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Integrated termite management for improved rainwater management:

A synthesis of selected African experiences

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Integrated termite management for improved rainwater management:

A synthesis of selected African experiences

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Abstract

In eastern Africa, termites are perceived by farmers, livestock keepers, and many development agencies as serious agricultural pests that destroy pasture, crops and wooden infrastructure. Commonly use control measures have proven to be ineffective. When the CGIAR Challenge Program on Water and Food (CPWF) undertook research aimed at increasing agricultural water productivity in eastern Africa, termites destroyed early experiments designed to rehabilitate degraded land and increase water productivity.

Building on indigenous knowledge from termite affected regions of Ethiopia, the CPWF and Uganda partners initiated research on integrated termite management. Results were promising. This literature review was commissioned to capture the state-of-knowledge about termite taxonomy, and diversity, farmers' ethno-ecological knowledge of subterranean termites and termite management practices and control measures used in African crop and rangeland production systems.

The paper offers some general lessons and guidelines for future agricultural research and development programs where termite damage is problematic. In brief, we conclude that ITM offers greater prospects for enabling termites to play important positive roles in agro-ecosystem functioning while reducing the damage they inflict on crop and livestock production.

Key words: Termite, diversity, ethno-ecological knowledge, management

1. Introduction

Recent advances in understanding Africa's challenge of supplying adequate agricultural water to meet the continent's demand for food call for a shift in emphasis from irrigation development to improved management of rainfed production systems (Comprehensive Assessment of Water Management in Agriculture 2007). This implies acknowledgement that precipitation rather than blue water is the ultimate natural water resource to be managed. Highly desertified or degraded croplands and rangelands are symptomatic of areas with low water productivity that typically result in lost food production, natural biodiversity, and jeopardized livelihoods. There are many approaches to increasing agricultural water productivity in rainfed agriculture (Comprehensive Assessment of Water Management in Agriculture 2007; Peden et al. 2009). One of these identified by the Challenge Program on Water and Food (CPWF) is integrated termite management (ITM).

In summary, degraded rangelands with little or no vegetative ground cover fail to capture and utilize available rainfall. The lack of associated litter and soil organic matter, a preferred food source for indigenous termites, compels them to feed on pasture grasses, crops, and woody material (Mugerwa 2007). Restoring the natural feed sources for termites affords an opportunity to revegetate landscapes and increase both agricultural production and biodiversity. The purpose of this literature review is to synthesize salient knowledge about the ecology and management of termites, especially those that are economically damaging to agricultural systems and related livelihoods and to recommend essential diagnostics and steps needed for widespread adoption of ITM.

Devastation of rangeland vegetation involving subterranean termites is a major constraint to animal production and functionality in several arid and semi-arid ecosystems. In the rangelands of Uganda for example, termites can consume over 60% of the available herbaceous (grasses and forbs) vegetation contributing to formation of denuded surfaces that facilitate extra-ordinarily high rates of erosion and eventually reduced soil productivity (Mugerwa 2011). The diminishing herbaceous component is associated with the distortion of the ecological equilibrium between grasses and woody species, upon which the structure of savannah vegetation depends. Eventually, termite infested grazing lands have been encroached by shrubs (Mugerwa 2011). Termites also construct numerous mounds ranging between 8 and 525 per hectare which greatly reduce the amount of land available for grazing. This results in concentration of livestock into smaller areas exacerbating the overgrazing problem and hence driving the ecosystem to extreme degradation. Consequently, herders face reduced feed availability and poor animal performance that eventually renders pastoral and agro-pastoral communities vulnerable to food insecurity and poverty (Mugerwa et al. 2011b).

Despite their damage on ecosystem components, there is no doubt that termites are beneficial in sustaining functionality and provision of ecosystem services in savannah ecosystems. Some have called them ecosystem engineers (Dangerfield et al. 1998). Through regulation of soil organic matter

(Nash and Whitford 1995) and their positive effects on soil properties such as porosity, aeration, and water infiltration and storage (Mando et al. 1996), they exert a strong influence over soil functioning. Their effect on soil structure and process eventually influences the spatial distribution and growth of vegetation (Mugerwa et al. 2011c) and communities of micro-organisms and other biota (Abensperg-Traun and De Boer 1990; Spain et al. 2004). Termites not only sustain functionality and productivity of soils but have also been harnessed to rehabilitate structurally crusted soils. Mando et al. (1996) demonstrated that attracting termites on crusted soils improved soil porosity, soil saturated hydraulic conductivity, soil water status and reduced soil bulk density and soil resistance to cone penetration.

Recognizing that termites are both destructive and beneficial in savannah ecosystems, sustaining the functionality and provision of ecosystem services can be achieved by controlling the pest termite species without causing ecological damage and loss of ecosystem services provided by termites and other arthropods. However, control of termites in Africa is largely based on use of synthetic chemicals (Sekamatte and Okwakol 2007). This control method is ecologically unsustainable since it poses a great threat to beneficial non-pest arthropods. Pesticides may also kill insects that prey on termites and aggravate the current termite problem (Sekamatte 2001). What is needed is sustainable termite management that ensures:

(1) control of the pest termite species without causing ecological damage and loss of ecosystem services provided by termites and other arthropods,

(2) conservation of non-pest termite species, and

(3) use of termites and associated resources without exhausting them (Sileshi et al. 2009).

Okwakol and Sekamatte (2007) reported that development of sustainable macrofaunal management practices for any ecosystem should be premised upon an explicit understanding of the structure and ecology of the concerned macrofaunal communities. The authors further demonstrated that understanding the assemblage structure (species composition, species and functional group diversity) of soil macrofauna is critical in generating coherent principals upon which sustainable management of the concerned macrofauna 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 potentially sound termite management practices that involve as cultivation, grazing and fire management.

Altieri (1993), Morse and Buhler (1997) emphasized the importance of farmers' ethno-ecological knowledge in the development of socially acceptable termite (pest) management interventions. The authors noted that the current philosophy in pest management recognizes the need for researchers to value farmers' indigenous knowledge systems (ethnoscience). 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; Price 2001; Nkunika 2002). The strong point of farmers' indigenous knowledge systems is that it results from frequent observation of crops, pasture and trees during the whole cropping, grazing and production cycles, and it comprehends continuities within the landscape and vegetation. Practices and principles grounded in the theory of ethno-ecology are often used for capturing farmers' pest management knowledge and practices (Björnsen Gurung 2003; Price and Björnsen 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; Price 2001; Nyeko et al. 2002; Björnsen Gurung 2003; Nyeko and Olubayo 2005; Price and Björnsen 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. Nevertheless, there may still be need to demonstrate the verity of farmers' knowledge through science based research.

In this paper, we sought to synthesize existing theory related to the composition and structure of termite assemblages, to describe the relationship between termites' foraging behaviour and other ecosystem components as well as to bring together information related to farmers' ethno-ecological knowledge on termite management within the African region. The synthesis was aimed at directing formulation of future termite research themes as well as guiding development of efficient, ecologically sound and sustainable termite control programs in semi-arid African agricultural production systems.

2. Community structure of subterranean termites in African ecosystems

Termites are a large and diverse group of insects consisting of over 2600 species worldwide. With over 664 species (Wanyonyi et al. 1984), Africa is by far the richest continent in termite diversity (Eggleton 2000). Several authors have described the termite assemblages in African ecosystems to be dominated by subterranean species from family Termitidae and subfamilies Macrotermitinae and Termitinae. In the drylands of Uganda for example, Sekamatte (2001) reported that the termite assemblages consisted of species from two families (Hodontotermitidae and Termitidae). The author further noted that Hodotermes and Microhodotermes were the only genera encountered from the family Hodontotermitidae and that species in these two genera were extremely rare. He however reported that species from two subfamilies (Macrotermitinae and Termitinae) constituted the majority of the species sampled. A more recent study by Mugerwa et al. (2011a) suggested that termite assemblages in the rangelands of Central Uganda consist of species from only one family (Termitidae), three subfamilies (Macrotermitinae, Termitinae and Nasutitermitinae) and eight genera (Macrotermes, Odontotermes, Microtermes, Ancistrotermes, Pseudocanthotermes, Trinervitermes, Cubitermes, and Procubitermes). The subfamily Macrotermitinae contains 69% of the total number of termite species while species from the genus Macrotermes constituted over 70% of the total species. The authors further noted that the species belonged to two feeding groups namely Group II (wood, litter and grass feeders) and IV (true soil feeders) based on the feeding group classification criterion developed by Donovan et al. (2001), with Group II species comprising of 75% of the total species. Apart from Trinervitermes oeconomus, a specialized grass feeder, all the species that were assigned to Group II are generalist feeders that predominantly feed on dead plant litter.

Review of numerous termite inventory reports and studies (Sands 1976; Abdurahman 1990; Cowie et al. 1990) in Ethiopia suggests that the termite fauna in the country is not well known. However, 61 species have so far been reported to occur in Ethiopia. These species belong to 25 genera and four families (Kalotermitidae, Hodotermitidae, Rhinotermitidae and Termitinae). The family Kalotermitidae is represented by four species (Neotermes erythraeus, N. superans, N. aridus and Epicalotermes aethiopicus). Only two species (Hodotermes mossambicus and H. erithreensis) from the family Hodotermitidae have so far been reported to occur in Ethiopia while the family Rhinotermitidae is as well represented by two species (Coptotermes amanii and Psammotermes hybostoma). The rest of the species belong to the family Termitinae which consists of four subfamilies (Macrotermitinae, Nasutitermitinae, Termitinae and Apicotermitinae). The family therefore represents over 85% of the species so far recorded in Ethiopia. The majority of the species in this family belong to the subfamily Macrotermitinae and the common species belong to Macrotermes, Odontotermes, Microtermes genera.

In the Darfur region of Sudan, Pearce et al. (1995) reported that the termite assemblages comprised of species from two families (Kalotermitidae and Termitidae). The family Kalotermitidae consisted of only three genera (Neotermes, Psammotermes and Coptoterme) while the family Termitidae consisted of two subfamilies (Termitinae with three genera and Macrotermitinae with nine genera). The majority of the species belonged to the subfamily Macrotermitinae. Ferrar (1982) studied the composition of termite assemblages in South Africa, Senegal, Ivory Coast and Nigerian savannahs where he observed that the species belonged to only three families: Kalotermitidae (3 genera), Rhinotermitidae (2 genera) and Termitidae (28 genera). He further noted that majority of the species belonged to one family (Termitidae) and two subfamilies (Termitinae and Macrotermitinae) with Macrotermes, Micrototermes and Odontotermes species dominating the assemblages. Species from the subfamilies Apicotermitinae and Nasutitermitinae were reported as the rarest species among members of the Termitidae family. In fact, Trinervitermes species were the only species of the subfamily Nasutitermitinae encountered on all sampled sites. Other species (Nasutitermes, Mimeutermes, Eulleritermes and Eutermellus) were limited to particular ecosystems.

The literature is indicative that termites from the family Termitidae and subfamilies Macrotermitinae and Termitinae dominate the termite assemblages in most African ecosystems. The subfamily Termitinae consists of about 272 species (Eggleton et al. 2002). The Macrotermitinae (fungus growing termites) consists of over 165 species (Eggleton et al. 1999) and is arguably the most destructive group of termite species to crops, rangeland and forestry. Development of integrated pest control strategies for termites in Africa therefore need to adequately account for the biology or behavioural ecology (e.g. foraging behaviour) of the Macrotermitinae subfamily as the group is responsible for much of the damage in African ecosystems. Aspects of nesting (mould and nonmound building behaviour), food preference (wood, grass, litter, etc.), predator-prey and foraging behaviour for the Macrotermitinae species need to be critically examined in IPM systems for termite species in Africa. Further, studies are necessary to differentiate the non pest species from pest species within the group so that management efforts are focused on the species of economic value. It is also necessary to study and develop complete and adequate termite inventories which need to be updated with time due ecosystem changes which lead to emergence of new species or even extinction of old species especially dues to anthropogenic impacts on ecosystem functionality. The termite inventories should not simply provide the taxonomic classifications of species but should also describe the biology and behavioural ecology of each species. Such detailed inventories will sufficiently guide management interventions over time as well as future research of termite–environment interactions.

3. Pest status of subterranean termites in African agricultural production systems

Throughout tropical Africa, several species of termites are considered as serious pests to crops, rangeland and forestry. Most pestiferous species to crops, trees, and rangeland belong to the family Termitidae, which comprises of four subfamilies namely Macrotermitinae, Nasutitermitinae, Termitinae, and Apictotermitinae. It is estimated that about 20% of members of the family Termitidae are serious pests (Pomeroy et al. 1991; Mitchell 2002) with over 90% of the termite damage in agriculture and forestry is attributed to members of the Macrotermitinae (Pomeroy et al. 1991; Mitchell 2002). The main genera in the subfamily Macrotermitinae are Odontotermes (79 species), Microtermes (33 species), Macrotermes (21 species), Ancistrotermes (9 species), Allodontermes (7 species), and Pseudacanthotermes (5 species) (Pomeroy et al. 1991; Darlington et al. 2008). Mugerwa (2011) noted that the major pest species that devastated pasture in the semi-arid ecosystems of Uganda belonged to the genera Macrotermes, Odontotermes and Pseudacanthotermes. The same genera were reported to constitute majority of pest species in the rangelands of Ethiopia (Wood 1991). Pearce et al. (1995) noted that the pest species responsible for the destruction of pasture and crops in the Durfur region of Sudan belonged to the genera Macrotermes, Odontotermes, Pseudacanthotermes, Ancistrotermes and Microtermes. Results from a termite survey conducted in six districts in southern Zambia revealed that the pest species in the sampled areas belonged to seven genera: Macrotermes, Odontotermes, Pseudocanthotermes, Allodontotermes, Ancistrotermes, Amitermes and Microtermes (Ahmed et al. 2010). Species from the genus Macrotermes particularly Macrotermes falciger were noted as the most common termite pests and arguably responsible for much of the damage caused by termites to agriculture production. Macrotermes species were reported in all the six districts while Odontotermes and Pseudocanthotermes species were reported to occur in four districts. The other genera were localized in particular sites making overall their contribution to termite damage levels relatively low as compared to the widely distributed species. The species recorded attacking crops, pasture and trees in Ethiopia are in the genera Macrotermes, Odontotermes, Pseudacanthotermes, Ancistrotermes, Amitermes and Microtermes (Abdurahman 1990). Macrotermes herus was noted as one the most destructive termite species to crops causing over 50% pre and postharvest losses in maize (FAO 1984) and severely damaging teff, vegetables and Eucalyptus in several parts of Wollega and Asossa zones (Crowe et al. 1977).

It can be concluded that majority of the pest termite species in African agricultural production systems belong to the subfamily Macrotermitinae. Although the species are generalist feeders, they have strong preference for dead dry material such as herbaceous and woody litter (Mitchell 2002). So to say, the majority of the species from the subfamily Macrotermitinae are not harvester species and will only resort to consuming standing crops (maize, sorghum, wheat, teff, pasture, etc.) once they are deprived of adequate sources of their preferred food. Evidence to support this concept was clearly presented by Mugerwa et al. (2011c) who noted that foraging intensity of Macrotermes species on alternative feed sources such as standing pasture increased with decrease in litter (both herbaceous and wood) quantity. Sekamatte et al. (2001) also demonstrated the same mechanism in maize fields where he reported that termite damage to maize crop was significantly reduced by increasing the quantities of maize stover mulch. The authors (Sekamatte et al. 2001; Mugerwa et al. 2011c) noted that in addition to availing the preferred food to termites, dry organic materials (herbaceous and wood litter) provide nesting sites to termite predator particularly predator ants which control the activity of termites. It therefore seems logical to mention that devastation of agricultural crops by Macrotermes species can by mitigated through provision of adequate feed resources to termites in form of dry organic materials and ensuring proliferation of termite predators. Development of integrated pest management strategies for controlling termites in African agricultural systems need to account for termite feed resources and enhancing proliferation of termite predators or termite enemies. In fact, the use of entomopathogenic fungi as a biological control agent of termites was driven by the need to enhance activity of termite enemies. Research aimed at mitigating Macroterm damage in African agricultural systems therefore need to focus on elucidating the ecological drivers of their foraging behaviour as well as the determinants of termites foraging intensity if sustainable and efficient termite control strategies are to be designed.

4. Farmers' ethno-ecological knowledge of subterranean termites in African agricultural production systems

4.1. Farmers' knowledge of termite taxonomy

Farmers possess overwhelming ability 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 in Uganda identified 14 species with distinct vernacular names. The farmers based their identification criteria on termite species' morphological, nesting and behavioural features. The features included size, colour and shape of termite casts (workers, soldiers and alates), shape and size of mounds, presence or absence of vents on mounds and types of nests among others. Behavioural features used by farmers to aid identification included flight periods of alates, feed resources and distribution. Mugerwa et al. (2011b) also reported that farmers were able to identify eight termite species out of sixteen species that occurred on their grazing lands based on simple taxonomic features. Based on feed sources, farmers demonstrated ability to identify and differentiate pestiferous termite species from non-pest termite species. Malaret and Ngoru (1989) also reported that farmers in Kenya could identify humus feeders and differentiate them from those that attacked crops or trees. 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). The farmers' classification criterion was noted to be consistent with the scientific taxonomic criteria. However, as noted by Nyeko and Olubayo (2005) and Mugerwa et al. (2011b), such community based taxonomic skills seemed limited to few farmers. This literature is suggestive that termite management interventions in any agricultural production system need to capitalize on farmers' taxonomic knowledge since the farmers possess considerable knowledge of the pestiferous termite species damaging their ecosystems. 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).

4.2 Farmers' knowledge of termite abundance and distribution

Farmers often possess good understanding of the abundance and distribution of termites in agro-ecosystems where they co-exist. Most farmers in the rangelands of Uganda rated Macrotermes bellicosus and M. herus as the most abundant termite species (Nyeko and Olubayo 2005; Mugerwa et al. 2011b), which is consistent 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 upslope than down slope respectively, disagreed with Pomeroy (1978) who stated that the two species were evenly distributed across the ecosystem. Farmers in Machakos District of Kenya associated Macrotermes and Odontotermes species with farmland more than bush land. Farmers in the rangelands of Nakasongola in Uganda also reported that the distribution of termite species was influenced by spatial and temporal variations. The occurrence of nests for Macrotermes and Odontotermes species was reported to be higher upslope than down slope while the occurrence of Cubitermes species was reported to be higher down slope than upslope (Mugerwa et al. 2011b). Recognizing the fact that Macrotermes and Odontotermes species are potential pests to rangeland vegetation, termite management interventions need to focus upslope rather than down slope. Farmers' knowledge on distribution and abundance of species is therefore critical in identification of hotspots where termite management interventions would be evaluated. It is therefore imperative to evaluate termite control strategies upslope where termite infestation and damage is arguably higher than downstream where termite densities and damage is low.

4.3 Farmers' perceptions of termites as pests

Many authors (Nkunika 1998; Nyeko and Olubayo 2005; Sekamatte and Okwakol 2007; Sileshi et al. 2008) demonstrated that farmers have good knowledge of pest termite species in their production systems. Farmers in Tororo District of Uganda ranked M. bellicosus and M. subhyallinus as the most serious pests to trees, crops and rangelands (Nyeko and Olubayo 2005). Although Pseudacanthotermes spriniger was reported to damage some crops in other ecosystems, farmers in Tororo District perceived it as a minor pest that did not merit control (Nyeko and Olubayo 2005). However, farms in Nakasongola District in Uganda (Sekamatte 2001) and in the Darfur region of Sudan (Pearce et al. 1995), considered Pseudacanthotermes springier as a major pest on rangeland vegetation. Farmers in the Darfur region of Sudan considered Microtermes lepidus as the most destructive species from the genus Microtermes. The farmers also demonstrated considerable knowledge on the mode of attack of particular termite species. Apparently these Microtermes species commonly attack plants through the roots and advances into the stem causing wilting and eventually death of the plant. Odontotermes species (another group of pest termites in the Darfur) usually covers the plant or parts of the plant with soil sheeting and eat the leaves/stem under this protective cover. Famers in the Darfur region of Sudan demonstrated that Macrotermes species attacked crops by cutting off young seedlings and mature plants at ground level (Pearce et al. 1995) which was in agreement with Mugerwa et al. (2008) who reported that the same species attacked and cut all pasture seedlings at ground level in the semi-arid ecosystem of Nakasongola. In southern Zambia, M. falciger was ranked as the most destructive pest termite while in eastern Zambia, farmers ascribed most of the crop damage to M. falciger and M. subhyallinus (Nkunika 1998). Microtermes species are considered major pests in Africa (Wood et al. 1980) but 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. The literature on farmers' knowledge of the pestiferous species is indicative that the same termite species may be destructive in one agricultural production system and yet non-destructive in the other system. This is possibly why farmers in Tororo District in Uganda ranked Pseudacanthotermes spriniger as a non-destructive species and yet farmers in the Darfur region in Sudan ranked it as a serious pest to rangeland vegetation. So to say, the fact that a species may be blamed for destruction of crops and pasture in one system does not necessarily merit control interventions in another system. Efforts to develop efficient ITM guidelines for any system need to exploit knowledge of the pestiferous termite species so as to focus control interventions on species of concern to the farmers rather than basing management interventions on experiences from other production systems. It also seems sensible to conduct ecological studies to elucidate the determinants of varying foraging behaviour of the same species across production systems. Such studies may aid in designing management interventions for the concerned species. Further, the review has revealed farmers are aware to a considerable degree of the actual termite species and the mode of attack of the various species. Sustainable termite management requires that termite management interventions target such species other than blaming all termite species, many of which are beneficial to the ecosystem.

4.4 Farmers' perception of susceptibility of plants to termites

Farmers were also able to group several crops based on their degree of tolerance and susceptibility to termite attack. Farmers rated maize (Zea mays L.), groundnut (Arachis hypogaea L.), and sugarcane (Saccharum spp.) as highly susceptible crops to termite damage in Uganda (Nyeko and Olubayo 2005), Kenya (Malaret and Ngoru 1989), and Zambia (Sileshi et al. 2008). Maize and groundnut were particularly rated as highly susceptible by most respondents (>90%) in eastern Zambia. The farmers' assessment is in agreement with the entomological studies conducted elsewhere in Africa (Wood et al. 1980). In Machakos District of Kenya, farmers identified 24 species of trees and shrubs as tolerant to termites (Malaret and Ngoru 1989). In Ethiopia, farmers reported that Chomo grass (local name) and Vetivar grass were tolerant to termite attacks. Ugandan farmers identified Eucalyptus species and Grevillea robusta as highly susceptible to M. bellicosus and M. subhyallinus (Nyeko and Olubayo 2005). The more serious damage on the exotic crops (e.g. maize and groundnuts) and trees (e.g. Eucalyptus and Grevillea) is probably because these species lack resistance to African termites (Mielke and Mielke 1982; Logan et al. 1990). The factors that enable such resistance remain unknown. Indigenous African crops and trees are expected to be resistant to these termites with which they have co-evolved. Contrary to scientific reports that termites rarely attack vigorously growing plants (Wood et al. 1980), some farmers stated that termites attack both healthy and unhealthy plants (Malaret and Ngoru 1989). Most farmers in eastern Zambia believe that crops become susceptible to termite attack at maturity and this agrees with the literature (Wood et al. 1980). According to these farmers, termite damage to crops and trees 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). 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).

Farmers' knowledge on the tolerance of certain plants to termite attack provides a firm justification to scientists to evaluate and establish the plant attributes responsible for the observed tolerance. Such attributes may be passed on to susceptible plants through breeding and biotechnology to improve their tolerance to termite attack. Second, such tolerant plants may be repulsive to termites and could be intercropped in various spatial and temporal patterns with the susceptible crops to mitigate damage. The mechanism through with such plants resist termite attack is therefore worth investigating if the plants are to be incorporated in ITM programs. For example, the natural chemical compounds in the whole Vetiver grass (including leaves and roots) are repulsive to termites and when the grass is planted around seedling of susceptible plants, termite attack is usually reduced (Le and Nguyen 2009). Hence, it would be worth investigating the temporal and spatial patterns of integrating Vetiver grass (Vetiveria zizanioides L.) in susceptible crops to termite damage to come up with the best temporal and spatial combination that efficiently control termite damage. Other tolerant plants such as the Chomo grass in Ethiopia may also be exploited in termite control. The farmers' knowledge on plant tolerance should however be used with caution as tolerance is a function of interactions between the plant and its environment. So to say, an individual plant species may show considerable tolerance in one production system but yet be very susceptible in another one. The tolerance is also influenced by the termite assemblage structure in a particular production system. In general, crop health is dependent on maintenance of soil fertility and prudent water management as well as the use of varieties suited to local conditions (SP-IPM 2010).

4.5 Farmers' knowledge of factors escalating termite damage in African agricultural production systems

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 depletion of the usual termite food due to deforestation and overgrazing. Farmers in Nakasongola District of Uganda also linked the surges in termite damage on vegetation to ecosystem deterioration attributed partly to overgrazing and deforestation (Mugerwa et al. 2011b). Ecosystem deterioration is thought to have also resulted in loss of suitable habitats for termites' natural enemies such as predatory ants, aardvark (Orycteropus afer), pangolin (Manis species), aardwolf (Proteles cristatus), and hedgehog (Pomeroy et al. 1991; Peveling et al. 2003) hence escalating termite activity and proliferation. Habitat loss has also been reported to result in disappearance of the aardvark in countries such as Ethiopia (Jiru 2006). Some farmers in the Nakasongola District feel that the termite problem was escalated by the environment policy restrictions on use of fires in management of arid and semi-arid environments. The farmers feel that fires are crucial in controlling proliferation of termites. The literature is suggestive that depletion of food resources for termites and the destabilization of the naturally occurring prey–predator interactions between termites and their predators could have triggered proliferation of termites and damage to other ecosystem components. It is thus fair to mention that restoration of the termites' preferred food resources and ensuring proliferation of termite natural enemies should be one of the guiding principle in ITM programs.

5. Common termite management practices in African agricultural production systems

5.1 Destruction of termitaria (mounds) and the colony

Mugerwa et al. (2011c) demonstrated that the density of mounds is directly proportional to the quantity of vegetation consumed by subterranean termites in the semi-arid ecosystems of Central Uganda. This is possibly because the majority of the pest termite species nest in epigeal mounds (termitaria). As such, farmers undertake several methods aimed at destroying/deactivating the colony in an attempt to reduce termite densities and subsequently mitigate termite damage on vegetation. Some farmers dig out the entire mound using locally available farm implements (e.g. hand hoe) until the queen is reached and removed. As the mound is dug out, the colony is exposed to direct sunshine rays leading to desiccation since they lack cuticles to protect them from heat.

Most farmers use synthetic chemicals to destroy the colony. Nyeko and Olubayo (2005) reported that farmers mix chemicals such as Ambush, Dimethoate, Diazole and Thiodan with water, make a hole on top of the mound and pour the mixture into the hole. This practices was also reported by Mugerwa et al. (2011b) as the most common termite control method undertaken by farmers in the rangelands of Nakasongola in Uganda. Several farmers noted that the method deactivates the colony for a short period and after some time, the colony rejuvenates. This probably meant that some individuals within the colony especially the queen do not get in contact with the chemicals and hence able to survive. Alternatively, the amount of the chemicals mixed in water may not be adequate to destroy the colony or the active ingredients within the chemicals may not be sufficient to destroy the colony.

Other than use of synthetic chemicals, farmers have reported use of organic insecticide to destroy termite colonies. Nyeko and Olubayo (2005) and Mugerwa et al. (2011b) noted that farmers ferment a mixture of water, tobacco leaves, red pepper and wood ash for 5–14 days, dig a hole on top of the mound, and pour it in the mound and seal. Others were noted to mix Tithonia, red paper and water, ferment for 2–3 days, and pour it into the mound before sealing it. Farmers also destroy colonies by pouring paraffin alone or in combination with all or either of red paper, wood ash, Aloe species while others use old engine oil instead of paraffin. Farmers also reported that they destroy epigeal nests by setting them ablaze. Nyeko and Olubayo (2005) noted that farmers insert dry wood, grass in to the mound, set it on fire and seal to confine the smoke while others simply seal the vents on mounds using banana stems. Farmers also dig trenches to direct running water in to mounds through vents or through holes dug on mounds while others pour hot water or human urine in mounds.

The efficacy of mound and or colony destruction as a termite management intervention is highly questionable and in many cases the practice simply relaxes termite activity but in the long run, the activity is restored. The possible explanation for the inefficiency of the method may be due to the following reasons. Application of synthetic or nonsynthetic chemicals to mounds to destroy the colony does not always reach the royal pair (queen and drone) because the pair is housed in very hard chamber constructed with highly compacted soil particles. This hard cell protects the queen from any intrusion including affected workers. Consequently, the queen will lay more eggs to replace the destroyed workers and soldiers casts. In cases where the queen is found and physically removed out of the nest, some species (especially species that belong to the genera Cubitermes, Macrotermes and Nasutitermes) have the ability to produce substitute queens to restore the colony.

These practices are directed toward mature colonies of the mound building species. 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). Mound destruction over expanses of land such as on grazing lands is labour intensive and costly in the long run so that many farmers cannot afford the practice. If mound destruction is practiced in agricultural systems where the mound density is extraordinarily high, then the method needs to be modified to make it less labour intensive and to ensure that either synthetic or nonsynthetic chemicals reach the queen. Equipment may be developed to direct the chemicals to the queen chambers other than physically digging out the queen. Once chemicals are to be used, their application should be in multiple doses so as to destroy the substitute queens as well. Otherwise, single doses usually provide temporary relief.

5.2 Use of live plants, dead plant materials and plant extracts

Farmers use various plant materials to control termites (Logan et al. 1990; Nkunika 1998). Farmers in Malawi and Zambia believe that planting Euphorbia tirucalli in crop fields or applying its branches in planting holes deters termites (Sileshi et al. 2008) while in Uganda, the pastoral and agropastoral communities believe that placing branches of the same plant in pasture deters termites from invading pasture. Other farmers fence off their paddocks using the plant to mitigate termite damage on wooden fencing poles. The leaves and roots of E. tirucalli are soaked in water and the solution is sprayed to protect seedlings from termites in Tanzania (Logan et al. 1990) while farmers in Zambia 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 use of plant materials in planting holes seem to be limited to food crops which involves digging holes before planting but is less applicable in permanent pasture swards. Placing of E. tirucalli branches in pasture to deter termites from consuming pasture seems to be the most applicable termite control intervention involving the use of plant materials that warrants evaluation. 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). Farmers also heap plant residues such as maize stover, tree branches, and grass mulch to attract termites as well as to localize termite activity in specific places in crop and pasture fields. Sekamatte et al. (2001a) demonstrated that increasing the quantities of maize stover in maize fields significantly reduced termite damage on maize crops. The mulch was noted to avail alternative food resources to termites and hence deterring them from attacking maize. Further, the mulch provided nesting sites for predatory ants and hence enhanced their multiplication and eventually predatory activity on termites. The literature suggests that some plant materials (both live and dead) repulse termites while others simply avail the termites with adequate feed resources to deter them from attacking crops. It therefore sounds logical that an integrated approach involving the use of repulsive plants or plant materials and provision of termites with adequate feed resources through mulching would mitigate termite damage in cropping systems beyond additive expectations. An example of such a strategy would involve planting Vetiver grass, a proven termite repulsive grass after every 2–4 rows of maize crops and then mulch the maize fields.

5.3 Use of animal excreta

Cattle excreta (dung, urine or mixture) 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) while in Monze region of Zambia, farmers apply fresh cow dung in maize fields to reduce termite damage on maize crops (Nkunika 1998). Similarly, farmers in southwestern Nigeria believe that goat and cow dung reduce termite damage (Banjo et al. 2003). Reduction in termite damage on rangeland vegetation using cattle excretes has been demonstrated in an experiment conducted in the 'Cattle Corridor' of Uganda. Mugerwa et al. (2008) reported that accumulation of cattle excretes in reseeded plots deterred termites from attacking and cutting pasture seedlings. Cattle excreta were reported to avail alternative feed sources to termites, but most importantly, excretes enhanced survival and proliferation of entomopathogenic organisms that could have checked termite activity. Further, excreta improved soil fertility and hence growth vigour of pasture reducing its susceptibility to termite damage. Based on results reported by Mugerwa et al. (2008), mechanisms in which manure reduces termite damage on pasture are three fold: (1) manure avails alternative food resources to termites hence relieving pasture of termite attack; (2) manure enhances proliferation of entomopathogenic organisms (termite enemies) which check the activity of termites, and (3) manure enhances soil fertility and thus boosts plant vigour making it less vulnerable to various forms of shocks.

5.4 Application of wood ash

Wood ash has been widely mentioned as one of the control practices in eastern and central Uganda (Nyeko and Olubayo 2005; Mugerwa et al. 2011b), eastern and southern Zambia (Nkunika 1998; Sileshi et al. 2008) and Nigeria (Banjo et al. 2003). Farmers in Uganda reported that ash may be broadcasted in pasture swards or top dressed on rows of re-seeded pasture seedlings. The mechanism by which ash provides protection against termites is still unknown and the method is largely limited by the limited availability of enough quantities of ash making it less applicable in ecosystems with high mound density. This makes the method less reliable to control termite damage.

5.5 Protein- or sugar-based products

In Uganda, farmers use dead animals, meat, and sugarcane husks to 'poison' Macrotermes mounds (Sekamatte et al. 2001b). 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. (2001b) demonstrated that the reduction in termite damage in plots that received fish meal is due to increased activity of predatory ants. The protein-based baits resulted in greater predatory ant nesting near maize plants and reduction in termite damage (Logan et al. 1990). This is suggestive that termite control needs to focus on interventions that enhance the survival and proliferation of termite predators.

5.6 Biological control of termites

In an experiment to mitigate termite damage in maize fields using an entomopathogenic fungus, Maniania et al. (2001) noted that application of Metarhizium anisopliae (Metch. Sorok. strain ICIPE 30) granules at planting significantly decreased termite damage in maize which eventually reduced plant lodging and escalated maize yield. The authors further noted that the application of the fungus at tasselling did not produce a significant reduction in maize lodging when compared with the untreated control. Termites were noted to attack maize plants at any stage of development from seedling to maturity, and the most important species belonged to the subfamily Microtermitinae (Wood et al. 1980; Cowie and Wood 1989). The trial revealed that the much smaller Microtermes species begin their attack at the seedling stage (4–5 weeks after plant emergence) and this continues to plant maturity, while damage by the larger Macrotermes species started at tasselling stage and thereafter. Although application of fungus at planting targeted Microtermes, the treatment was also successful in preventing damage from Macrotermes populations which usually attack plants during maturity. Trials carried out in Uganda with the same isolate (ICIPE 30) against termites, have also demonstrated a 70% increase in maize yield, comparable to that obtained with the use of the chemical insecticide lindane (Sekamatte 2000). A single-season application was also observed to provide full protection for another three seasons in maize planted on the same plot (Sekamatte 2000). The mechanism by which M. anisopliae protects maize against termite damage may be twofold: (1) direct kill as a result of contact with fungal conidia and (2) avoidance as a result of repellent action of the spores (Ko et al. 1982; Milner and Staples 1996). Metarhizium anisopliae has a high potential for exploitation into a commercial bio-insecticide in Africa. Their low toxicity to humans compared with chemical pesticides is an advantage, especially in Africa, where the risk of misuse of pesticides is very high. Further studies should include optimization of dosage for field application and treatment of large area in different agro-ecological zones, with different socio-economic characteristics.

In another experiment to establish the parasitism effect of Megaselia scaralis (Dipteria: Phoridae) on Pseudocanthotermes species, Sekamatte et al. (2000) demonstrated that M. scaralis was a primary parasitoid of Pseudocanthotermes species in Uganda. The phorid was noted to be prevalent in heaps of decomposing crop residues in which it got greater opportunity to oviposit in termites and the larger sized caste, the major soldiers were more vulnerable to attack by the phorid. The response of phorids to crop mulches was mediated by a number of factors including food needs, aspects of habitat suitability and movement patterns of the host termites. The higher parasitism under mulch was probably not due to presence of mulch its self, but rather due to the modified behaviour of the termites. It was noted that instead of constructing surface soil tunnels, the termites foraged most of the time on or inside dry hollow maize stalks which offered comparatively poor protection against phorids compared to continuous soil tunnels on un-mulched ground. The study revealed that termite parasitism by phorids was favoured by presence of mulch. The mulch presented a concentrated food for the host termites and probably caused microclimate changes such as increased relative humidity, lowered temperatures and reduction in wind turbulence that allowed easy movement of the phorid fly. The authors recommended that more scientific investigation should be conducted to determine the host range of M. scaralis and its potential in ITM.

6. Suggested integrated and sustainable termite management approaches in African agricultural production systems

The perception that termites damage croplands and rangelands in eastern Africa is in reality often the symptom of the process of land degradation. Under these conditions, ecosystem structure and natural biodiversity have been lost and human livelihoods dependent on the land suffers. ITM requires approaches that lead to rehabilitation of degraded lands. Achieving this will foster environmental health and human prosperity through increased land and water productivity.

A starting point for adoption of ITM is developing farmers', extension workers' and researchers' skills in identifying termite species with emphasis on the most problematic ones. There is considerable depth of understanding from the perspectives of both indigenous and taxonomic knowledge. However, more research is needed to integrate these two approaches for classification.

For any termite management/control strategy to be effective in African production systems, a number of conditions need to be satisfied. These include: (1) provision of adequate food resources to termites to deter them from attacking crops; (2) enhancing multiplication and proliferation of both micro (such as entomopathogenic fungi) and macro (such as predatory ants) termite enemies; (3) reduce vulnerability of crops through improved agricultural water and soil nutrient management for vigorous growth; and (4) integration of repellent organisms (such as vetivar grass) in African cropping and pasture systems. Review of the various termite management practices revealed that no single management practice met all four of these conditions. Thus these termite control practices tend to be ineffective. This calls for an integrated termite control (ITM) approach addressing all the above aspects of termite control mechanisms.

Looking beyond ITM to the wider challenges of rehabilitating degraded lands and reversing desertification, evidence from the CGIAR Challenge Program on Water and Food suggests that ITM provides one practical entry point to enhance production, accumulation and turnover of plant biomass—a key requirement to improving agricultural water productivity, food production, and livelihoods in many areas of sub-Saharan Africa (Peden et al. 2009; Swaans and Peden 2013).

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