the farmers (60% of respondents) rated severity of termite damage on vegetation as high. Farmer's perception of severity of termite damage was found to be a function of only one operator-specific variable, dominant termite species. The probability of a farmer perceiving severity of termite damage as high or low (only two responses for logistic) differed significantly (X^2=57, DF=3, P<0.001; X^2=52, DF=3, P<0.001; X^2=56, DF=1, P<0.001) with the dominant termite species on farmers' grazing lands in Nakitoma, Nabiswera and Wabinyonyi sub-counties respectively. Farmers perceived severity of termite damage as low on grazing lands where the dominant termite species were *Cubitermes* species (*Termitidae: Termitinae*).

Kruskal–Wallis test showed that there was a significant difference (X^2= 451.5, P>0.0001) among farmers' ranking of factors favouring the destructive behaviour of termites on rangeland vegetation. The significant differences in farmers' ranking of the factors were maintained among the various sub-counties (Table 2.2). Farmers' ranking of overgrazing and deforestation was significantly higher (X^2= 156, P>0.0001) than for other factors. However, deforestation was ranked highest of the two factors in Wabinyonyi and Nabiswera sub-counties. The farmers reported that overstocking is a common phenomenon on most grazing lands due to the strong social attachment to large numbers of cattle. This has resulted into overgrazing followed by emergence of large bare surfaces that enhance extra-ordinarily high rates of erosion (NEMA, 2007). It was further observed that charcoal making is increasingly becoming the major source of livelihood to people whose grazing lands can no longer sustain livestock production or where climatic variations have made livestock production a non-sustainable source of livelihood. 55% of the interviewed farmers were practicing charcoal making as an alternative source of livelihood alongside livestock production. The combined effect of overstocking and charcoal making has resulted in severe denudation of the herbaceous and woody components of the ecosystem, consequently driving the system to extreme degradation. The farmers' rating of overgrazing and deforestation as the major factors enhancing termite damage on rangeland vegetation was seen to be consistent with their rating of termite damage levels in sites with varying levels of primary production.

Table 2.2: Farmers' rankings of factors enhancing termite damage on rangeland vegetation

Sub-county	causes	Sum of ranks	(Chi-square, DF, p-value)
Wabinyonyi	Deforestation	6580^{c}	X^2= 156, 4, P>0.0001
	Overgrazing	6260^{c}	
	Droughts	3060^{b}	
	Reduced use of fire	2420^{ab}	
	Reduced no. of predators	1780^{a}	
Nakitoma	Deforestation	6260^{c}	X^2= 156, 4, P>0.0001
	Overgrazing	6580^{c}	
	Droughts	1780^{a}	
	Reduced use of fire	2420^{ab}	
	Reduced no. of predators	3060^{b}	
Nabiswera	Deforestation	6580^{c}	X^2= 156, 4, P>0.0001
	Overgrazing	6260^{c}	
	Droughts	3060^{b}	
	Reduced use of fire	2420^{ab}	
	Reduced no. of predators	1780^{a}	

Numbers within a sub-county followed by different letter superscripts indicate significant differences (Kruskal–Wallis multiple pair wise comparison test, $p < 0.05$).

Damage levels of pestiferous termite species on rangeland vegetation varied with primary productivity attributed to extent of anthropogenic disturbance among different sites. Majority of farmers (98%) rated termite damage levels as low in sites with high primary productivity (areas with dense herbaceous cover (55-100% cover) while 99% of the respondents rated damage levels to range between high and very high in sites with low primary productivity (areas with sparse herbaceous cover (below 55% cover). Reduced number of termite predators from the ecosystem and reduced use of fire as a rangeland management tool were ranked as the least important factors enhancing termite damage on vegetation in Wabinyonyi and Nabiswera sub-counties while increased occurrence of drought was ranked lowest in Nakitoma sub-county.

2.4.2 Diversity of termite species

Over 57% of farmers were aware of at least one termite species encountered on their grazing lands (Table 2.3). Farmers' identification of termites was based on a number of characteristics. These included: (i) presence of mounds, (ii) shape of mound, (iii) size of mound, (iv) presence or absence of vents on mounds, (v) size and color of alates, (vi) size, color and shape of soldiers and workers, (vii) flight period of alates, (viii) feed source and (ix) spatial distribution.

A total of eight species were identified in the local language and some of these were markedly consistent with farmers' identification of termite types reported by Nyeko and Olubayo (2005). The findings revealed that Nsejere (*Macrotermes bellicosus*), Mpawu (*Macrotermes herus*) and Nkurukuku (*Cubitermes* species) were the most common termite species and were reported by 97, 95 and 95% of the respondents respectively. Bulala (*Odontotermes* spp. 3) and Ntaike (*Odontotermes* spp. 2) were also noted as the least known termite species to farmers. Farmers identified all the species known to them by their local names. All species belonged to one family (*Termitidae*), three sub-families (*Macrotermitinae*, *Termitinae* and *Nasutitermitinae*) and four genera. The two genera (*Odontotermes* and *Macrotermes*) were also reported by Sekamatte (2001) as most dominant genera on rangelands in Semi-arid Nakasongola.

Table 2.3: Farmers' identification of termite species

Termite species	Main characteristics
"Mpawu" (*Macrotermes herus*), N=114, 95%	Builds big-sized mounds with no basal ventilation holes. The mounds are more rounded than those of *Macrotermes bellicosus*. The outer wall of the mounds is usually massive and is made of solid, highly compacted soils. In very hot areas, the mound bears a chimney of up to 5m. Mounds located in valleys are massive and are also covered with vegetation. Some mounds bear an overhung. Alates swarm between March and April usually before or after a rainfall. Alates are dark brown in color and medium-sized. The soldiers have yellowish heads and dark brown abdomens. The termite feeds on both fresh and dry materials, relatively tolerant to poorly drained soil and hence can be found in both lowlands and upper slopes.
"Ntunda" (*Macrotermes* spp. 1), N=68, 65%	Builds small mounds with vents. The mounds are usually constructed on the sides of the bigger mounds constructed by Mpawu and Nsejere termites. The soldiers have big yellowish heads similar to soldiers of "Mpawu". Alates have black abdomens with pale white wings and usually swarm in September during evening hours. The termite feeds on small quantities of soft dry materials. The termites can be evenly distributed as long as there are big mounds where they construct their small mounds.
"Naakka" (*Odontotermes* spp. 1), N=100, 83%	Does not build mounds. The soldiers have big yellowish heads similar to soldiers of "Mpawu". In case of any danger to the colony, the soldiers produce a characteristic sound by rubbing their mandibles on dry materials to alert the rest of the colony. Alates are small in size, have black abdomens and white wings. Alates swarm in October and usually respond to rains of the previous night. The termite usually feeds on soft dry materials such as litter from forage leaves and stems. The alates are so delicious and highly cherished in Central Uganda (Buganda). Mostly abundant on up slopes.
Ntaike (*Odontotermes* spp. 2), N=62, 59%	Does not construct mounds. Alates swarm from bare ground in September usually around midday, especially during bright sunshine. Alates are easy to lure out when some noise is made around the exit points. The soldiers have white abdomens and workers have pale red heads. The termite consumes minute amounts of soft dry materials. Mostly abundant on up slopes.

Table 2.3 continued

Termite species	Main characteristics
"Bulala" (*Odontotermes* spp. 3) (N=60, 57%)	Does not build mounds but forms circular patches on ground with small vents in the middle of the patch. Alates are medium-sized and brown. Alates swarm in April at any time of the day. Workers are small with dark brown heads. Soldiers are medium-sized with brown heads and white abdomen.
"Nsejere" *Macrotermes bellicosus* (Smeathman) N=116, 97%	Builds big mounds with/without basal ventilation holes. The shape of mounds ranges from roughly cone-like to irregular shapes. Some mounds bear tall, thin walled hollow structures (turrets) for ventilation (Plate 2.2). The turrets disappear on mounds located in relatively cooler areas. The occurrence of a basal shaft for ventilation is only common on mounds of this species. The size of mounds varies from place to place but mounds located in valleys are usually massive and are covered by vegetation. Alates are dark brown in color and are largest of all types of alates. Alates swarm in May, especially on a rainy day. The soldiers have big dark brown heads with dark abdomens (Plate 2.3). The soldiers are very active, so defensive and take longer to desiccate and/or die when exposed to heavy direct sunshine as compared to other types. The termite feeds on both fresh and dry materials, tolerant to poorly drained soil and hence can be found in both lowlands and upper slopes.
"Kaseregeti" *Pseudacanthotermes militaris* (Hagen) N=113, 94%	Does not construct mounds. Workers are small in size, yellow in color and pointed. Alates medium sized and dark. Alates swarm from 1 to 4 pm between late October and December, depending on availability of rainfall. Two types of soldiers: medium sized with red heads and small dark ones. Feed on all sorts of dry and fresh organic materials. The species are common up-slope.

Table 2.3 continued

Termite species	Main characteristics
"Nkulukuku" (*Cubitermes* spp.), N=114, 95%	Builds small mounds. The mounds are usually constructed using highly compacted soil making them very strong (Plate 2.4). Workers have swollen abdomens which are usually black in color. The abdomen of workers is usually full of soil. The soldiers have yellowish cylindrical heads. The termite usually feeds on soil. Alates are black in color. The workers are mostly cherished by predator insects and easily desiccate under direct sunshine. Mainly located in waterlogged areas in lowlands.

Plate 2.2: Mound of Macrotermes bellicosus

Plate 2.3: Soldier of Macrotermes bellicosus

Plate 2.4: Mounds of *Cubitermes* species

2.4.3 Spatial and temporal variability in termite damage

Generally, farmers considered damage levels to be higher in the dry months than in the wet ones (Table 2.4). The farmers also illustrated variations in damage levels among the different dry seasons and rated damage levels as very high and high for the second and first dry seasons respectively. Variations in damage levels were reported among the different rainy/wet seasons. However, farmers noted that once denuded patches are reseeded with pasture, termites can cause very high damage levels on pasture seedlings even in the wet seasons. This is in line with Mugerwa *et al.* (2008) who observed that termites damaged all pasture seedlings a few days post emergence in the wet season.

Table 2.4: Termite damage levels in different seasons

	Frequency	% of respondents
Damage level in first rainy season (March-May)		
Low	102	87.9
Moderate	14	12.1
Damage level in second rainy season (Sep-Nov)		
Low	97	83.6
Moderate	18	16.4
Damage level in first dry season (Jun-Aug)		
Low	29	25
Moderate	22	19
High	55	45.8
Very high	10	8.6
Damage level in second dry season (Dec-March)		
High	39	33.6
Very high	77	66.4

Level of termite damage was rated as low, moderate, high and very high.

Variations in levels of termite damage to rangeland vegetation among various topographic classifications were reported by majority of respondents (Table 2.5). Farmers reported the level of termite damage to rangeland vegetation as very high and low on upland and lowland respectively.

Table 2.5: Damage levels on varying topography

Topography	Frequency	% of respondents
Lowland (N=108)		
Low	87	80.6
Moderate	21	19.4
Mid slope (N=108)		
Low	8	7.4
Moderate	79	73.1
High	21	19.4
Upper slope (N=108)		
High	36	33.3
Very high	72	66.7

Level of termite damage was rated as low, moderate, high and very high

2.4.4 Control of termites on grazing lands

Farmers reported eight different methods for controlling termites on grazing lands (Table 2.6). Generally, the farmers' attempts at termite control involved use of plant extracts, physical methods (queen removal), chemical methods (inorganic chemicals and engine oil), use of organic materials (cow dung, organic heaps), heat and/or smoke (fire, hot water). Use of chemicals and removal of the queen from mounds were reported as the most common control methods attempted by 74% and 30% of the farmers, respectively. Findings from the study revealed that only a few farmers knew about the various control methods. Use of cattle manure and organic baits were the only control methods reported to be effective against all types of pestiferous termite species on grazing lands. Further, the operation of the two control methods did not involve destruction/disturbance of termite nests (mounds) unlike the rest of the methods.

Table 2.6: Termite control methods attempted by farmers

Method	How applied	Effectiveness
Cattle manure (N=18, 16% of respondents)	Accumulation of cattle manure through formation and alternation of livestock 'bomas' on termite infested degraded pasture.	Effective against all termite species that damage pasture.
Wood ash (N=20, 17%)	Dig hole on top of mound and pour available quantities of hot ash and seal the mound. Ash is also broadcasted or top dressed in rows of reseeded pasture seedlings.	Less effective on non-mound bulding termites and on termites that construct big mounds.
Chemicals (N=85, 74%)	Mix chemicals (usually diazole or ambush) with water. Dig out a portion of the mound from the top, pour in the mixture and cover the mound.	Effective against termites whose nests can be easily identified to allow spot application
Fire (N=10, 8%)	Dig hole on top of the mound, insert wood and grass and set fire to it, then seal to confine the smoke and heat.	Effective against termites that construct small to medium-sizes mounds but ineffective against termite that construct very big mounds.
Hot/cold water (N=10, 8%)	Dig a hole on top of the mound and pour hot or cold water and seal.	Less effective

Table 2.6: Continued

Method	How applied	Effectiveness
Queen removal (N=36, 30%)	Dig out the entire mound until the queen is reached. Remove the queen from the nest.	Less effective especially on termites that construct big mounds.
Heaps of crop residues (N=6, 5%)	Heap organic residues such as maize stover, tree branches, grass mulch to attract termites as well as to localize termite activity in specific places.	Effective against all termite species that damage pasture.
Tobacco leaves + red paper + wood ash + water. (N=7, 6 %)	Mix water with tobacco leaves, red pepper and wood ash and ferment for 5 days. Then pour in mounds and seal.	Less effective

2.5 Discussion

2.5.1 Genesis and prevalence of the termite problem

Restructuring of ranches in the early 1990's is blamed as the initial cause of severe deterioration of grazing lands in semi-arid Nakasongola (Nakasongola District State of Environment Report, 2004). The restructuring partitioned formally big ranches into smaller ones and subjected them to a constant stocking rate of 2.5 livestock ha^{-1}. This was followed by fencing off most of the established ranches in an attempt to control grazing and spread of livestock disease amongst livestock on different ranches. Most semi-arid ecosystems are largely non-equilibrium systems, characterized by extreme changeability and unpredictability of ecosystem dynamics, and require flexible land use strategies. The changes brought by the restructuring were inconformity to system behaviour. Restrictions on livestock mobility due to fencing and subsequent subjection of the system to constant stocking rates led to severe overgrazing and eventually degradation of the ecosystem. It is therefore not surprising that the farmers reported the termite problem to have intensified about ten to twenty years back shortly after the ranching restructuring exercise.

Increase in termite damage due to overgrazing and deforestation in rangeland ecosystems has also been reported by NEMA (2007), Mugerwa *et al.* (2008) and Wood (1991). Mugerwa (2009) also noted that the rate of consumption of herbaceous vegetation by termites was higher in highly disturbed than in less disturbed or intact ecosystems. Overgrazing and deforestation are associated with a reduction in availability of feed resources to termites. Termites of the genus *Macrotermes*, the dominant species on the grazing lands in Nakasongola (Sekamatte, 2001) are predominantly litter feeders but can also forage on dung, wood and grass (Wood, 1991). Reduction in the availability of litter deprives the species of their major source of food and in turn the species resort to standing grass for nourishment. Mitchell (2002) also reported that when litter production is reduced due to a combination of droughts and overgrazing, generalist feeders (*Macrotermes and Odontotermes* species) resort to standing grass as the main source of nutrition. Further, denudation of rangeland vegetation attributable to overgrazing and deforestation is associated with destruction of nesting sites for termite predators. Sekamatte (2003) also noted that denudation of basal vegetation resulted into loss of nests for termite predators particularly predator ants that nest in litter. In the same regard, farmers also reported that predator mammals (such as *Orycteropus afer*) that tunnel into mounds to prey on all casts of termites have been lost from the ecosystem due to hunting. Consequently, the prey-predator relationship between termite and their predators has been disturbed leading to increased population of termites which is associated with severe damage to vegetation. The results of the study supports the general notion that as termite-infested grazing lands become degraded due to overgrazing and indiscriminant tree cutting, termites become more destructive to the ecosystem. The findings imply that deterioration of the rangeland ecosystem deprives termites of resources necessary for their survival resulting into competition for common resources between termites and livestock.

2.5.2 Diversity of termite species

The findings of this study are consistent with Sekamatte (2001) who noted that termites from two sub-families (*Macrotermitinae* and *Termitinae*) were common species on grazing lands of Nakasongola. Sekamatte (2001) further reported that members of the genera *Cubitermes* and *Macrotermes* were the most abundant termite species in Nakasongola rangelands while Nyeko and Olubayo (2005) observed that *Macrotermes bellicosus* and *Macrotermes hyalinus* dominated the termite assemblage structure in the rangelands of Tororo District in Uganda. Farmers demonstrated that use of simple features such as mound structure, mound building character, flight period of alates and size, shape and color of soldiers, workers and alates are effective simple means of identifying termites. Based on feed sources, farmers demonstrated ability to identify pestiferous termite species responsible for denudation of pasture. However, as earlier noted by Nyeko and Olubayo (2005), such community based taxonomic skills seemed limited to few farmers. Mechanisms are necessary to promote farmer-to-farmer dissemination of such important information. Further, local names of species need to be compiled so that researchers and extension workers can communicate effectively with farmers on particular species rather than using general names of pest groups such as termites, which comprise of over 2600 described species (Kambhampati and Eggleton, 2000). The absence of some genera (such as *Ancistrotermes* and *Microtermes*) earlier reported by Sekamatte (2001) implied that the farmers' list of species was not exhaustive and necessitates more scientific investigations on termite assemblage structure in the area.

2.5.3 Spatial and temporal variability in termite damage

Farmers reported the level of termite damage to rangeland vegetation as most severe in the dry periods. A similar negative relationship between termite damage and rainfall was reported by farmers in Tororo District and Darfur region of Uganda and Sudan respectively (Nyeko and Olubayo, 2005; Pearce *et al.*, 1995), and is consistent with the general notion that peak termite attack on biomass occurs during dry periods (Logan *et al.*, 1990). Lepage (1982) noted that periods of intense foraging of *Macrotermes* species reflect the dynamics of colony energy requirements. In tropical environments where swarming occurs early in the rainy season, the highest food demand for nymphal maturation occurs during the subsequent dry season, and this suggests an adjustment in foraging to the needs of the colony (Lepage and Darlington, 2000). These findings suggest that grazing management techniques that enhance production of large amounts of biomass during wet periods and subsequent accumulation of litter during dry periods would help to meet the high food demands in dry periods. This would in turn reduce termite damage to pasture. Resting termite infested areas in the wet season would allow accumulation of litter which will nourish the termites to deter them from pasture. No wonder, termite damage is less severe in areas rested from grazing for about one year (Mugerwa, 2009).

The variability in levels of termite damage among various topographic classifications was attributed to the differing ecological conditions (such as vegetation and soil characteristics, fauna and flora biodiversity) that resulted into varying distributions and abundance of termite species over the various topographic classifications (Holt and Greenslade, 1979). Holt and Greenslade (1979) further noted that differences in distribution and abundance of mound building fauna from site to site were related to differences in the drainage capacity of the soil. In this regard, farmers noted that the abundance of pestiferous species was remarkably high in the upland and only one pestiferous species (*Macrotermes bellicosus*) was reported to be evenly distributed across grazing lands irrespective of topography. Lowlands were mainly associated with *cubitermes* spp. (*Termitidae*: *Termitinae*), which are largely soil feeders and cause insignificant damage to pasture. Malaret and Ngoru (1989) also noted that farmers in Machakos District of Kenya associated *Macrotermes* and *Odontotermes* spp. (*Termitidae*: *Macrotermitinae*) with sparse vegetation more than dense vegetation while Nyeko and Olubayo (2005) noted that *Macrotermes bellicosus* was rated as most abundant in the upland. The findings imply that upland vegetation is more susceptible to termite attack and consequently damage. The uplands need to be grazed lightly or rested from grazing for some time to allow sufficient production of biomass and accumulation of litter. This will provide sufficient food resources to termites and consequently deter them from damaging pasture. During such periods of rest or light grazing on uplands, heavy grazing may be done down slope.

2.5.4 Control of termites on grazing lands

Although use of synthetic chemicals was reported as the most common termite control strategy among farmers, the method is largely unaffordable by small scale farmers in Uganda (Sekamatte, 2001). Further, the use of chemicals has been discouraged for health and environmental reasons (UNEP/FAO/Global IPM Facility, 2000). The use of non-chemical control methods has thus been emphasized following the ban on persistent organo-chloride insecticides. The non-chemical control methods attempt to (i) prevent termite access to plants; (ii) reduce termite numbers in the vicinity of plants, and (iii) reduce susceptibility or increase resistance of plants themselves (Logan *et al.*, 1990). Although there is limited published information on non-chemical control practices on grazing lands, Mugerwa *et al.* (2008) noted that construction of livestock 'bomas' (Plate 2.5) on termite infested areas allowed accumulation of cattle manure and subsequently reduced termite damage on reseeded seedlings. Cattle manure was noted to provide alternative sources of nourishment to termites and hence relieved pasture from termite attack. In other studies, Mando *et al.* (1997) noted that grass mulch attracted termites, while Sekamatte (2001) reported that mulching maize fields with maize stover significantly reduced termite damage on maize. The mulch was also reported to provide alternative sources of food to termites as well as enhancing survival of termite predators which in turn reduce termite activity. Although few farmers attempted to use cattle manure (16%) and heaps of crop residues (5%) as a termite control practice, the methods are ecologically acceptable and practical. It is therefore important that potential methods such as use of cattle manure and heaps of organic materials be evaluated for their efficacy and where possible improvements made on them to make them more effective.

Plate 2.5: Cattle manure on the surface of a livestock "boma" in Nakasongola

Findings from the study revealed that all control methods reported by farmers (other than use of cattle manure and heaps of crop residues) attempt to mitigate termite damage on rangeland vegetation through killing the termites. In view of the important role of termites as useful ecosystem engineers in savanna ecosystems, termite management strategies that foster co-existence between termites and other ecosystem components are necessary in sustaining the ecological integrity of savanna ecosystems. As earlier noted, use of cattle manure attempts to control termite damage through provision of alternative feed sources to termites as well as enhancing activity of termite predators without killing the termites. In this regard, the beneficial roles that termites play in an ecosystem are maintained.

2.6 Conclusion

It was evident in the study that farmers are aware of the genesis of the termite problem. Although a number of factors were fronted to explain surges in termite damage to vegetation, majority of farmers largely attributed the termite problem to ecosystem deterioration associated with overgrazing and deforestation. Sustainable termite management strategies on grazing lands should not only target termites but also focus on ensuring ecological integrity as well as proper functioning of the ecosystem. It is also necessary to conduct scientific experimental investigations to establish degradation thresholds beyond which termites become destructive to rangeland vegetation. Such information would assist to guide management decisions in an attempt to maintain an ecologically favourable equilibrium between termites and other ecosystem components. The study has also provided some basic information about farmers' knowledge of the biology and ecology of termites that could aid the development and promotion of sustainable and socially acceptable termite control measures in rangelands. Farmers demonstrated a deep knowledge of the diversity, pest status and the spatial and temporal distribution of termites. Based on community-based taxonomic skills, farmers identified eight termite species in their local names, which were remarkably consistent with scientific identifications. Such indigenous scientific taxonomic knowledge need to be documented, promoted and where possible improved to facilitate communication between farmers, extension staff and scientists on specific termite species.

Farmers reported a continuum of methods used to control termites on grazing lands but the use of synthetic chemicals was the most common method. In the event that use of chemicals has been blamed for health and environmental reasons, it is necessary to evaluate the efficacy of ecologically sound termite control strategies and where possible improvements made on them. It was also evident that much of the indigenous knowledge on control of termites was limited to few farmers. This necessitates efforts to educate farmers on various termite control strategies as well as to encourage farmer to farmer transfer of such information.

Chapter 3

Termite Assemblage Structure on Grazing lands in Semi-arid Nakasongola

3.1 Abstract

Termites are regarded as the primary cause of vegetation denudation in semi-arid Nakasongola, Uganda. Despite their damage to ecosystem functioning, there have been little efforts devoted to the description of the termite assemblage structure in the area. A survey was conducted in the study area to describe the termite assemblage structure to inform the development of sustainable termite management strategies. The survey yielded 16 termite species from eight genera, three sub-families and one family. Species from the sub-family *Macrotermitinae* constituted 69% of the total number of species sampled. Members from the genus *Macrotermes* were the dominant species and constituted 38% of the total number of species sampled. The assemblage comprised of two feeding groups namely Group II and Group IV, with most of the species belonging to Group II. Most of the species were noted to nest in epigeal and hypogeal nests with a few species nesting in wood. Vegetation cover categories were noted to influence termite species richness. Highest species richness (14 species) occurred in sparse vegetation category followed by dense category (11) and the least (8 species) occurring on bare ground. The termite assemblage of Nakasongola was dominated by *Macrotermes* species which largely forage on litter and nest in epigeal mounds.

3.2 Introduction

Termites are occasionally associated with severe damage to rangeland vegetation, particularly, in degraded arid and semi-arid ecosystems (Pearce *et al.*, 1995; Michell, 2002). Throughout tropical Africa, several species of *Macrotermitinae* consume grass litter as a significant part of their diet and the most common of these species belong to the genera *Macrotermes, Odontotermes* and *Pseudacanthotermes* (Wood, 1991). Typical foraging is characterized by subterranean galleries leading to surface foraging holes from which termites emerge to remove dead grass and grass litter under cover of constructed soil sheeting. Termite foraging is particularly obvious during the dry season when bare rangeland can have up to 55 foraging holes per m^2 (Cowie and Wood, 1989). In Nakasongola District of Uganda, termites have been reported to cause reduction in the herbaceous (grasses and forbs) component of the vegetation and partly contributing to formation and expansion of bare surfaces (Sekamatte, 2001; NEMA, 2007). Consequently, the herders are faced with reduced feed availability, poor livestock performance, high livestock mortalities and eventually high levels of poverty among pastoral communities. Through removal of the sparse herbaceous vegetation, termites have also contributed to distortion of the complex ecological interactions between grasses and woody species leading to encroachment of grazing lands with shrubs. Mugerwa *et al.* (2008) noted that termites were the major barrier to pasture restoration on degraded bare patches in Nakasongola due to severe destruction of reseeded seedlings. Cowie and Wood (1989) also reported that *Psedocanthotermes* species were associated with significant reduction of grass cover during dry periods, while Mitchell (2002) observed that pestiferous termite species consumed over 60% of standing grass biomass. Termites have also been reported to cause severe damage on woody species. Farmers in Nakasongola reported that *Combretum collinum*, *Combretum molle*, and *Acacia hockii* were the most susceptible woody species leading to their decline from the ecosystem.

Despite the enormous damage to ecosystem function in semi-arid Nakasongola, there has been little effort devoted to the documentation of termite community inventories (Nyeko and Olubayo, 2005; Okwakol and Sekamatte, 2007). At any given site, the composition of a local termite assemblage will govern the overall impacts of termites on ecosystem processes (Lavelle *et al.*, 1997; Jones & Prasetyo, 2002). This is because most termite assemblages are made up of species that represent a diverse range of feeding (e.g. wood, soil, grass) and nesting (e.g. mounds, hypogeal and arboreal nests, nests in wood) strategies (i.e. different 'functional groups'). Consequently different species and groups of species are likely to have different ecological effects on ecosystem components (Dawes-Gromadzki, 2005).

Detailed knowledge of local species diversity as well as the diversity of functional groups of termites (different groups of species that have different ecological strategies, e.g. different feeding habits) is critical (Dawes-Gromadzki, 2008). It is a prerequisite for evaluating and quantifying the type and extent of their functional roles in ecosystem processes, i.e. the contributions that different termite species and functional groups make to the regulation of different ecosystem processes. It is also important for the development of sound management practices, e.g. agricultural, grazing and fire management (Abensperg-Traun, 1991; Inoue *et al.*, 2001). Jones (2002) also noted that accurate assessments of structures of termite assemblages are necessary to explain the ecological influence of termites on various sites. Okwakol and Sekamatte (2007) observed that sustainable management of soil macro-fauna in Uganda is constrained by a shortage of information on the activity, behaviour and environmental tolerances of many species of this fauna and by the limited understanding of the structural and functional stability of soil fauna communities in general. The study was therefore aimed to examine the termite assemblage structure on grazing lands in semi-arid Nakasongola with the intention to inform development of sustainable termite management strategies as well as mitigate termite-induced rangeland deterioration.

3.3 Materials and Methods

3.3.1 Description of the study area

The study was conducted on three ranches (Kamukama, Kyapapa and Mandwa ranch) located in Nakasongola District (55^{0}140'N, 32^{0} 50'E) (Figure 3.1).

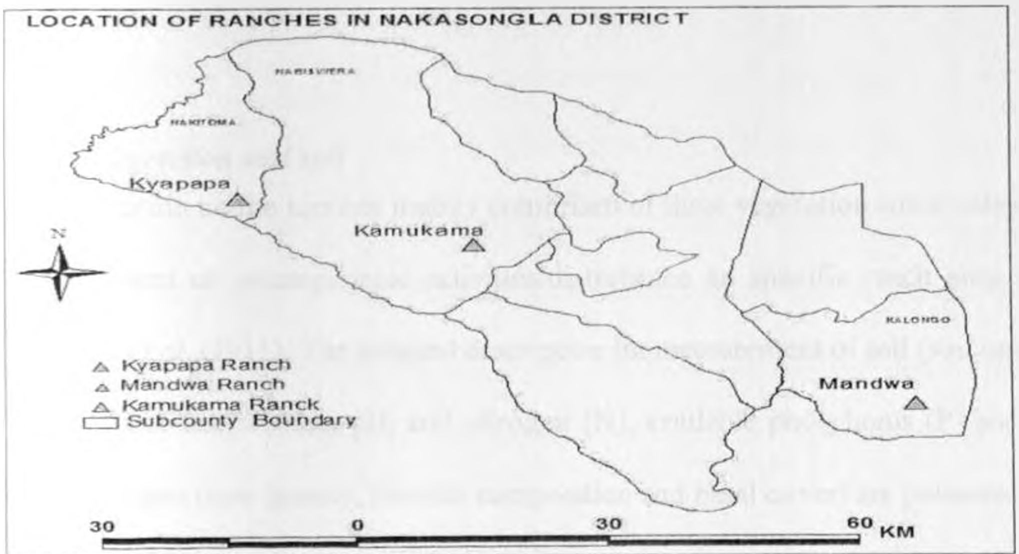


Figure 3.1: A map of Nakasongola District showing the location of study sites

Kamukama ranch is highly degraded with a larger portion of bare surfaces (between 75 to 100% of total grazing land) that facilitates extra-ordinarily high rates of erosion. Large gullies ranging from 1-3 meters wide and 2-4 meters deep are a common feature on the bare surfaces. The ranch is as well highly infested with termites and the resultant vegetation is partly a product of termite activity. The number of mounds ranges from 33 to 525 with an average of 227 mounds ha^{-1}. We particularly selected the ranch to represent sites that are highly infested with termites. The number of epigeal mounds per hectare (mound density) was used as a proxy for level of termite infestation (Obi and Ogunkunle, 2009). Kyapapa ranch on the other hand is moderately degraded with 25-50% of grazing land being bare. Smaller numerous gullies ranging from 1-2 meters wide and 1-2 meters deep are also typical of the bare surfaces. The ranch is moderately infested with termites and the number of epigeal mounds ranged from 8 to 300 with an average of 119 mounds per hectare. The ranch was selected to represent sites that are moderately infested with termites while Mandwa ranch (80 epigeal mounds per hectare) was selected to represent sites that are less infested with termites.

3.3.2 Vegetation and soil

The vegetation on the ranches mainly comprised of three vegetation cover categories depending on the extent of anthropogenic activities/disturbance on specific ranch sites as described by Mugerwa *et al.* (2011). The detailed description for measurement of soil (soil organic matter, soil moisture and temperature, pH, soil nitrogen (N), available phosphorus (P) and potassium (K)) and vegetation (tree density, floristic composition and basal cover) are presented in chapter four. The three vegetation cover categories included dense vegetation cover, sparse vegetation cover and bare ground. The vegetation cover categories are majorly a product of intricate interactions between climatic conditions and anthropogenic activities such as overgrazing, indiscriminate tree cutting and bush burning among others. The dense vegetation cover category on Kamukama ranch mainly comprised of *Tarrena graveolens* and *Acacia* species forming 62%, 3% of the total woody canopy cover and woody density of 575, 125 trees per hectare respectively. The basal vegetation was dominated by *Brachiaria* species contributing 88% of the basal herbaceous cover. The sparse vegetation cover category was dominated by *Cynodon dactylon* and *Loudentia* *lagerensis* forming 67% and 12% of the herbaceous species cover. Scattered woody species on the sparse vegetation cover category were also dominated by *Tarrena graveolens* forming 34% of the woody canopy cover. The bare ground category mainly comprised of highly scattered *Harrisonia abyssinica* and *Tarrena graveolens* forming less than 0.5% woody canopy cover each.

On Kyapapa ranch, the dense vegetation cover category mainly comprised of *Securidaca longepedunculata* and *Terminalia brown* forming 70%, 7% of the total woody canopy cover and woody density of 400, 300 trees ha^{-1} respectively. The basal vegetation was dominated by *Hyparrhenia* and *Brachiaria* species contributing 32 and 17% of the herbaceous basal cover. The sparse vegetation category was dominated by *Brachiaria* species forming 50% of the total species cover. Scattered woody species on the sparse vegetation category were dominated by *Securidaca longepedunculata* and *Terminalia brown* forming 16 and 8% of the woody canopy cover. The bare ground mainly comprised of highly scattered *Tarrena graveolens* forming 12% canopy cover.

The dense vegetation category of Mandwa ranch mainly comprised of *Tarrena graveolens* and *Lantana camara* forming 31%, 13% of the woody canopy cover and woody density of 100, 50 trees ha^{-1} respectively. The basal herbaceous vegetation was dominated by *Brachiaria* species and *Imperata cylindrica* contributing 33 and 31% of the basal cover. The sparse category was dominated by *Hyparrhenia* and *Brachiaria* species forming 63% and 23% of the total species cover. The soil pH, soil moisture, soil temperature, bulk density, soil organic matter, nitrogen, phosphorus and potassium on all study sites ranged between 3.6 to 5.8, 1.18 to 15.22, 26.7 to 33.5 °c, 1.23 to 1.7 g/cm^3, 0.13 to 1.7%, 0.01 to 0.2%, 1.5 to 8.7 ppm and 0.17 to 0.46 cmoles/kg(me/100g) respectively.

3.3.3 Sampling and classification of termite species

As indicated in the preceding section, the vegetation on Kamukama and Kyapapa ranches was demarcated (blocked) into three vegetation cover categories (dense, sparse and bare ground) while that of Mandwa ranch was demarcated into two categories (dense and sparse vegetation cover categories). Termite sampling was conducted between December and January, the period when termite activity and subsequent destruction of vegetation by termites is reported to be severe (Nakasongola District State of Environmental Report, 2007). Five plots measuring 50 x 50 m were randomly established (Dawes- Gromadzki, 2008) on each vegetation cover category resulting into 15 plots for Kamukama and Kyapapa ranches and 10 plots for Mandwa ranch. Sampling was conducted in 2010 and 2011. Termite samples were collected from each plot following a standardized direct search sampling protocol based on searching different microhabitats (Dawes-Gromadzki, 2005). Four trained people searched each plot for 1 hour (a total of 4 person-hours per plot). Searching was conducted in pairs, with the two pairs starting at opposite plot corners. Working back-and-forth across the plot, the first member of each pair examined epigeal and intermediate mounds (new and old so that both the mound builders and secondary occupants were recorded) and foraging trails (carton runways) on trees and surface litter, including those from arboreal nests. The second member examined standing dead wood (including tree stumps), lying dead wood (including logs, branches and twigs), carton sheeting on dead wood and soil beneath rotten wood for termites. For each termite population encountered, representatives of the soldier and worker castes were collected and preserved in 80% ethanol. Taxonomic identification for collected samples was done at family, sub-family, genus using standard determination keys by Webb (1961) and where possible to species' level using the termite record of Sekamatte (2001). Termite species were also classified into nesting groups, and the nesting habitats were recorded for each termite collection. The nesting groups were defined as: (1) hypogeal nesting (found below ground); (2) wood nesting (found in woody items); (3) epigeal (in mounds protruding above ground); and (4) arboreal (in tree nests) (Eggleton *et al.*, 2002). Species were also assigned to feeding groups based on *in situ* observations and gut content classification method by Donovan *et al.* (2001).

3.3.4 Data collection and analysis

The number of encounters for each termite species was recorded during sampling and the average number of encounters per specie for the two sampling periods (years) was obtained. In order to establish the general picture on the composition of termite assemblage in Nakasongola, the data collected from the various vegetation categories and ranches was pooled before analysis. Termite species accumulation curves were constructed to calculate the average species richness for all possible combinations of sites (plots) using Biodiversity R (Oksanen *et al.*, 2005). The same curves were used to compare species richness among pooled plots for the different vegetation cover categories. The first- and second-order Jackknife, Chao and bootstrap formulae estimates were used to make predictions of the total species richness in the survey area (Kindt and Coe, 2005). Rank abundance curves were constructed to establish the most abundant termite species and to estimate their approximation to the theoretical ecological distribution curves to ascertain termite conservation status in the survey area using Biodiversity R (Oksanen *et al.*, 2005). In order to establish the influence of vegetation cover categories on termite species composition, the data on species encounters from various vegetation categories was subjected to linear discriminate analysis (Huberty, 1994) in XLSTAT (2011) based on the assumption that within-class covariance matrices are equal. Discriminate analysis was used to establish a set of linear combinations of the quantitative variables (species encounters) that best reveals the differences among the vegetation cover classes.

3.4 Results

3.4.1 Species composition

Termite species representing one family (*Termitidae*), three sub-families (*Macrotermitinae, Termitinae* and *Nasutitermitinae*) and nine genera were identified from 824 termite collections obtained from the three ranches (Table 3.1). Due to the absence of a well developed inventory on termites species in Nakasongola and the widely recognized difficulties in identification of termite species based on morphological characteristics of soldier and worker casts, most of the species could not be identified beyond genus level. The sub-family *Nasutitermitinae* and the genera *Trinervitermes* and *Procubitermes* were recorded for the first time. Species from the sub-family *Macrotermitinae* constituted 69% of the total number of species sampled.

Table 3.1: Diversity and relative abundance (average no. of encounters per species for the two sampling periods) of termite species collected from three sites (ranches). Feeding groups are II = wood, litter and grass feeders; IV = true soil feeders. Nesting groups are: w = nesting in wood; h= hypogeal nests, e = epigeal mound, a = arboreal nest. Termite species in groups I (lower termite dead wood and grass-feeders) and III (Termitidae feeding in the organic rich upper layers) were not captured and identified in this study

Termite species	Feeding group	Nesting group	Kamukama Ranch			Kyapapa Ranch			Mandwa Ranch	
			Bare	Sparse	Dense	Bare	Sparse	Dense	Sparse	Dense
TERMITIDAE										
Macrotermitinae										
Macrotermes bellicosus (Smeathman)	II	e	3.5	14	9	5.5	12	5	5	1
Macrotermes herus	II	e	0	13	9	5	11	0	0	2
Macrotermes sp.1	II	e	0	0	13	3.1	7	0	10	4
Macrotermes sp.2	II	w	5.5	16	9	0	11	10	0	0
Macrotermes sp.3	II	a	0	6	0	0	0	0	0	0
Macrotermes sp.4	II	h	0	6	0	0	0	4.2	0	0
Odontotermes sp.1	II	w	0	0	9	0	7	0	0	0
Odontotermes sp.2	II	h	2.1	11	7	0	6	6	5.2	0
Microtermes spp	II	h	0	0	0	0	4	0	0	0
Ancistrotermes spp	II	h	0	0	0	2.5	0	4	0	0
Pseudocanthotermes militaris (Hagen)	II	w	0	0	0	0	4	0	0	0
Termitinae										
Cubitermes sp.1	IV	e	0	46	0	5	67	0	7	2
Cubitermes sp.2	IV	h	2	0	8	0	4.5	0	0	0
Cubitermes sp.3	IV	e	0	0	0	2	0	0	0	0
Procubitermes spp	IV	e	0	4	0	0	0	0	7	0
Nasutitermitinae										
Trinervitermes oeconomus (Tragardh)	II	e	0	0	0	0	0	0	0	1.3

Members from the genus *Macrotermes* were the dominant species and constituted 38% of the total number of species sampled. Unlike other species, *Trinervitermes oeconomus*, *Cubitermes* spp.3, *Microtermes* spp. and *Pseudocanthotermes militaris* were very rare species and only occurred in one sampling plot. The species composition of termite assemblages significantly (Wilks' Lambda test, $p<0.0001$) varied among ranches and among vegetation cover categories (Figure 3.1). Factor 1 (X-axis) and Factor 2 (Y-axis) explained 75.7 and 24.3% of the total variance due to species composition among vegetation cover categories. The factor loadings for bare, dense and sparse vegetation cover centroids were -3.255, -0.570 and 2.664 on factor 1 respectively. The loadings on factor 2 were -1.311, 1.846 and -0.726 for bare, dense and sparse respectively. The results for factor loadings implied that the composition of termite assemblages for bare and sparse cover categories was distinguished on Factor 1 and the high factor loading of the dense vegetation category implied that it was distinguished from other categories using Factor 2. Termite assemblage structure in the dense vegetation cover category was dominated by *Macrotermes herus*, *Macrotermes* spp.4, *Cubitermes* spp.1 and *Ancistrotermes* spp. However, *Macrotermes herus* and *Macrotermes* spp.4 were more common than other species in the dense vegetation cover category. It was also noted that *Trinervitermes oeconomus* only occurred in the dense cover category. *Macrotermes billicosus*, *Macrotermes* spp.1, *Odontotermes* spp.1, *Odontotermes* spp. 2, *Microtermes* species and *procubitermes* species loaded highly but positively on Factor 1 and therefore the species mostly occurred on sparse vegetation cover and rare on bare ground. However, *Cubitermes* spp.3 loaded highly but negatively on Factor 1 implying that the species occurred on bare surfaces.

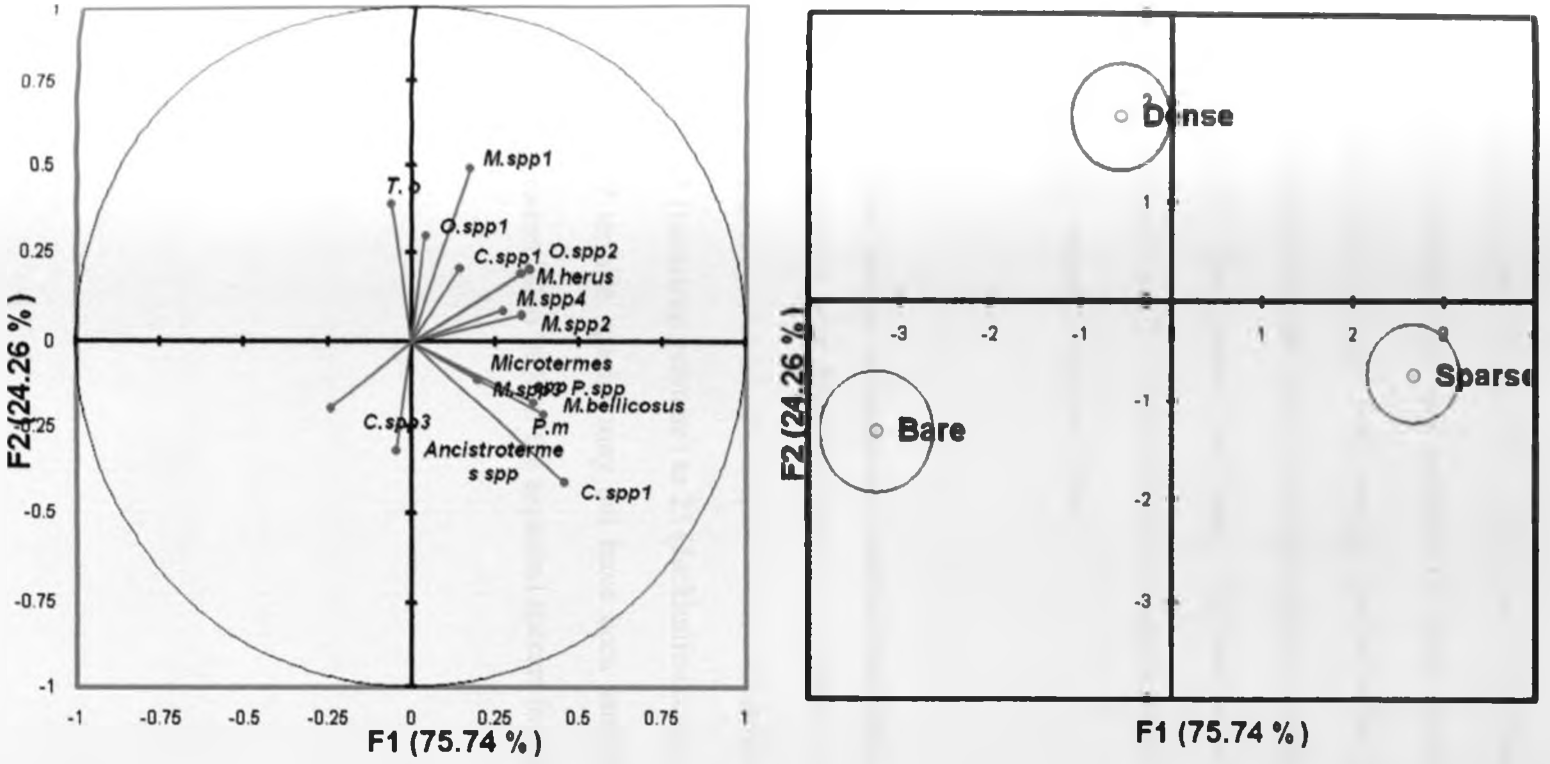


Figure 3.1: Discriminate analysis ordination graphs showing centroids (weighted averages) of vegetation categories and termite species (weighted averages of site scores). The eigenvalues of axis 1 (horizontally) and axis 2 (vertically) are 6.19 and 1.98 respectively. The species are *Trinervitermes oeconomus* (T.o), Macrotermes spp.1 (M.spp.1), Macrotermes spp.2 (M.spp.2), Macrotermes spp.3 (M.spp.3), Macrotermes spp.4 (M.spp.4), Odontotermes spp.1 (O.spp1), Odontotermes spp.2 (O.spp2), Cubitermes spp.1 (C. spp.1), Cubitermes spp.2 (C. spp.2), Cubitermes spp.3 (C. spp.3), Procubitermes spp (P.spp) and *Pseudocanthotermes militaris* (P.m).

3.4.2 *Feeding groups and nesting sites*

The termite assemblage comprised of two feeding groups (Table 3.1). Group II (Wood, litter and grass feeders) species dominated, comprising of 75% of the total species. The rest of the species were true soil feeders (Group IV). Apart from *Trinervitermes oeconomus* (specialized grass feeder), all the species that were assigned to Group II are known to be generalist feeders that predominantly feed on litter. Four nesting habitats were represented, with 44% of the species nesting in epigeal mounds and 31% of the species nesting in hypogeal nests. Epigeal nesting species included *Macrotermes bellicosus*, *Macrotermes herus*, *Macrotemes* spp.1, *Cubitermes* spp.1, *Cubitermes* spp.2, *Trinervitermes oeconomus* and *Procubitermes* spp. The number of epigeal mounds ranged from 8 to 525ha^{-1}.

3.4.3 *Diversity (species richness and relative abundance of species)*

A total of 16 species were sampled (Figure 3.2). However, estimation of the expected number of species in the survey area using Chao, bootstrap, Jackknife-first and second order formulae gave a range of 17 (bootstrap estimate) to 23 (Jackknife-second order estimate) species. Based on this range, 1 to 7 termite species may not have been sampled and the sampled species therefore represent between 70 to 94% of the expected species from the survey area.

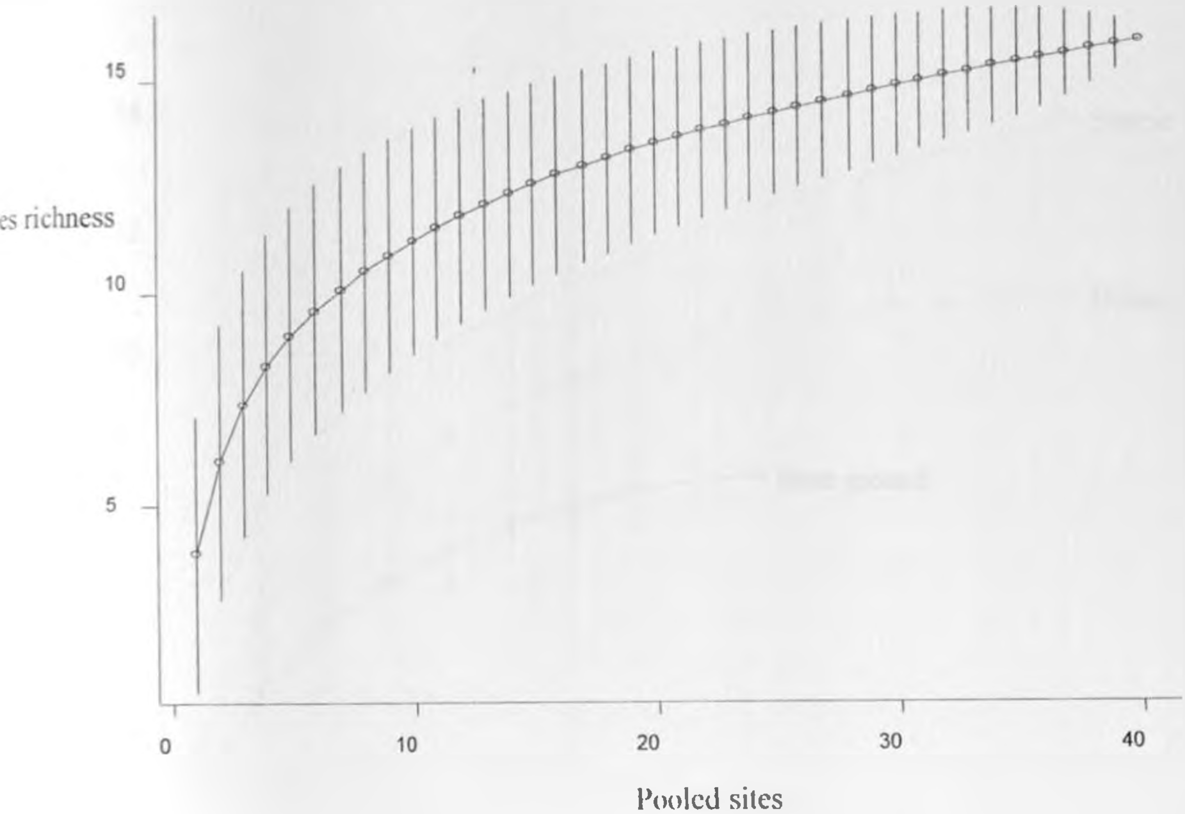


Figure 3.2: Species accumulation curve for termite species sampled from three ranches in Nakasongola. The bars indicate +2 and -2 standard deviations.

Overall species richness was influenced by vegetation categories (Figure 3.3). Highest species richness (14 species) occurred in the sparse vegetation cover category followed by dense category (11) and the least (8 species) occurring on bare ground. Because species richness is positively correlated with sample size (Kindt and Coe, 2005), comparisons among vegetation categories could adequately be conducted considering 10 sites instead of 15. In light of this, 12, 10 and 8 species occurred on sparse, dense and bare ground respectively.

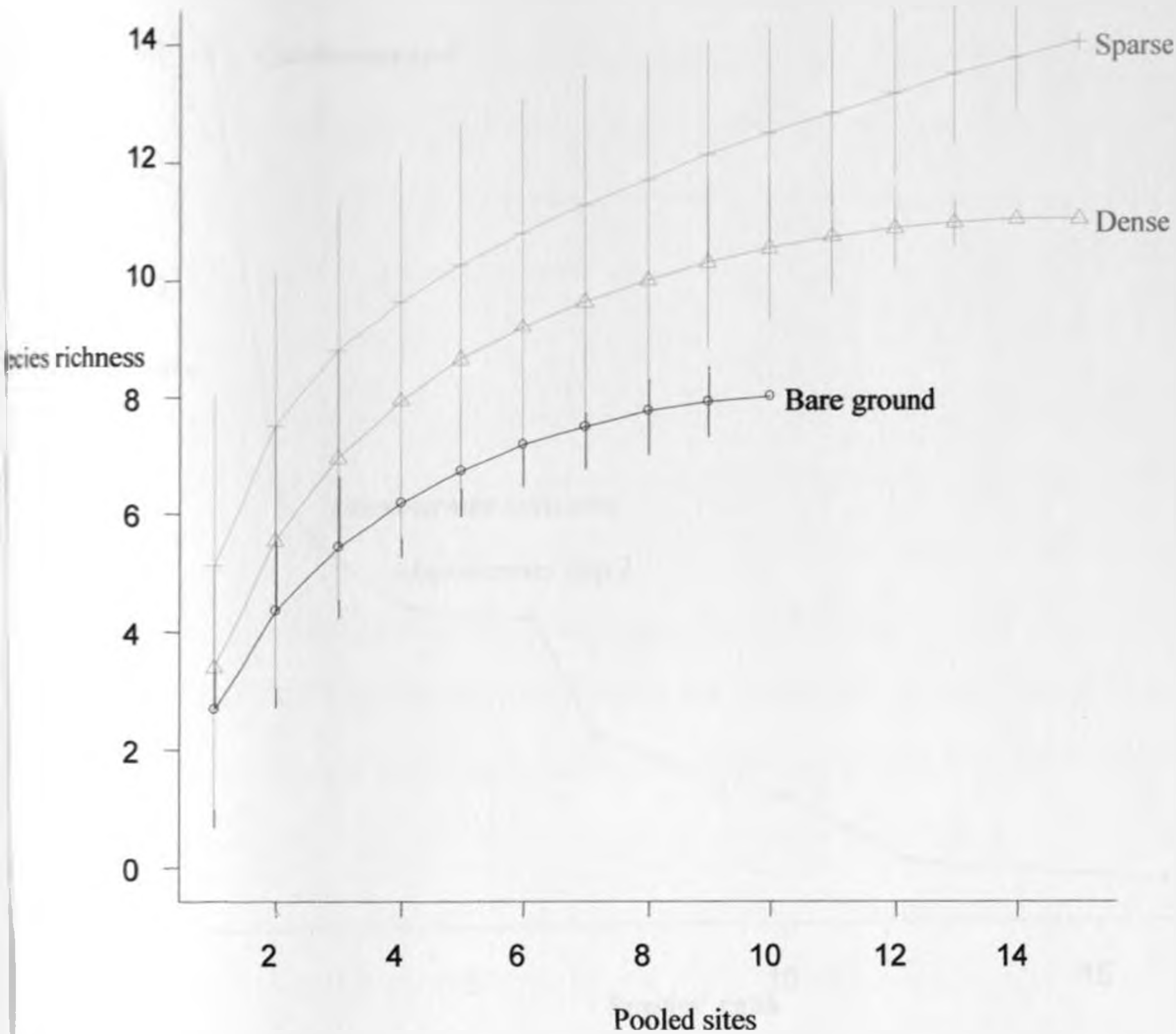


Figure 3.3: Species accumulation curves for termite species sampled from the three vegetation cover categories. The bars indicate +2 and -2 standard deviations.

At species level, *Cubitermes* spp.1, *Macrotermes bellicosus*, *Macrotermes* spp.2, *Macrotermes* spp.1 and *Odontotermes* spp.2 were the most abundant species on grazing lands with total abundance of 142, 66, 55, 48 and 46 encounters respectively (Figure 3.4). At genus level, members of the genus *Macrotermes* were the most abundant species, followed by *Cubitermes* and *Odontotermes*.

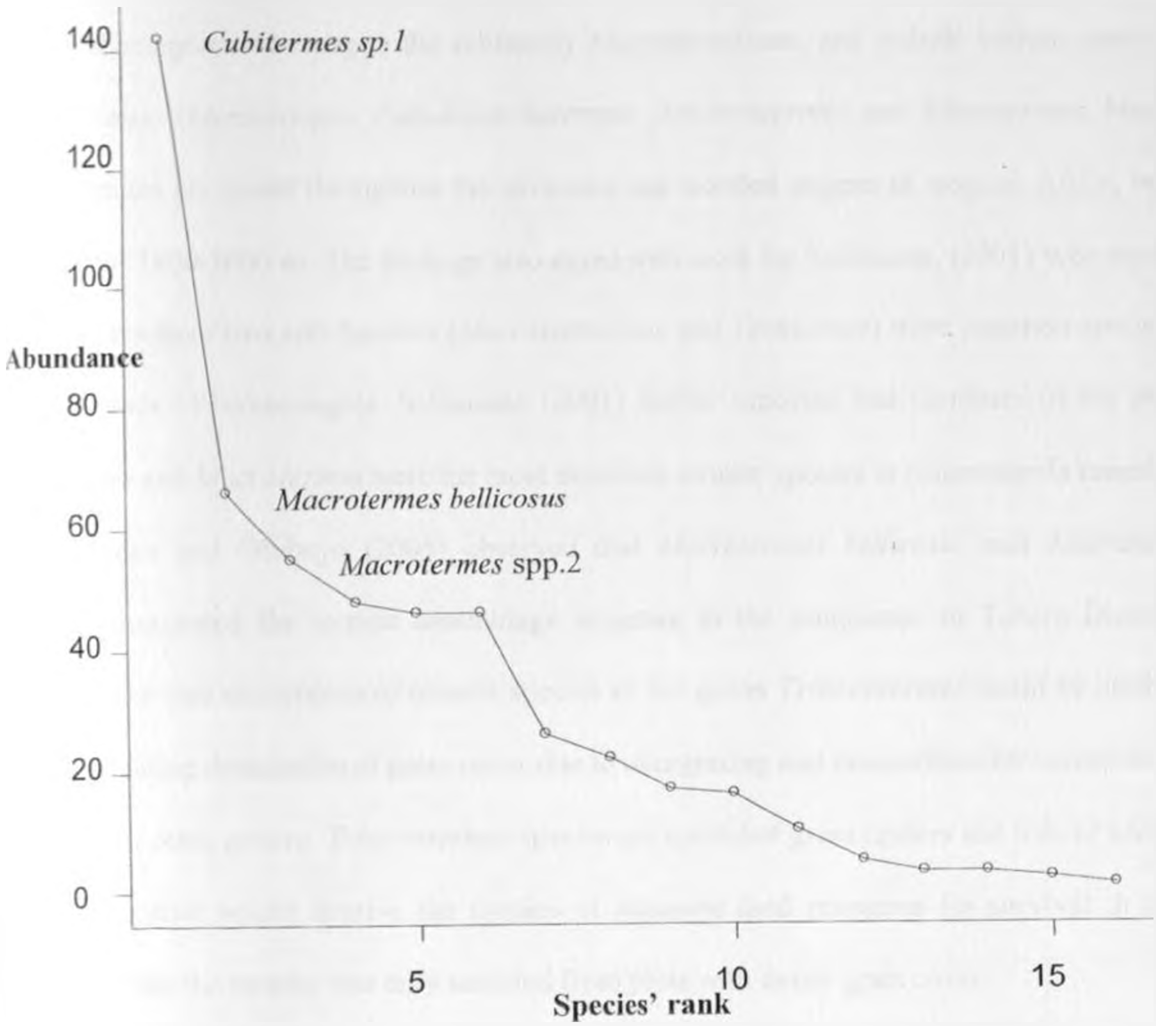


Figure 3.4: Rank-abundance curve for termite species sampled from three ranches in Nakasongola rangelands.

The total abundance of all members of *Macrotermes*, *Cubitermes* and *Odontotermes* was 236, 169 and 68 respectively. *Trinervitermes oeconomus* and *Cubitermes* spp.3 were the least abundant species.

3.5 Discussion

3.5.1 Composition of termite species

The results of the survey were consistent with Wood (1991) who noted that the dominant species in natural ecosystems belong to the subfamily *Macrotermitinae*, and include various species of *Macrotermes, Odontotermes, Pseudacanthotermes, Ancistrotermes* and *Microtermes*. Most of these termites are found throughout the savannas and wooded steppes of tropical Africa, below altitudes of 1800-2000 m. The findings also agree with work by Sekamatte, (2001) who reported that termites from two sub-families (*Macrotermitinae* and *Termitinae*) were common species on grazing lands of Nakasongola. Sekamatte (2001) further reported that members of the genera *Cubitermes* and *Macrotermes* were the most abundant termite species in Nakasongola rangelands while Nyeko and Olubayo (2005) observed that *Macrotermes bellicosus* and *Macrotermes hyalinus* dominated the termite assemblage structure in the rangelands of Tororo District in Uganda. The rare occurrence of termite species of the genus *Trinervitermes* could be attributed to the escalating denudation of grass cover due to overgrazing and competition for resources with members of other genera. *Trinervitermes* species are specialist grass feeders and loss of adequate grass vegetation would deprive the species of adequate feed resources for survival. It is not surprising that the termite was only sampled from plots with dense grass cover.

The species composition of termite assemblages was noted to vary with vegetation cover categories. The changes were attributed to vegetation induced alternations in micro-climate, availability of feed resources as well as nesting sites. The observations are in line with findings of Wood (1991) who noted that denudation of herbaceous and woody vegetation through overgrazing and deforestation respectively, destroyed the nests of species building small mounds (e.g. *Trinervitermes*) and those with shallow, subterranean nests (e.g. many soil feeders) leading to their disappearance from the ecosystem. Bandeira *et al.* (2003), Jones *et al.* (2003) and Vasconcellos *et al.* (2010) also noted that the type of vegetation influenced the composition of termite assemblages while Lavelle *et al.* (1997) showed significant declines in litter arthropod communities in savannas cleared of natural vegetation.

3.5.2 Feeding groups and nesting sites

Group II (Wood, litter and grass feeders) was the dominant feeding group on grazing lands in semi-arid Nakasongola. The group was dominated by species from the sub-family *Macrotermitinae*. These species are known to be generalist feeders and feed on various feed resources such as grass, wood, litter, and dung (Woods, 1991 and Donovan *et al.*, 2001). Mitchell (2002) noted that generalist feeders such as members of the genera *Macrotermes* and *Odontotermes* are predominantly litter feeders. Once the species are deprived of sufficient amounts of litter or when the density of termite mounds is high, they resort to standing biomass and can consume more than 60% of the standing crop. In the current study, specialized grass feeders such as *Trinervitermes oeconomus* were very rare and this could be attributed to the low plant richness of the ground layer and the general patchiness of ground vegetation (Dawes-Gromadzki, 2008). Further, the deterioration of rangeland ecosystem attributable to overgrazing and indiscriminate tree cutting could have derived members of the sub-family *Macrotermitinae* of adequate litter for nourishment which in turn resorted to grass for survival. This scenario could have increased competition for grass between the specialized grass feeders and the generalist feeders and possibly the specialized grass harvesters were out competed. The study therefore revealed that the termite species in Nakasongola are largely litter feeders but possibly resort to herbaceous vegetation once deprived of adequate litter by inappropriate rangeland management practices such as overgrazing. This leads to the common perception that termites are the primary cause of denudation. Studies elsewhere have also shown that in the absence of overgrazing, the grass consumed by termites is insignificant and has no effect on subsequent grass production (Collins, 1980). Woods (1991) also noted that on overgrazed land in Ethiopia, the termites remove the remaining dry grass and grass litter leaving the soil bare and the false impression that they are the primary cause of denudation. Rangeland management practices that sustain availability of adequate feed resources (largely litter) would deter generalist feeders from destroying rangeland vegetation.

Epigeal-nesting species were the most common species followed by hypogeal-nesting species and this was attributed to the high termite encounter rates in mounds and lying dead wood. Dawes-Gromadzki (2008) also noted that epigeal nesting species were the most abundant species accounting for 88% of the total species in Savanna woodland reserve in Tropical Australia. Wood-nesting species were also represented but arboreal-nesting species were very rare. In fact, the arboreal nesting species was sampled twice during the sampling exercise. The epigeal nesters were dominated by *Macrotermes* and *Cubitermes* species. The number of epigeal mounds per hectare recorded in the current study is far above the average number of mounds in Uganda (1-4 ha^{-1}) reported by Pomeroy (1977). Pomeroy (1977) further noted that the greatest abundance of mounds in Uganda was 18.75 mounds ha^{-1}. Okwakol and Sekamatte (2007) reported that the densities of large mounds of *Macrotermitinae*, which support millions of individuals, range between 2.02 per hectare and 13.25 ha^{-1} and those of the smaller mounds of *Cubitermes* spp. to be 167ha^{-1}. This would give a maximum density of 180 mounds ha^{-1} for both *Cubitermes* species and members of the sub-family *Macrotermitinae*. This density is still below that observed in the current study. The results imply that the density of mounds and the subsequent populations of epigeal nesting species is on the rise and this pose a great threat to the remaining rangeland vegetation since the species are as well potential pests to vegetation. The increase in populations of epigeal nesting species could be partly attributed to loss of predator mammals (such as *Orycteropus afer*) that tunnel into mounds to prey on all casts of termites. The mammals which used to constitute a considerable part of the biotic component of the ecosystem were lost due to hunting. Further, the deterioration of the ecosystem could have destroyed the nesting sites of insect predators such as ants that nest in litter. The combined effect of loss of mammal and insect predators could have led to proliferation of termites and the associated increase in mound construction.

3.5.3 Diversity

The survey yielded 16 termite species from one family, three sub-families and eight genera. Based on the Jackknife second order estimate (23 species) of expected termite species in the survey area, the assemblage seems to be species poor. Although the survey added two new genera to the already existing inventory of termite genera on grazing lands in Nakasongola, one genus (*Hodotermes*) reported to occur on grazing lands (Sekamatte, 2001) was not represented. Lack of this genus could partly explain the missing species. Generally, fewer species occurred on bare surfaces as compared to dense and sparse vegetation categories. The possible explanation for this trend is that, removal of trees and denudation of basal vegetation attributed to indiscriminate tree cutting and overgrazing respectively, affects the micro-climate and the quantity and quality of feeding and nesting sites (Jones *et al*., 2003). This results in simplification of termite assemblages both in diversity and feeding groups. Bandeira *et al.* (2003) also noted that chopping down of trees increases the input of dead plant matter to the soil, this may increase populations of some termites, especially wood and leaf feeders. With time, the reduction of food resources, lack of soil cover and micro-climate changes may cause population reduction and local extinction (Bandeira *et al.*, 2003). While comparing species richness between primary woodland, disturbed woodland and cleared areas, Vasconcellos *et al.* (2010) also noted that species richness was significantly lower on cleared areas than in the primary woodland. Unlike previous studies by Bandeeira *et al.* (2003) which showed that species richness reduced from the most preserved sites to the most disturbed sites, the findings from this study revealed that species richness was higher in the sparse vegetation category than in the dense category, which is known to be experiencing minimum disturbance. This observation is consistent with the 'intermediate disturbance hypothesis' which states that habitats with intermediate levels of disturbance allow the maximum number of species to coexist; both competitive exclusion of species by competitive dominants at low disturbance, and persistence of only fugitive species at high disturbance are avoided (Abugov, 1982).

3.6 Conclusion

The survey yielded 16 termite species from eight genera, three sub-families and one family. Members of the genus *Macrotermes* were the most abundant species, followed by *Cubitermes* and *Odontotermes*. At species level, *Cubitermes* spp.1 and *Macrotermes bellicosus* were the most abundant species while *Trinervitermes oeconomus* and *Cubitermes* spp.3 were the least abundant species. The termite assemblage comprised of two feeding groups namely Group II (Wood, litter and grass feeders) and Group IV (true soil feeders). Most of the species belonged to

Group II. Apart from *Trinervitermes oeconomus* (specialized grass feeder), all the species that were assigned to Group II are known to be generalist feeders that predominantly feed on litter. Most of the species were noted to nest in epigeal and hypogeal nests with a few species nesting in wood. Vegetation cover categories were noted to influence species richness. Highest species richness occurred in sparse vegetation category followed by dense category and the least occurring on bare ground.

Chapter 4

Effect of biotic and abiotic factors on composition and foraging intensity of subterranean termites

4.1 Abstract

Elucidating the influence of biotic and abiotic factors on composition and foraging intensity of subterranean termites in savanna ecosystems is critical in development of sustainable termite management strategies. The objective of the study was therefore to analyze the effect of the biotic and abiotic factors on composition and foraging intensity of subterranean termites on grazing lands in semi-arid Nakasongola, Uganda. Principal component analysis was used to select factors which were then subjected to canonical correspondence analysis and non-linear regression to model the relationships. *Macrotermes* species occurred in sites where the quantity of litter was generally above the mean (778kg/ha). However, *Macrotermes herus* and *Macrotermes* spp.4 occurred in sites where the litter quantity was below the mean. *Trinervitermes oeconomous* and *Odontoremes* spp.1 occurred in the direction of increasing quantity of vegetation biomass. Generally, most species occurred in sites where soil pH was above or slightly below the mean (4.8). Also, most of the species occurred in sites where bulk density was below and slightly above the mean (1.55 g/cm^3). Results from nonlinear regression of percentage of bait consumed with basal cover indicated that highest consumption of baits (95%) occurred within a range of 55-60% of basal cover beyond which the amount of bait consumed reduced. Litter and biomass quantity, pH and bulk density were noted as the most influential environmental variables driving the variability in composition of termites while basal cover was the major determinant of termite foraging intensity.

4.2 Introduction

Determinants of the structure and activity of subterranean termites at a large-scale are well known: climate, soil type, land use management practices and landscape structure are among the most influential factors (Dauber *et al.*, 2003; 2005). At smaller scales, however, there is less agreement about the biotic and abiotic factors that drive variability in composition and activity of macro-fauna including subterranean termites (Lavelle and Spain, 2001). Mitchell (2002) reported that the amount of available litter (both leaf and wood) was a major determinant of foraging intensity on vegetation by generalist feeders such as members of the genera *Macrotermes* and *Odontotermes*. He further noted that in sites with limited litter resources, termites resorted to standing herbaceous biomass and consumed more than 60% of the standing crop. Attignon *et al.* (2005) and Mathieu *et al.* (2009) also reported that high encounters of *Macrotermes* species (mainly fungus growers) were associated with sites with high litter biomass and low soil water content. Curry (1994) observed the survival and activity of macro-fauna on various sites to be influenced by the micro-climate and the quality of food in the various sites. Micro-climate is very important since the body temperature of soil macro-fauna varies with external temperature (thermo-conformers) and the range tolerated by many species is narrow (Geiger and Aron, 2003). Geiger and Aron (2003) further noted that soil macro-fauna including subterranean termites need to maintain body water content within fairly narrow limits, which creates a dependence on soil water. This implied that the structure, survival and activity of subterranean termites would be enhanced on sites with acceptable levels of soil water content. Martison *et al.* (2008) reported that soil macro-fauna organisms are also sensitive to the nutrient content of their food because they need to maintain their internal chemical concentrations and the balance between the different nutrients of their body within a strict range. To this effect, elements of food quality such as phosphorus (McGlynn and Salina, 2007), nitrogen (Waren and Zou, 2002) and

Ca^{2+} (Reich *et al.*, 2005) content, can become limiting factors to composition, survival and activity including foraging intensity of subterranean termites. Mathieu *et al.* (2009) also reported that the composition and activity of subterranean termites was influenced by presence of basal vegetation with more diversity in areas covered with grass tufts than on bare ground.

In the rangelands of Nakasongola District in Uganda, vegetation is typically dominated by large herb turfs of the genera *Hyparrhenia* and *Brachiaria*, which clearly alternate with bare ground and shrubs. The vegetation cover is highly variable, from dense to completely bare ground leading to heterogeneous habitats with varying biotic and abiotic factors. The composition and foraging intensity of subterranean termites seem to be driven by the site-specific biotic and abiotic properties occurring on the different vegetation patches. On some patches, the termite assemblage structure is dominated by *Macrotermes* species while *Cubitermes* species dominate on other patches. Further, the population and foraging intensity of subterranean termites also varies from one site to another with most of the patches experiencing extra-ordinarily high foraging intensity of termites resulting into denudation of basal vegetation, forage scarcity and eventually poor livestock performance. Typical foraging is characterized by subterranean galleries leading to surface foraging holes from which termites emerge to remove dead grass and grass litter under cover of constructed soil sheeting. Termite foraging is particularly obvious during the dry season when bare rangeland can have up to 55 foraging holes per m^2 (Cowie and Wood, 1989). During such times the combined grazing effect of livestock and termites is considerable denudation of tracts of grassland, exposing soils to erosion by both wind and water (Mitchell, 2000).

Recognizing the impact of biotic and abiotic factors on composition and foraging intensity of subterranean termites in savanna ecosystems presents an opportunity for development of sustainable termite management strategies in the termite infested rangelands such as Nakasongola. This requires adequate knowledge of the site-specific influence of biotic and abiotic factors on the composition and foraging intensity of termites. This will ensure that management of rangeland ecosystems aim at provision and harnessing of the necessary ecological resources and conditions to overcome the detrimental impact of subterranean termites on rangeland vegetation. However, such information is still poorly documented. In particular, we lack information on the biotic and abiotic factors that enhance foraging intensity of subterranean termites as well as the ecological factors that are responsible for the variation in termite assemblage structure across various rangeland sites.

The aim of this study was thus to analyze the effect of biotic (tree canopy cover, density of woody species, herbaceous biomass and basal cover) and abiotic (soil moisture, soil temperature, bulk density, soil pH, litter quantity and soil organic matter) factors on the composition and foraging intensity of subterranean termites on the grazing lands in semi-arid Nakasongola. Two hypotheses were examined: (1) the composition of subterranean termites will not vary among sites with different biotic and abiotic factors and (2) the percentage of baits consumed by subterranean termites (foraging intensity) will not vary among sites with different biotic and abiotic factors.

4.3 Materials and methods

4.3.1 Description of the study area

The study was conducted on one savanna site, locally referred to as Kamukama ranch. The location, vegetation and soil on the site are already described in Chapter three.

4.3.2 Sampling and classification of termite species

The standardized sampling protocol developed by Jones and Eggleton (2000) was used to sample termites. The protocol involved lying belt transects of 100m length by 2 m width, divided into 20 contiguous sections of 5 x 2 m. Each section was sampled by two trained people for 30 minutes (a total of one hour of sampling per section). In each section the following microhabitats were searched: 12 samples of surface soil (each measuring 12 x 12 cm, to 10 cm depth); accumulations of litter and humus at the base of woody plants, the inside of tree stumps, dead logs, branches and twigs; the soil within and beneath rotten logs; subterranean nests, mounds, carton sheeting and run ways on vegetation, and arboreal nests up to a height of 2 m above ground level. At least three workers and three soldiers (if present) from every termite population encountered were sampled and the samples were preserved in 80% ethanol. The belt transect provides a measure of relative abundance of termites based on the number of encounters with each species in the transect. An encounter was defined as the presence of a species in one section. The vegetation of the study site was blocked into three vegetation categories based on the quantity of vegetation covering the ground. The three categories included dense, sparse and bare ground. Two replicate sample belt transects were run in each of the three vegetation categories between December and January, the period when termite activity and subsequent destruction of vegetation by termites is reported to be severe (Nakasongola District State of

Environmental Report, 2007). Sampling for termite species was conducted in 2010 and 2011. Taxonomic identification for collected samples was done at family, sub-family, genus using standard determination keys by Webb (1961) and where possible to species' level using existing records of termite species in Nakasongola rangelands by Sekamatte (2001).

4.3.3 Sampling for biotic and abiotic variables

Several environmental variables were recorded between 2010 and 2011 to assess their influence on termite assemblages. Measurements were made during the main rainy (March-April/June-July) season and the dry season (December to February). The soil water content (percent H_2Og^{-1} oven-dry soil) was measured from four surface soil samples (2-10 cm) taken from sections 3, 8, 13 and 18 of every belt transect (Attignon *et al.*, 2005). The same samples were analyzed for bulk density, soil pH and soil organic matter according to methods described by Anderson and Ingram (1993). Soil temperature was determined by randomly inserting thermometers into the soil at any two locations in each of the four sections (3, 8, 13 and 18). The same sections were also sampled for herbaceous biomass quantity and litter quantity (both wood and leaf litter). The number of functional/live termite mounds per section was also quantified. Because the size of the sections was not sufficient to quantify canopy cover (Kent and Coker, 1992), three plots of 50 m by 50 m were established in every vegetation category to enable estimation of tree/woody species density and woody canopy cover. Herbaceous biomass quantity was estimated by randomly placing two quadrats ($1m^2$) in each of the four sections. The above ground herbaceous vegetation within each $1m^2$quadrat was cut at ground level, put in plastic bags and weighed as described by L.'tMannetje (1978). To quantify the amount of litter available, two quadrats ($1m^2$) were placed randomly in each of the four sections and all available dead plant material enclosed by the quadrat was collected, oven dried and weighed. The woody canopy cover and the number of woody species for each plot were estimated according to methods described by Kent and Coker (1992).

4.3.4 Estimation of foraging intensity

The effect of biotic and abiotic factors on foraging intensity was estimated using dried *Hyparrhenia rufa* grass baits as described by Pearce (1997) and Nash *et al.* (1999). *Hyparrhenia rufa* was selected because the grass is reported to be among the most susceptible grass species in the area and is thus readily consumed by subterranean termites. Four litter bags (18cm x 15cm) of mesh size 4 mm, containing the same quantity of dried *Hyparrhenia rufa* grass were randomly placed on the surface in each of the four sections (3, 8, 13 and 18) of every belt transect. The bags were surrounded by three big stones to hold them in position or to prevent livestock and run-off from displacing them. The bags were removed after two weeks and were replaced twice in every season. After collection of baits, gallery carton and soil were carefully removed from all baits. The cleaned baits were oven dried at 60°c for 72-96 hours and the dry weight recorded. The percentage of bait consumed (PC) was estimated as $PC = ((W_i-W_f)/ W_i)*100$ were W_i is initial weight of grass bait before consumption by termites, W_f is final weight after consumption by termites. The percentage of bait consumed by termites was used as a proxy for determination of foraging intensity.

4.3.5 Data analysis

In order to establish the effect of environmental variables on composition of termite species, the biotic and abiotic factors were subjected to principal component analysis (PCA) to obtain non-correlated factors which were linear combinations of the initial variables (Jolliffe, 2002). Based on the eigenvalues and the variability explained by each factor, a few factors were selected. The vegetation and soil variables were analyzed separately in PCA and the selected variables for vegetation and soil were subjected to canonical correspondence analysis (CCA). Factors that accounted for at least 90% of the cumulative variability were taken. PCA (Pearson type; correlation biplot) of vegetation variables led to selection of three factors which accounted for 92% of the cumulative variability. PCA (Pearson type; correlation biplot) of soil variables led to selection of four factors that accounted for 98% of the cumulative variability. The selected factors were then used to model relationships in CCA (ter Braak and Verdonschot, 1995) by extracting synthetic environmental gradients from the ecological data set as well as to develop ordination biplots. In order to establish the effect of environmental variables on foraging intensity (percentage of baits consumed), the biotic and abiotic factors were also subjected to principal component analysis (PCA) to obtain non-correlated factors which were linear combinations of the initial variables (Jolliffe, 2002). Based on the eigenvalues and the variability explained by each factor, a few factors were selected. The selected factors were subjected to non-linear regression to clearly model the relationship.

4.4 Results

4.4.1 Effect of environmental variables on composition of subterranean termites

Principal component analysis on vegetation variables indicated that the first three factors explained 92% of the cumulative variability (Table 4.1). Biomass production (BP), number of wood species (NWS) and litter quantity (LQ) were strongly correlated with factors one (r =

0.88), two (r = 0.73) and three (r = 0.5) respectively. Biomass quantity, number of woody species and litter quantity also loaded highest on F1, F2 and F3 respectively.

Table 4.1: Cumulative variability explained by five factors and factor loadings of vegetation variables

	F1	F2	F3	F4	F5
Eigenvalue	3.287	0.852	0.457	0.256	0.148
Variability (%)	65.75	17.03	9.14	5.12	2.96
Cummulative (%)	65.75	82.78	91.92	97.04	100
Factor loadings					
Biomass quantity (BP)	0.88	-0.35	-0.16	0.04	0.29
Litter quantity (LQ)	0.84	-0.03	0.47	-0.28	-0.01
No. of woody species (NWS)	0.61	0.73	-0.28	-0.15	0.03
Woody canopy cover (WCC)	0.87	0.24	0.2	0.39	-0.06
Basal cover (BC)	0.84	-0.38	-0.30	-0.06	-0.25

The factor loading for BP, NWS and LQ was 0.88, 0.73 and 0.47 on factor 1 (F1), factor (F2) and factor (F3) respectively.

The three vegetation variables were thus selected for inclusion in canonical correspondence analysis to establish the effect of the factors on composition of termite species. On the other hand, principal component analysis on soil variables showed that the first four factors explained 98% of the cumulative variability (Table 4.2). Soil water content (SWC), pH, bulk density (BD) and soil organic matter (SOM) were highly correlated with factors one (r = 0.86), two (r = 0.69), three (r = 0.69) and four (r=0.38) respectively. SWC, pH, BD and SOM also loaded highest on F1, F2, F3 and F4 respectively. The factor loading for SWC, pH, BD and SOM was 0.86, 0.69,

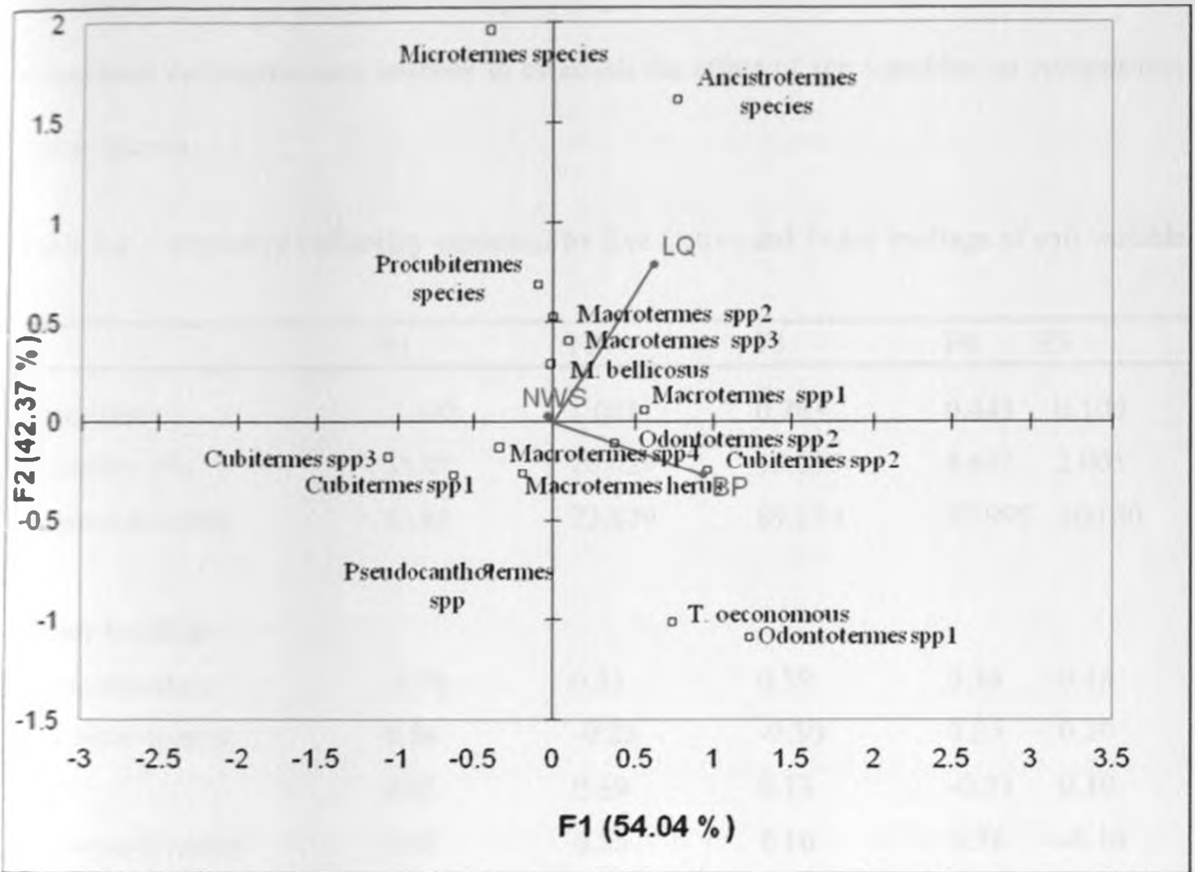


Figure 4.1: Ordination biplot based on canonical correspondence analysis of species/vegetation matrixes displaying 17.6% the inertia (= weighted variance) in species' abundances and 96% of variance in weighted averages with respect to the vegetation variables. The eigenvalues of axis 1 (horizontally) and axis 2 (vertically) are 0.29 and 0.23 respectively. The eigenvalue of axis 3 (not displayed) is 0.019.

By projecting species points on the line of litter quantity, it was indicated that *Macrotermes* spp.2 had the highest weighted average for litter quantity while *Pseudocanthotermes* species seemed to occur in sites where the litter quantity was extremely below the average. It was further noted that although *Macrotermes* species occurred in sites where amount of litter was above the mean, the species disappeared in sites where litter quantity was greatly above the mean. *Trinervitermes oeconomous* and *Odontoremes* species were noted to occur in the direction of increasing biomass production and once the line of biomass production is extended beyond the

0.69 and 0.38 on F1, F2, F3 and F4 respectively. Four soil variables were selected for inclusion in canonical correspondence analysis to establish the effect of the variables on composition of termite species.

Table 4.2: Cumulative variability explained by five factors and factor loadings of soil variables

	F1	F2	F3	F4	F5
Eigenvalue	2.692	1.001	0.763	0.443	0.100
Variability (%)	53.85	20.029	15.255	8.861	2.005
Cummulative (%)	53.85	73.879	89.134	97.995	100.00
Factor loadings					
Soil temperature	-0.78	0.31	0.39	0.34	0.15
Soil water content	0.86	-0.25	-0.30	0.25	0.20
pH	0.63	0.69	0.13	-0.33	0.10
Soil organic matter	0.83	0.35	0.16	0.38	-0.16
Bulk density	0.51	-0.5	0.69	-0.11	0.02

Since the origin (0, 0) of any environmental variable on the ordination biplot represents the mean of that particular variable (Figure 4.1), *Macrotermes* species are generally considered to have occurred in sites where the quantity of litter was above the mean (778kgha^{-1}). However, *Macrotermes herus* and *Macrotermes* spp.4 occurred in sites where litter quantity was below the mean. *Pseudocanthotermes* species, *Cubitermes* spp.3 and 1 also occurred in sites where the amount of litter was lower than the average litter quantity.

displayed maximum point, *Trinervitermes oeconomous* and *Odontoremes* spp.1 would have the highest weighted average than all the displayed species. The point for number of woody species (NWS) occurred at the origin of both litter quantity and biomass production and was associated with species which occurred in sites where the quantity of litter and biomass was around the mean.

Projection of soil variables on the axes showed that pH was more correlated with axis 1 while BD was more correlated with axis 2 than other variables (Figure 4.2). Generally, most species occurred in sites where soil pH was above or slightly below the mean (4.8). It was noted that the majority of *Macrotermes* species and *Odontotermes* species occurred in sites where the pH was slightly above or below the mean. The species (*Macrotermes* and *Odontotermes*) were noted to disappear in the direction of increasing pH. Most of the species occurred in sites where bulk density was below and slightly above the mean (1.55 g/cm^3). The diversity of species was noted to decline in the direction of increasing bulk density. It was also noted that *Macrotermes* spp.1, *Odontotermes* spp.1, *Microtermes* species and *Pseudocanthotermes* species were the only members of the sub-family *Macrotermitinae* that occurred in sites where bulk density was below average. Most members of the sub-family *Macrotermitinae* occurred in sites where bulk density was slightly above the mean and finally disappeared in sites with high bulk density. Only Ancistrotermes species and Cubitermes spp.3 were noted to occur in sites with high values of bulk density. *Trinervitermes* species were noted to have the highest weighted average for soil organic matter although *Procubitermes* species and *Cubitermites* spp.2 also occurred in sites with high soil organic matter. Most of the *Macrotermes* species (*M. herus, M. bellicosus, M.* spp.2 and 4) were noted to occur slightly below the mean (2.1%) and all the species disappeared in sites where the soils were low in organic matter. Most of the species were also noted to occur in sites where soil water content was slightly above or below the mean (8.13%). *Pseudocanthotermes* species occurred in sites where soil water content was highest while Ancistrotermes species occurred in sites with low soil water content.

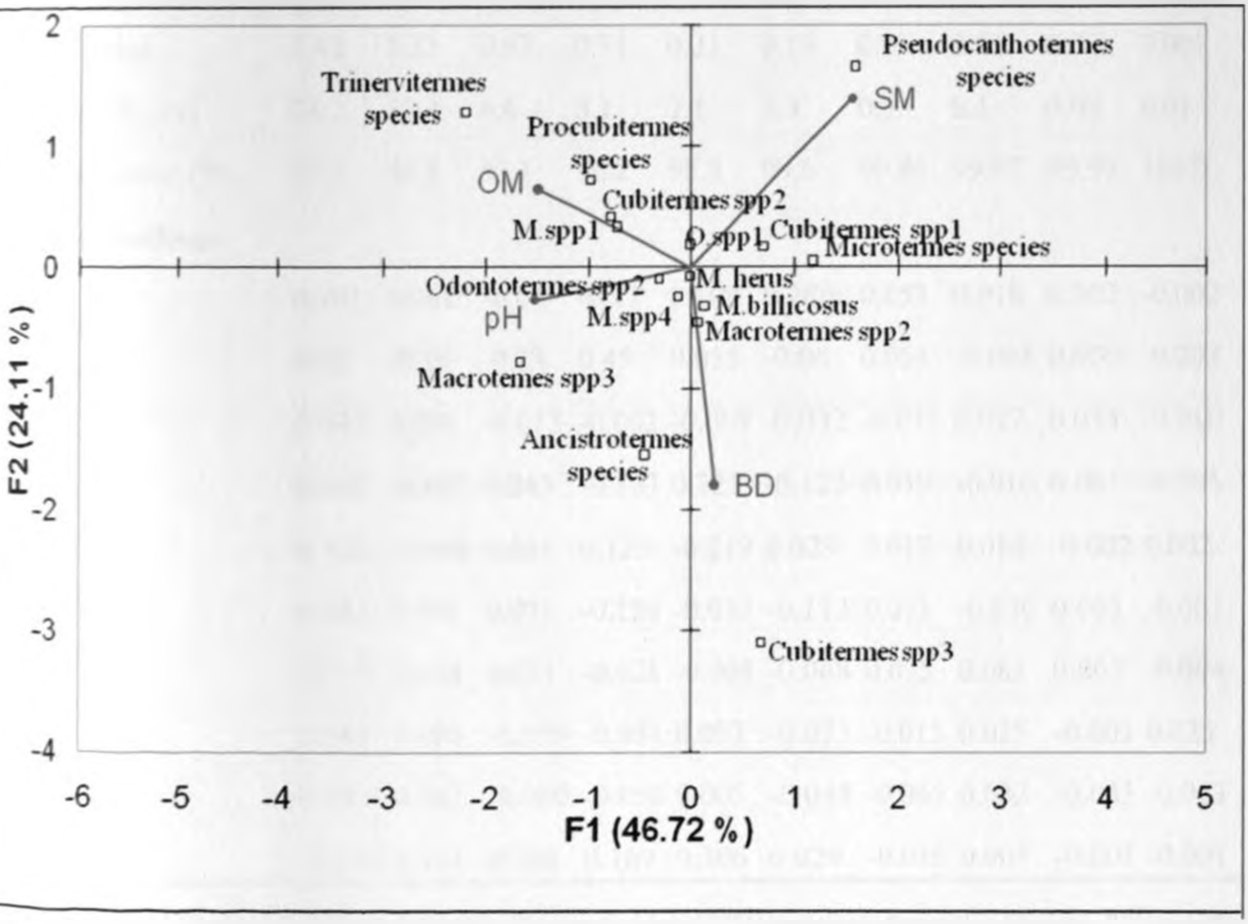


Figure 4.2: Ordination biplot based on canonical correspondence analysis of species/soil matrixes displaying 24% the inertia (= weighted variance) in species' abundances and 71% of variance in weighted averages with respect to the soil variables. The eigenvalues of axis 1 (horizontally) and axis 2 (vertically) are 0.34 and 0.18 respectively. The eigenvalue of axis 3 and 4 (not displayed) are 0.12 and 0.09 respectively.

4.42 Effect of environmental variables on foraging intensity of subterranean termites

Principal component analysis on environmental variables led to selection of four principal components (factors) that contributed 96% of the cumulative variability (Table 4.3).

Table 4.3: Cumulative variability explained by ten factors and factor loadings of environmental variables

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Eigenvalue	7.42	1.23	0.67	0.31	0.21	0.13	0.03	0.01	0.002	0.001
Variability (%)	74.2	12.3	6.6	3.1	2.1	1.3	0.3	0.1	0.02	0.01
Cummulative (%)	74.2	86.5	93.1	96.2	98.3	99.6	99.86	99.97	99.99	100.0
Factor loadings										
BQ	0.941	0.061	-0.04	-0.11	0.109	0.286	0.053	0.016	0.002	-0.002
LQ	0.85	-0.10	-0.23	0.45	0.055	-0.04	0.054	-0.003	0.000	-0.003
BC	0.992	0.091	-0.013	-0.002	-0.009	-0.032	-0.071	0.027	0.034	-0.010
NWS	0.692	-0.607	0.243	-0.163	0.221	-0.123	0.039	-0.016	0.001	-0.005
WCC	0.723	-0.048	0.641	0.123	-0.219	0.029	0.017	0.010	-0.002	0.002
NM	0.583	0.791	0.031	-0.124	-0.015	-0.113	0.071	-0.030	0.005	-0.003
ST	-0.991	0.004	0.011	-0.028	-0.008	-0.068	0.075	0.081	0.005	-0.004
SM	0.986	0.090	-0.059	-0.034	0.093	-0.073	-0.015	0.035	-0.001	0.025
SOM	0.980	0.167	-0.060	-0.050	0.005	-0.048	-0.045	0.032	-0.033	-0.013
BD	-0.754	0.414	0.354	0.169	0.306	0.029	-0.036	0.005	-0.001	-0.001

^{BQ} Biomass quantity, ^{LQ} litter quantity, ^{BC} basal cover, ^{NWS} number of woody species, ^{WCC} woody canopy cover, ^{NM} number of mounds, ST soil temperature, ^{SM} soil moisture, ^{SOM} soil organic matter, ^{BD} bulk density.

Based on the loading of various environmental variables on the selected factors, four variables were selected to explain the effect of the variables on foraging intensity of subterranean termites. The selected variables included basal cover (BC), number of mounds (NM), litter quantity (LQ) and woody canopy cover (WCC). BC and NM loaded highest on F1 (0.99) and F2 (0.79) while WCC and LQ loaded highest on F3 (0.64) and F4 (0.45) respectively. Pearson correlation tests showed significant ($p<0.05$) correlations between BC and the other three selected variables. BC was positively correlated with NM ($r=0.65$, $p=0.001$), WWC ($r=0.7$, $p<0.0001$) and LQ ($r=0.83$, $p<0.0001$). Based on results from principal component analysis and Pearson correlation tests, only one variable (BC) was selected to explain the variability in foraging intensity since the remaining variables were positively correlated with the selected variable.

Results from nonlinear regression of percentage of bait consumed with basal cover indicated that highest consumption of baits (95%) occurred within a range of 55-60% basal cover (Figure 4.3). Below this range, bait consumption was noted to decrease up to 0%.Beyond the same range, bait consumption was observed to decline but did not reach 0%. Reduction in basal cover from 100 to 80% was noted to double bait consumption from 38 to 76% while basal cover reduction from 80 to 60% caused 24% increase in bait consumption.

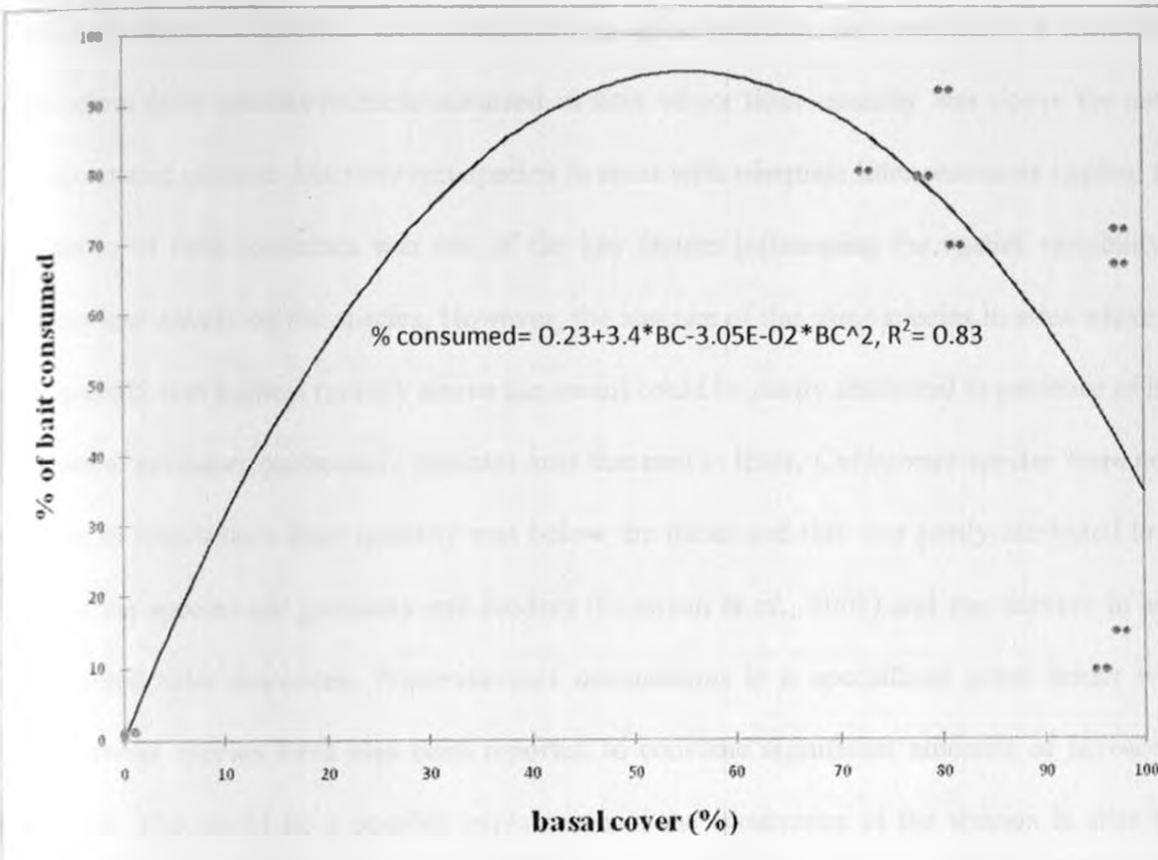


Figure 4.3: Nonlinear regression curve of basal cover and percentage of bait consumed.

4.5 Discussion

4.5.1 Effect of environmental variables on composition of subterranean termites

Although *Macrotermes* species are regarded as generalist feeders (Wood, 1991; Donovan *et al*., 2001) that forage on various organic resources such as grass, wood, dung and plant debris, Mitcheal (2002) noted that the species are predominantly litter feeders and their diversity and density would increase in areas with adequate availability of food (litter) resources. Okwakol and Sekamatte (2007) also noted that increased availability of litter due to clearance of trees led to an increase in density and diversity of litter feeding species, particularly *Macrotermes* species in forest ecosystems in Uganda. These observations agree with the observed trend in the current study where more species richness occurred in sites where litter quantity was above the mean. The occurrence of more *Macrotermes* species in areas with adequate litter resources implied that availability of food resources was one of the key factors influencing the spatial variability in diversity and density of the species. However, the absence of the same species in sites where the litter quantity was highest (greatly above the mean) could be partly attributed to presence of high densities of predators particularly predator ants that nest in litter. *Cubitermes* species were noted to occur in sites where litter quantity was below the mean and this was partly attributed to the fact that the species are generally soil feeders (Donovan *et al.*, 2001) and can survive in areas with limited litter resources. *Trinervitermes oeconomous* is a specialized grass feeder while *Odontotermes* species have also been reported to consume significant amounts of herbaceous vegetation. This could be a possible explanation of the occurrence of the species in sites with high biomass production as the sites could avail the species with adequate food resources.

The significant positive correlation between pH and soil organic matter meant that sites with low soil pH had low soil organic matter, which limited availability of nutrients for plant establishment and this could have limited availability of adequate food resources for survival and activity of most termite species. Further, limited availability of soil organic matter meant that termites lacked the necessary nutrients to sustain their nutritional requirements. In this regard, Martison *et al.* (2008) also reported that soil macro-fauna organisms are sensitive to the nutrient content of their food because they need to maintain their internal chemical concentrations and the balance between the different nutrients of their body within a strict range. To this effect, elements of food quality such as phosphorus (McGlynn and Salina, 2007), nitrogen (Waren and

Zou, 2002) and Ca^{2+} (Reich *et al.*, 2005) content, can become limiting factors to composition, survival and activity including foraging intensity of subterranean termites.

Trampling by grazing animals causes soil compaction, reduction of permeability, organic carbon, and nutrients, and restrict plant growth (Yates *et al.*, 2000), reducing the input of organic matter into the soil and resources available to decomposers (Chapin *et al.*,2002). Eventually, the soil faunal diversity and density is likely to decrease in highly compacted areas. This explains the limited occurrence of termites in sites where the bulk density was greatly above the mean. The results also indicated that members of the sub-family *Macrotermitinae*, the dominant sub-family on grazing lands in semi-arid Nakasongola, are sensitive to changes in bulk density and their activity and survival could be influenced by interventions that alter soil bulk density. Since the species are associated with destruction of herbaceous vegetation in termite infested rangelands, management decisions aimed at reducing bulk density below the average value reported in the current study would possibly check their activity and eventually reduce their destructive effect on herbaceous vegetation. However, more scientific investigations are necessary to determine the most appropriate level of bulk density that ensures optimum biomass production for livestock nutrition but also mitigates the destructive effect of subterranean termites on vegetation.

4.5.2 Effect of environmental variables on foraging intensity of subterranean termite

The significant positive correlation between basal cover and litter quantity meant that sites with high proportion of basal cover also had high quantities of litter. This implied that such sites had adequate food resources for both generalist termite feeders (members of sub-family

Macrotermitinae) and the specialized grass feeders (*Trinervitermes* species). This could have resulted to the low response of termites to supplementary food sources in form of baits. The observed increase in bait consumption due to a decline in basal cover from 100% implied that feed availability was limiting and hence termites responded greatly to provision of additional food resources in form of baits. However, this trend occurred up to a certain point (55-60%) beyond which the proportion of bait consumed started to decline. As basal cover continues to decline, the land becomes bare leading to high rates of run-off, erosion, and eventually loss of soil organic matter. The bare surfaces are also associated with low soil water content due to reduced water infiltration and high soil temperature which limit the survival and populations of termites. Eventually, the consumption of baits decreased as the land became bare not because the termites had plenty of food resources to forage on but because there were limited populations of termites to feed on the baits. The findings of the study suggested that availability of adequate food resources (litter and standing biomass) is critical in determining the foraging intensity of subterranean termites on organic resources. This implied that the foraging intensity of subterranean termites on alternative food resources would be high in sites with inadequate conventional food resources. No wonder, foraging intensity of termites on rangeland vegetation was reported to be highest on degraded patches with sparse vegetation cover and limited availability of plant biomass and litter. The results of the study are consistent with findings of Wood (1991) who noted that destructive effect of termites on rangeland vegetation was more severe on overgrazed land with limited net primary productivity and litter availability.

4.6 Conclusion

In sum, the composition and foraging intensity of subterranean termites on grazing lands in semi-arid Nakasongola was influenced by certain biotic and abiotic factors. Litter and biomass quantity were noted as the most influential vegetation variables while soil pH and bulk density were noted as the most influential soil variables driving the variability in composition of subterranean termites. Increasing litter quantity was noted to favor occurrence of *Macrotermes* species to a certain level beyond which the species disappear. Recognizing the fact that *Macrotermes* species are reported as the major pests to vegetation on grazing lands in Nakasongola, interventions that enhance optimal accumulation of litter will reduce their destructive effect on vegetation. It was further observed that basal cover was the main determinant of foraging intensity of termites on dried *Hyparrhenia rufa* grass. The foraging intensity was noted to decrease with increase in basal cover suggesting that management decisions for rangeland vegetation need to focus on maintaining adequate basal cover if termite damage on vegetation is to be reduced.

Chapter 5

Synthesis

Devastation of rangeland vegetation by subterranean termites is regarded as a major challenge to livestock production and ecological sustainability in semi-arid Nakasongola. 60 and 7% of the farmers rated severity of the termite problem as high and moderate respectively. The farmers noted that deterioration of the rangeland ecosystem was the genesis of the termite problem in the area and majority of the farmers reported that the problem was first experienced in the early 1990's shortly after the erroneous restructuring of ranches. The severity of the problem was found to be a function of the termite species occurring on farmers' grazing lands. It was noted that grazing lands dominated by *Cubitermes* spp. (*Termitidae*: *Termitinae*) experienced low damage levels as compared to grazing lands dominated by *Macrotermes* spp. (*Termitidae*: *Macrotermitinae*). The farmers reported that damage levels varied among seasons and within seasons. Damage levels in the dry season were generally reported to be higher than those in the wet season while some farmers reported that the second dry season (November/December-February/March) experienced higher damage levels than the first dry season (June-August). It was noted that damage levels varied with topography with the upper slopes experiencing higher levels than mid-slopes and lower slopes. The farmers noted that overgrazing and deforestation were the major factors enhancing the destructive behaviour of termites on vegetation. The farmers' perceptions were supported by trials established to assess the effects of ecological factors on foraging intensity of termites. The results from the trials revealed that foraging intensity by subterranean termites was higher in areas cleared of vegetation and low in areas with adequate vegetation cover. On sites with limited basal vegetation cover (possibly due to overgrazing), termites consumed more grass baits than on sites with adequate basal cover. The high response of termites to baits on sites with insufficient basal cover meant that food resources were limited and hence termites had to respond to additional food sources. The findings thus implied that rangeland management practices that deprive termites of their main sources of food (mainly litter) may escalate foraging on alternative organic materials such as grass leading to vegetation denudation.

The termite assemblages on grazing lands in semi-arid Nakasongola consisted of sixteen species from one family (*Termitidae*), three sub-families (*Macrotermitinae, Termitinae* and *Nasutitermitinae*) and eight genera. The genera included *Macrotermes*, *Odontotermes*, *Microtermes*, *Pseudocanthotermes*, *Cubitermes*, *Procubitermes*, *Trinervitermes* and *Ancistrotermes*. Species from the sub-family *Macrotermitinae* constituted 69% of the total number of species sampled. Members from the genus *Macrotermes* were the dominant species and constituted 38% of the total number of species sampled. At species level, *Cubitermes* spp.1, *Macrotermes bellicosus*, *Macrotermes* spp.2, *Macrotermes* spp.1 and *Odontotermes* spp.2 were the most abundant species on grazing lands with total abundance of 142, 66, 55, 48 and 46 encounters respectively. *Trinervitermes oeconomus*, *Cubitermes* spp.3, *Microtermes* spp and *Pseudocanthotermes militaris* were very rare species and only occurred in one sampling plot. Some farmers demonstrated overwhelming skills to identify some of the species and their classifications were consistent with scientific taxonomic procedures. They used simple futures such as: presence of mounds; shape of mound; size of mound; presence or absence of vents on mounds, size and color of alates; size, color and shape of soldiers and workers; flight period of alates; feed source and spatial distribution. All the species belonged to two feeding groups namely group II and group IV. Group II (Wood, litter and grass feeders) species dominated the assemblages comprising of 75% of the total species. The rest of the species were true soil feeders. Apart from *Trinervitermes oeconomus* (specialized grass feeder), all the species that were assigned to Group II were generalist feeders that predominantly feed on litter. Four nesting habitats were represented, with 44% of the species nesting in epigeal mounds and 31% of the species nesting in hypogeal nests. Epigeal nesting species included *Macrotermes bellicosus*, *Macrotermes herus*, *Macrotemes* spp.1, *Cubitermes* spp.1, *Cubitermes* spp.2, *Trinervitermes oeconomus* and *Procubitermes* spp. The number of epigeal mounds ranged from 8 to 525ha^{-1}. These results are suggestive that members of the sub-family *Macrotermitinae* particularly *Macrotermes* and *Odontotermes* species are responsible for the reported damage on grazing lands and that sustainable termite management interventions need to focus on these species.

The diversity and composition of termite species was noted to vary with environmental variables. The quantity of plant biomass and available litter were the major vegetation variables influencing composition and diversity of termite species. Generally, *Macrotermes* species occurred in sites where the quantity of litter was above the mean. On the other hand, *Pseudocanthotermes* species, *Cubitermes* spp.3 and 1 occurred in sites where the amount of litter was lower than the average litter quantity. It was noted that although *Macrotermes* species occurred in sites where amount of litter was above the mean, the species disappeared in sites where litter quantity was greatly above the mean. *Trinervitermes oeconomous* and *Odontoremes* species were noted to occur in the direction of increasing quantity of biomass suggesting dependence of the species on plant biomass for nutrition. Majority of *Macrotermes* species and *Odontotermes* species occurred in sites where the pH was slightly above or below the mean (4.8). The species (*Macrotermes* and *Odontotermes*) were noted to disappear in the direction of increasing pH. Most of the species also occurred in sites where bulk density was below and slightly above the mean (1.55 g/cm^3).

The diversity of species was noted to decline in the direction of increasing bulk density. It was also noted that *Macrotermes* spp.1, *Odontotermes* spp.1, *Microtermes* species and *Pseudocanthotermes* species were the only members of the sub-family *Macrotermitinae* that occurred in sites were bulk density was below average. Most members of the sub-family *Macrotermitinae* occurred in sites where bulk density was slightly above the mean and finally disappeared in sites with high bulk density. Only *Ancistrotermes* species and *Cubitermes* spp.3 were noted to occur in sites with high values of bulk density. Such findings imply that activity of the pestiferous species could be checked through interventions that manipulate soil parameters like soil organic matter and pH as well as vegetation variables such as litter quantity and herbaceous basal cover.

5.1 Recommendations and suggestions for future research

Termite species from the sub-family *macrotermitinae* dominated the termite assemblages in the termite infested ecosystem of Semi-arid Nakasongola. The species are predominantly litter feeders but can forage on herbaceous biomass in absence of adequate litter sources to cause significant denudation of rangeland vegetation. Ecologically sustainable management of these species requires the following:

1. Ensuring ecological integrity of termite infested ecosystems through undertaking appropriate ecosystem management techniques that maintain an ecological equilibrium between termites and other ecosystem components to prevent competition for ecological resources. Anthropogenic activities that degrade ecosystems such as overgrazing and indiscriminate tree cutting need to be checked.

2. Ensuring adequate availability of organic materials (such as litter) and herbaceous vegetation cover to avail termites with adequate food resources to prevent termites from damaging vegetation.

3. Promote proliferation of termite predators such as predator insects and mammals to check termite activity in termite infested ecosystems.

Further research in the field need to evaluate the trade-offs and efficacy of potential termite control strategies undertaken by farmers, particularly those that can be used to substitute use of inorganic chemicals for termite control. It is necessary to conduct studies aimed at developing thresholds for litter (both quantity and quality), density of mounds, amount of vegetation cover e.t.c, beyond which termites become destructive. There is also need to investigate factors enhancing surges in construction of termite mounds that reduce grazing capacity in semi-arid rangelands. Finally, similar studies need to be undertaken in other rangeland ecosystems of Uganda to fully document the termite assemblages upon which interventions can be premised.

5.2 Limitations

The following are some of the limitations of the study:

1. The results of the study may not apply to ecosystems with a different composition of termite assemblage.

2. The study did not identify most of the species to species level due to the high costs of species identification.

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Appendix 1: Questionnaire on farmers' knowledge of the termite problem on grazing lands in Nakasongola district

Household ID ....Date of interview..

District...Sub-county...

Parish...Village...

A. Socio-demographic information (tick where applicable)

1. Name of respondent ....
2. Sex of respondent

   1 = Male [ ] 2 = Female [ ]
3. Age of respondent................... years
4. Educational level of respondent

   1 = None [ ] 2 = Primary [ ] 3 = Secondary [ ]

   4 = Tertiary [ ] 5 = Other (please specify).............................
5. What is the main occupation of the household head?

   1= Livestock farmer [ ] 2= Crop farmer [ ] 3= Pottery /crafts maker [ ]

   4= Charcoal burning [ ] 5 = Petty trader [ ] 6= Civil servant [ ]

   7 = Local leader (e.g. Chief, LC1, LC2, LC3) [ ]

   8 = Other (please specify)...
6. What is the major type of livestock kept by your household?

   1 = Cattle [ ] 2 = Goats [ ] 3 = Sheep [ ]

   4 = Pigs [ ] 5 = Chicken [ ] 6 = Other (specify).........................
7. Do you have adequate forages for your animals throughout the year?

   1 = Yes [ ] 2 = No [ ] <u>**If yes, Go to Q16**</u>

8. **If no,** what are the main causes of the forage scarcity?

....

....

....

B. Trends, causes and variations in termite activity

. Are termites a problem on your grazing land?

1= Yes [ ] 2= No [ ]

If yes, what is the estimated proportion of your grazing land that is facing the termite problem?

1= Low (less than 25%) [ ] 2= moderate (25-50%) [ ]

3= high (50-75%) [ ] 4= very high (75-100%) [ ]

18. When did you first realize termites as a problem on your grazing land?

1=1-5 yrs ago [ ] 2= 6-10 yrs ago [ ] 3=11-15 yrs ago [ ]

4=16-20yrs [ ] 5= 21-30 yrs ago [ ] 6 =other (specify)..................

19. Have you noticed any increase in the termite problem over the past years on your grazing land?

1= Yes [ ] 2= No [ ]

If yes, what do you think are the reasons for the increase in the termite problem over the past years? Rank in order of decreasing importance.

1st..

2nd..

3rd..

4th..

5 ....

20. Have you noticed any variations between the termite problem and vegetation cover type on your grazing land?

1= Yes [ ]   2= No [ ]

If yes, indicate the level of termite damage in relation to various vegetation cover types on your grazing land. **Tick where appropriate.**

	Termite damage level			
Vegetation cover type	**Low**	**Moderate**	**High**	**Very high**
Dense herbaceous layer				
Sparse herbaceous layer				
Bare ground				

21. Explain the variation in the termite problem indicated above

....

....

....

....

22. Have you noticed any temporal (time) variations in termite damage on your grazing land?

1= Yes [ ]   2= No [ ]

If yes, how does termite activity/damage vary over the year? **Use the codes below the table.**

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Level of termite damage												

1= (low) 2= (moderate) 3= (high) 4= (very high)

23. What do you think are the reasons for the temporal variations in termite damage?

....

....

24. Does termite activity vary with topography on your grazing land?

1= Yes [ ] 2= No [ ]

If yes, indicate the level of termite activity among the different topographic classifications on your grazing land. Tick where appropriate.

	Infestation level			
Topographic type	**Low**	**Moderate**	**High**	**Very high**
Lowland/valley				
Mid-slope				
Up-slope				

C. Termite diversity and abundance

25. Do you know the species of termites that have infested your grazing land?

1= Yes [ ] 2= No [ ]

If yes. Please mention them.

....

....

26. Describe the attributes that you use to distinguish between the mentioned termite species in 25 above

Termite species	Distribution across habitats	Description of distinguishing attributes

Distinguishing attributes include size and shape of mounds, flight period, colour, size and shape of casts, feed materials, e.t.c

D. Effects of termite activity on productivity of grazing lands.

A) Forage production

31. Do termites destroy forages on your grazing land?

1=Yes [ ] 2=No [ ]

If yes, what are the different forms of termite damage on forages?

1= Destroy leafy parts [ ] 2=destroy forage roots [ ] 3= cut forage stems [ ]

4= construct soil runways/soil sheets on forages and then desiccate them [ ]

5= build mounds on forages [ ] 5= others specify.....................................

32. At what stage of development are forages most susceptible to termite damage?

1=Seedling emergence [ ] 2= tiller development [ ] 3=Vegetative production [ ]

4= Flowering and seed formation [ ] 5=Senescence [ ] 6. Other (specify).............

33. Which group of forages is mostly destroyed by termites?

1=Grasses [ ] 2=Herbaceous legumes [ ] 3=fodder trees [ ]

34. Do termites show preference for particular forage species within the same group?

1=Yes [ ] 2= No [ ]

If yes, mention the forage species in order of decreasing preference by termites.

Grasses	Herbaceous Legumes	Fodder trees
1st		
2nd		
3rd		
4th		
5th		

35. Why do you think termites prefer particular forage/non-forage species to others?

....

....

E. Control/management practices mechanisms

43. Have you attempted to control/manage termites on your grazing land?

1=Yes [ ] 2=No [ ]

If yes, state the control practice, means of application of the method and its effectiveness

Control method	Means of application	Effectiveness

44. Mention the limitations associated with the adoption of the above termite control measures on grazing lands? Rank in order of decreasing importance.

1st..

2nd..

3rd..

4th..

5th..

Thank you for your time