Control of rodent pests in maize cultivation: the case of Africa

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1 Introduction

Rodents cause serious problems to human communities in Africa as a result of their involvement in the spread of diseases (Katakweba et al. 2012) and in the losses of crops through direct consumption (Mulungu et al. 2003; Bekele et al. 2003) and spoilage (Mdangi et al. 2013). For example, Taylor (1968) reported 20% damage to maize crop after the outbreak of rodents in Western Kenya. Earlier reports (Taylor 1968) on economic losses due to rodents in Kenya indicated 20–30% damage to maize crops, and a 34–100% loss during rodent outbreaks. In Ethiopia, it has been estimated that rodents consume up to 26.4% of maize crop in most years (Bekele et al. 2003). In Northern Ethiopia, surveyed farmers estimated 9–44% pre-harvest yield losses in annual production of cereal crops due to rodent attacks (Meheretu et al. 2010), while Central Ethiopia showed 26.4% loss of yield in maize (Bekele et al. 2003). In Tanzania, rodents are estimated to cause on average 15% yield loss (Makundi et al. 1991), which would mean the loss of around 382 673 tonnes per year of the actual yield (FAO statistics 2014). This amount of maize, with an estimated value of US$42.5 million (at US$11.1 per 100 kg bag of maize), would be enough to feed 2.1 million people for a whole year (at about 0.5 kg/day/person). However, in many parts of Africa, this figure has risen dramatically over the last few years, most noticeably in places where rodent outbreaks occur (Mwanjabe et al. 2002; Taylor and Green 1968, 1976). Today, it is not usual for smallholder maize farmers to report chronic rodent damage

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of more than 80% in certain cropping seasons and localities (Mwanjabe and Leirs 1997; Mulungu et al. 2003). To overcome such problems, a sound understanding of rodent population dynamics and breeding patterns can help in the design and implementation of appropriate control strategies (Leirs et al. 1997; Singleton et al. 1999). According to Mulungu et al. (2005), there are about 31 rodent pest species involved in crop damage in Tanzania. However, the most important pest species are *Mastomys natalensis*, *Arvicanthis* spp. and *Gerbilliscus* spp. (Taylor and Green 1976; Fiedler 1994; Leirs et al. 1994), with *M. natalensis* being the most predominant rodent pest species (Leirs 1995; Mulungu et al. 2011; Massawe et al. 2012).

Outbreaks of *M. natalensis* cause significant impacts on food security at different scales, from the household through to the regional level (Leirs et al. 2010). Losses of up to 80% in maize crop have been reported in Tanzania (Mulungu et al. 2003). Irregular rodent outbreaks can result in extreme crop losses, with the potential for causing widespread famine (Mwanjabe et al. 2002). Acute effects of rodent outbreaks have been reported over large areas from many localities in Africa (Leirs et al. 2010), but chronic seasonal damage to agriculture can be even more important in terms of socio-economic impact (Skonhoft et al. 2006).

In typical farm-fallow mosaic habitats under maize cultivation, the population dynamics of *M. natalensis* generally show seasonal trends related to variations in rainfall, peaking towards the end of the rainy season when food resources are plenty (Leirs 1992; Leirs et al. 1996). Their breeding decreases during the drier months (Wube 2005), indicating that rainfall is the ultimate source of variation in rodent density (Taylor and Green 1976; Leirs 1995; Massawe et al. 2012). By contrast, in areas where farmers grow maize twice a year, rodent density increases (Mulungu et al. submitted). These two scenarios suggest that breeding is highly influenced by the presence of a staple crop and that the population dynamics and breeding patterns of *M. natalensis* are influenced by local cropping and environmental conditions. Thus, extended rainy seasons could result in longer breeding duration, with subsequent increases in population size attributed to the quality of food resources (Leirs et al. 1994).

Severe rodent damage to grains in stores contributes to the food shortage in rural communities of Africa, resulting in the immediate financial loss. Post-harvest losses in India, for example, has been reported to be 2.5% due to rodent (Haris and Linblad 1978) while in Tanzania, the extent of rodent damage on maize seeds under storage has been reported to be 35% (Mdangi et al. 2013; Makundi et al. 2006). This would mean a loss of around 1 280 650 tonnes per year of the actual yield (FAO statistics 2007), which could be higher in years with rodent population outbreaks in houses.

In recent years, in Tanzania, new developments in rodent pest management include a system designed to provide an early warning of damage, which includes an understanding of the population processes that give rise to rodent pest's problems and provides the framework for evaluating the causes and solutions. To implement control strategies, population models incorporating simulations and aspects of economics for predicting outbreaks have been developed (Skonhoft et al. 2006). Simulations based on bioeconomics models have shown that the most economically rewarding strategies (such as controlling rodents one month before planting) differ significantly from current practices of symptomatic treatment when severe rodent damage is noticed in the maize fields. Therefore, shifting from symptomatic practices and controlling rodents on a calendar basis can substantially improve the economic conditions for the majority of maize producers in Africa.

2 The impact of rodents on maize crops in Africa

2.1 Rodent damage in fields

The major vertebrate pests in Africa are rodents, although birds and other mammals may sometimes affect maize crop. Although rodents are often used as a protein supplement in some regions of Tanzania for example, they are, however, serious agricultural pests throughout the continent (Mulungu et al. 2003; Makundi et al. 1991). In fact, they do more damage than plant diseases and all other animal pests put together (Hoppe 1980). Annual crops such as maize are affected adversely by rodents. Several reports including the extent of damage caused by rodents to maize have been published (Myllymaki 1987; Leirs 1989; Key 1990; Mwanjabe and Sirima 1993; Fiedler 1994; Mwanjabe et al. 2002; Mulungu et al. 2003, 2005, 2008). These studies support the fact that rodents are a serious pest problem in maize fields.

Nature of the damage

The pattern and the extent of damage by pest rodents depend upon the species, the intensity of infestation, the type and the growth stage of the crop, and the nature of the surrounding habitat (Mulungu et al. 2005). Much of the estimated damage occurs in the pre-harvest stages of the crop, although damage occurs even at the maturity stage of the crop, at sowing stage and at seedling stage. Understanding the mechanism, the extent of the damage and the situations vulnerable to attack by rodents in maize crop and regions is important in planning management strategies (Parshad 1999). Maize damage by rodent pests is therefore not the same in time but follow crop growth stages with different rodent pest species. In Africa, maize seeds are usually sown directly into fields by hand. Rodent pest species commonly dig up and consume both seeds and seedlings (Fig. 1). Damages of this type are light and are often ignored by farmers, as it merely leads to a patchy crop, but heavily damaged fields may require re-sowing after implementing some form of rodent control programme. The soft stems of the young maize plants are also vulnerable to rodent attacks as they are highly attractive to rodents, although their loss does not necessarily have a direct effect on reducing crop yield. For example, Mulungu et al. (2012) reported that *Gerbilliscus vicinus* ate more plant material indicating that this species prefer seedling/soft stems of young plants.

The most commonly reported type of damage that is inflicted by rodents is to the developing maize cobs (Mulungu et al. 2005). Maize stems are relatively robust, and the

Figure 1 Rodents dig up sown maize seeds and seedlings in fields.

more agile rodents such as *M. natalensis* are able to climb them to attack the cobs in situ. Cobs damaged this way may be completely destroyed, but more often, they are only partially damaged. Mulungu et al. (2003) identified two types of partial damages to maize cobs. In one type, the damage is confined to the removal of kernels in strips down the longitudinal axis of the cobs, and in the other, kernels are taken in rings around the circumference.

Rodent pests consume both milky (Fig. 2) grains, when the maize stems are standing upright, and dry grains; therefore, the rodent damage is continuous and persists until the crop has been harvested. Few maize plants could fall and be attacked by rodents. It has been reported that rodent activity is increased, especially when the maize fields are surrounded by vegetation cover (Funmilayo and Akande 1977). Most of the damage is caused to ears on dislodged or leaning plants, starting with the outer rows and moving towards the centre of the field.

The spatial patterns of rodent individuals in maize fields vary according to habitat quality due to changes in land use, and it is expected that the individuals of resident animals will exhibit important spatio-temporal differences that can potentially affect crop damage patterns and severity (Mulungu et al. 2005; Mulungu et al. 2015a). Understanding the pest distribution patterns is an important prerequisite for developing an effective management programme for the pest in question. Massawe et al. (2003) reported a clustered distribution of rodent captures, and Mulungu et al. (2015a) reported that *M. natalensis* in irrigated rice fields generally exhibits an aggregated spatio-temporal distribution at different crop growth stages. The distribution of damage within maize fields, however, probably depends on local conditions; areas close to other infested crops or to land offering harborage to rodents are more prone to attack (Mulungu et al. 2005). The spatial distribution of rodent damage in the maize field however, is either random or regular, depending on the cropping patterns (Mulungu et al. 2005) suggests that crop damage depends on the individual's movements (Cheson 1981). Random damage distribution is observed in fields which are planted with maize and that particular field is surrounded by other maize cultivated fields (Mulungu et al. 2005). These observations suggest that the individual rodents present in these fields after ploughing are either residents or passerby animals indicating that no visitors from the fallow land to maize fields because the fallow land was far from the maize field. The distribution of crop loss over a wide area is related to the pest distribution in both time and space (Kumar 1984). However, populations of rodents not only vary in relation to time, but also spatially, with the spatial variation being influenced by habitat type (Leirs et al. 1997). With very few exceptions of some rodent pest species, majority of them favour habitats with a high degree of heterogeneity and are discouraged by intensively cultivated mono-cultures (Myllymäki 1987). Similarly, the timing

Figure 2 Rodents damage to maize cobs at maturity stage of the crop.

of rodent damage and distribution within the crop field vary considerably with the rodent species, the local environment and the age of the crop (Hampson 1984). In maize fields surrounded by fallow land, the rodent damage is reported to be regular, indicating that rodent pest species have more time to cause damage to maize seeds and plants, as fallow lands are the focal point for rodent and they act as a cover for rodent to some extent. The feeding behaviour of *M. natalensis* at the crop's maturity stage means more cob damage at the periphery of the maize fields. It is common for rodent to cause damage to maize at maturity; however, the damage is often limited, or negligible, unless the maize has fallen on the ground, which may be mainly due to termite attack on the roots.

Crop compensation/recovery after rodent damage

It has been reported that in many studies, non-uniform plant spacing within the row has little or no effect on plant growth and on grain yield of maize if the plant population is adequate for high yield (Edmeades and Daynard 1979). The same has been reported by Myllymäki (1987) who reported that compensation in maize crop is minimal after rodent damage has occurred. This in fact has been observed at low levels of rodent damage, when farmers may actually thin the seedlings to two per planting hole so as to reduce competition between plants. It is also important to note that different factors contribute to crop loss, and the yield response is usually variable at a given location and time (Walker 1990), which may be due to environmental factors, for example rainfall (Mulungu et al. submitted).

However, Abdulahi (1994) reported that when maize seeds have been planted in a space of 75 by 25 cm and 0, 15, 30 and 45% damage levels of the plant population were removed at the 6-leaf, 9-leaf and tasselling stages, no significant yield difference between the 0% plant removed and at 15% of the plant population at the 6-leaf and 9-leaf stages suggesting the compensation by the remaining plants. By contrast, yield difference was recorded between the 0% plant removed and the other plant removal levels such as 30 and 45. Yield losses of 10.9 and 26.4% were recorded when 30 and 45%, respectively, of the plant population was removed at the early, indicating that crop damage and yield loss are not the same, and maize plants could tolerate up to 15% loss of plant populations due to pest damage at the early stage of crop development without significant yield reductions (Abdulahi 1994). However, Pommel and Bonhomme (1998) reported that with plant populations of 130 000 ha $^{2\,1}$, the ears lost corresponding to missing plants are poorly compensated by increased yield of surrounding plants because of additional light interception: when two or three adjacent plants were missing, compensation for missing plants was only 16% and 34%, respectively.

2.2 Rodent damage in stores

Rodents cause direct damage to maize grains by gnawing and feeding (Table 1) and indirect damage by spoilage (Mdangi et al. 2013). Many farmers in Africa store maize grains in sacks; however, storing in this way, rodent problems may increase although the problem may vary from just an occasional damaged grain sack to severe damage that results in the collapse of bag stacks depending on the type of houses. Mdangi et al. (2013) reported that damage of maize grains is greater in houses thatched with grasses as compared to those with corrugated iron. The author also found higher rodent population in the storage of houses which are thatched with grasses as compared to those with corrugated iron sheets. They contaminate (with their droppings, urine, hair, and other body parts),

Table 1 Stored maize grains at farm and village level in Asia, Africa and Latin America

Continent	Country	Type of storage	Percentage damage or loss
Asia	Nepal	Sack	3–5
	The Philippines	Cribs, sacks	2–3
	Thailand	Sacks in roof, maize in cribs	5
	Turkey	Farm houses, underground pits	5
Africa	Egypt	Houses and stores	50
	Ethiopia	Huts on stilts, underground, bags	5–15
	Ghana	Traditional barns or in rooms; drying in field, on platform, on ground, and use of mud silos.	2–3
	Malawi	Woven cane bins, grass baskets, Cribs Cob maize	0.5–15
	Sierra Leone	Roof and cribs	2–3
	Zaire	Bags in roof	3
	Zambia	Farm cribs	10
	Tanzania	Sacks	35
Latin America	Mexico	Cribs, sacks in roofs	5–10
	Brazil	Stacks, sacks, cribs	4–8

deteriorate, and make the crop susceptible to fungal and bacterial infections during pre- and post-harvesting stages (Gregory 2002). It has been reported that, within six months, one pair of mice can eat more than 2 kgs of food and may deposit about 18 000 droppings (Alberta Agriculture Food and Rural Development 1996). Maize seeds contaminated by mice are about 10 times more than what is eaten. Apart from the maize seedseaten, spoiled or contaminated, there are additional 'invisible' losses such as the replacement or repair of packaging materials and the cost of rebagging spilled food. Much of the spillage arises when rodents attack food packaging to obtain nesting material; stacks of heavily infested bagged foodstuffs may ultimately collapse. Rats and mice gnaw inedible materials including electrical wiring, so their presence in buildings can constitute a fire hazard.

2.3 Disease transmission to humans

Rodents are capable of transmitting diseases to people either directly – by bites, through the air or during the handling of rodent carcasses – or indirectly, through contact with food and water contaminated with rodent hair, droppings and urine, which also constitute filth in the grain (Mgode et al. 2014). Therefore, they play an important role as reservoirs and hosts for many pathogens of animal and humans (Gratz 1994). Agents of rodent-borne zoonoses include viruses, bacteria, rickettsia, protozoa and helminths (Gratz 1994, 1997). Infections with zoonotic haemoparasites are widespread in wild rodents (Korbawiak et al. 2005). They include borrelia, trypanosomes, bacilli, plasmodia and coccobacilli (Juha et al. 2003; Powelczyk et al. 2004). In humans, these pathogens are responsible for many rodent-borne diseases including plague, leptospirosis, toxoplasmosis, leishmaniasis and haemorrhagic fevers. In additional, they cause spoilage and contamination of food such as maize grains with hair, urine, and faeces. They also bite people, killing chicks and lead to storage structural damage (Meerburg et al. 2009).

3 Rodent pests affecting maize

3.1 Species

Africa has almost 400 rodent species, but only about 5% are crop pests. Of these *Mastomys natalensis* (multimammate rat) and, to a lesser extent, *Arvicanthis* species (grass rats) are the dominant rodent pests of sub-Saharan Africa, and they frequently involved in rodent population outbreaks. Both species damage maize crop (Taylor and Green 1976; Table 2) and are found in cereal-growing areas. They have a similar ecological requirement, being essentially animals of grasslands, and under natural conditions, they feed on grass or grass seeds, supplemented by insects (Leirs et al. 1994; Mulungu et al. 2012). All species have short life spans of one to two years and a high reproductive potential (Taylor and Green 1976).The African giant rat (*Cricestomys giambianus*), cane rat (*Thryonomys* spp), gerbils (*Gerbillicus* spp), spine mice (*Acomys* spp), stripped grass mouse (*Lemniscomys* spp), crested porcupine (*Hystrix cristata*), ground squirrels (*Xerus* spp), and mole rat (*Tachyoryctes* spp) and *Cryptomys* spp are found in different localities and countries (Fiedler 1994; Table 2). These species are also pests of maize, and they cause serious damage to crops before and after harvest (Mulungu et al. 2006), but are relatively slow breeding.

3.2 Distribution

Multimammate and grass rats are widely distributed. *Mastomys natelensis* is found throughout the continent, with other *Mastomys* species more locally present. *Arvicanthis* species live in the northern part of the continent. Both live in grasslands and wooded savannah, cultivated areas and villages. By contrast, the orange-toothed mole rat is found in the moist uplands of Ethiopia, Somalia, Kenya, Tanzania, Uganda and the eastern Democratic Republic of the Congo.

3.3 Ecology and breeding patterns

Rodents, for example mole rat, feed on sweet potato roots and can cause serious damage by digging through the mounds or ridges to eat them, or by attacking them when they are exposed above ground. Rats live above ground and nest on or in the ground or in trees, depending on the species. Species that cause outbreaks have high reproductive capabilities. The gestation period of the multimammate rat is only 21 days; as soon as they give birth they can conceive again after 24 hours. Mole rats burrow into the soil, eating storage roots from below ground and live and breed in underground burrows. Gestation is longer at about 7 weeks. It has been reported that rat outbreaks is caused by several factors, including (i) a long rainy season that provides more food and cover, allowing better survival (ii) a reduction in competition from other rat species, predators and disease, when there is a return to rains after consecutive dry years (iii) early breeding, when unusually heavy rains occur during the rainy season and the progeny join the main breeding season

Table 2 Rodent pest species in Africa

S/N	Rodent pest species	Crop attacked
1	*Mastomys natalensis* Smith (Shamba or multimammate rat)	Cereals, potatoes, root crops, legumes, cotton, sugar cane
2	*Mastomys erythroleucus*	Cereals, potatoes, root crops, legumes, cotton, sugar cane
3	*Rattus rattus* L. (Roof rat)	Cereals in stores, cassava, potatoes, beans, cotton, groundnuts
4	*Arvicanthis abyssinicus* Rupell (Unstriped grass mouse)	Thin-stemmed cereals, especially wheat, oats, barley, millets, root crops, planted seeds, sugar cane
5	*Arvicanthis niloticus* Desmarest (nile or grass rat)	Thin-stemmed cereals, especially wheat, oats, barley, millets, root crops, planted seeds, sugar cane
6	*Arvicanthis neumanni*	Thin-stemmed cereals, especially wheat, oats, barley, millets, root crops, planted seeds, sugar cane
7	*Arvicanthis nairobae*	Thin-stemmed cereals, especially wheat, oats, barley, millets, root crops, planted seeds, sugar cane
8	*Mus musculus*	Stored cereals, beans and other stored products
9	*Mus minutoides*	Cereals
10	*Mus mahomet*	Cereals
11	*Funisciurus spp* (Tree squirrels)	Maize, fruits, etc.
12	*Heliosciurus spp* (Sun squirrels)	Maize, fruits, etc.
13	*Cricetomys gambianus* (Giant African rat)	Cassava, coffee, cereals, etc., debarking of young trees and eating roots
14	*Gerbilliscus spp* (Gerbils)	Root crops (cassava, sweet potatoes, etc.), attack cereal seeds and seedlings in the field
15	*Heliophobius spp.* (Mole rats)	Root crops (cassava, sweet potatoes), roots of other crops, including cereals, cabbages, tomato and banana rhizomes
16	*Tachyoryctes spp.* (orange-toothed mole rats)	Root crops (sweet potatoes, Irish potatoes, cassava), cereals (damage to the shoots), vegetables (cabbages, tomato), pineapples, forage crops, banana rhizomes
17	*Lemniscomys striatus*	Cereals and grasses (minor damage to a variety of crops)
18	*Lemniscomys rosalia*	Cereals and grasses (minor damage to a variety of crops)
19	*Lemniscomys zebra*	Cereals and grasses (minor damage to a variety of crops)
20	*Lemniscomys barbarus*	Cereals and grasses (minor damage to a variety of crops)
21	*Otomys spp* (Swamp rats)	Young plantation trees and cereals
22	*Thryonomys spp.* (Cane rats)	Cereals
23	*Rhabdomys spp.* (Four-striped mouse)	Cereals and young trees
24	*Dasymys spp.* (short-tailed mouse)	Cereals, cassava
25	*Hystrix spp.* (porcupines)	Cereals, cassava

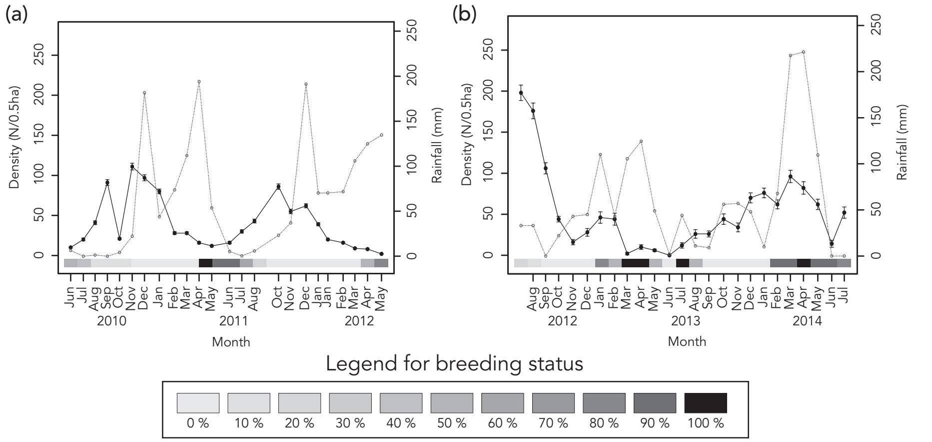

Figure 3 Population density (M(h)) of *Mastomys natalensis* ± standard error bars (full black line), rainfall (grey dotted line) and proportion of breeding females (greyscale gradient, from light = 0% to dark = 100% breeding) in three different cropping systems: (a) rainfed maize/single crop farm (3h area); (b) rainfed maize/double crop (0.5 ha).

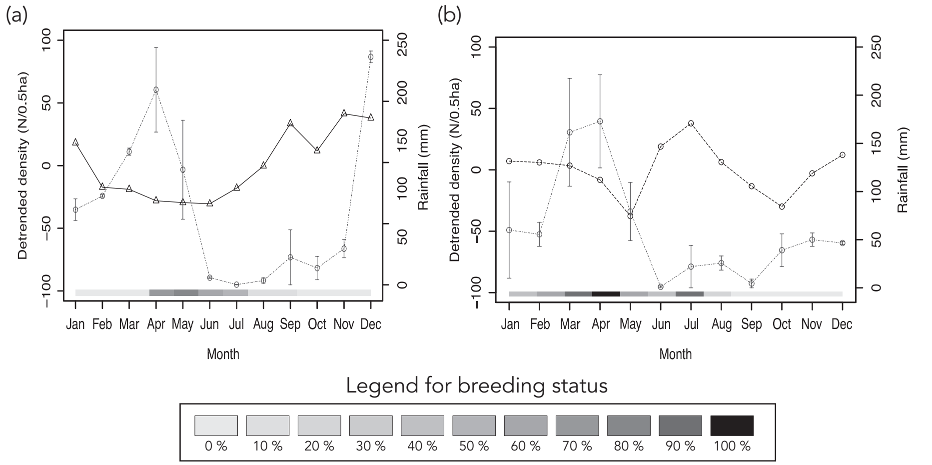

Figure 4 Seasonal density pattern after de-trending over the year at (a) rainfed maize/single crop, and (b) rainfed maize/double crop. Detrended population density bars (full black line), rainfall (grey dotted line) and mean monthly proportion of breeding females ± standard error (greyscale gradient, from light = 0% to dark = 100% breeding).

population later in the year. Breeding and population size of *M. natalensis* are reported to be linked to rainfall in the rainfed maize areas. In these areas, breeding, and hence population, are much more determined by rainfall and its population is low (Fig. 3a and b). Taylor and Green (1976) observed aseasonal breeding in an aseasonal crop in Kenya. Delany and Monro (1986) reported that African murid rodent populations generally respond to rainfall through breeding, which can be triggered by the appearance of new vegetation that may contain chemical substances that promote reproduction through reproductive hormones following rainfall (Linn 1991). Firquet et al. (1996) reported that the presence of germinating grasses induces sexual maturation in subadult female *M. natalensis*. The same authors also reported that, in October 1994, when no more reproductive activity was seen in *M. natalensis* in harvested rainfed maize fields in Morogoro, most adult females were still pregnant in old irrigated maize fields , just 50 km away; the pregnant females and young animals, showing that sexual maturation was still continuing.

In areas where farmers produce two maize crops per year, breeding duration is extended (Fig. 4a and b). Bekele and Leirs (1997) reported that breeding in mosaic crop-fallow fields is seasonal and is related to rainfall periods, but extended rainy seasons resulted in longer periods of breeding, higher litter sizes and an increase in population. Previous studies in Zimbabwe showed that breeding of *M. natalensis* was continuous and extended in irrigated and longer rainfall duration in wheat fields (Swanepoel 1980). In this situation, the link with rainfall is much weaker, although breeding is still most prominent in the rainy seasons as in single maize production areas. Evidently, in these areas, the rodents are not

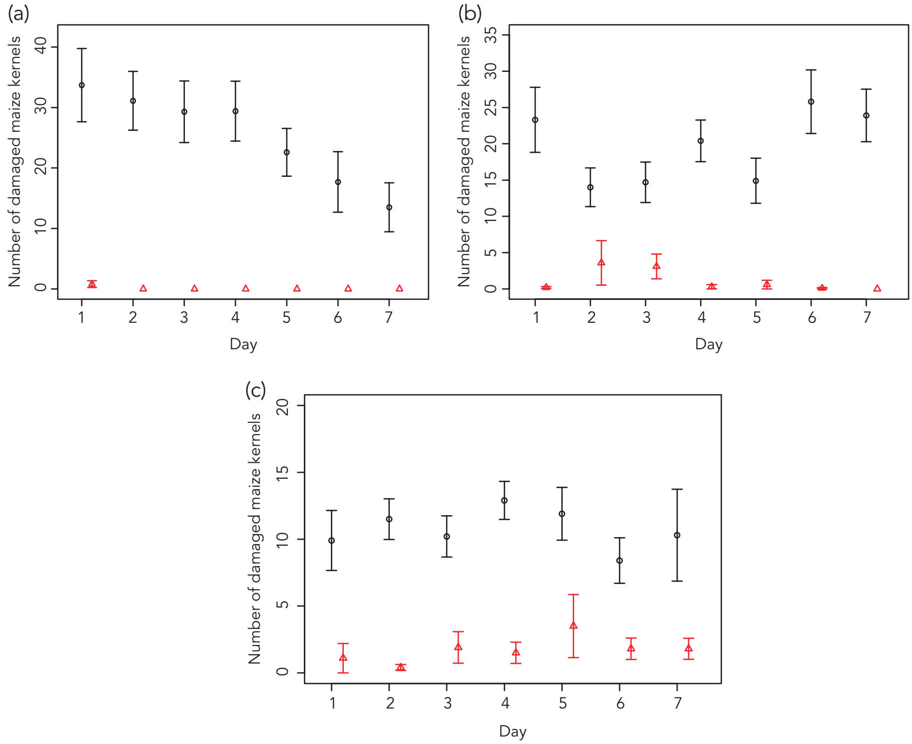

Figure 5 Mean proportion of damaged treated maize vs. the number of damaged maize seeds for each day in the control group (●) and the treated group (Δ) for different plant extracts of (a) *Ricinus communis*, (b) *Jatropha curcas* and (c) *Capscum chinense* fruit.

influenced by rainfall per se, but rather by the quantity and quality of their food, which is dependent on the phenology of crops and the surrounding vegetation.

Odhiambo et al. (2008) reported that *M. natalensis* is an opportunistic feeder consuming all types of food in different frequencies reflecting the availability of food items in its habitat. Variation in food supply of small mammals in different habitats has been reported (Bomford 1987). Odhiambo et al. (2008) reported that, although *M. natalensis* had a wide range of food items in its diet, there was a clear seasonal effect on the consumption of different food categories. They fed more on seeds, arthropods and grasses during the wet season and on other plant materials during the dry season in the south-west of Tanzania. Similar findings have been reported elsewhere in the species' range (Monadjem and Perrin 2003). The population dynamics and breeding patterns strongly suggest that food quality affects the timing and duration of breeding (Leirs et al. 1994). Elsewhere, it has been reported that the apparent seasonal reproductive cycles in tropical rats probably relate to the seasonal changes in the quantity and quality of cover and food (Boutin 1990; Christensen 1993; Pucek et al. 1993; Leirs et al. 1993; Leirs et al. 1994; Jędrzejewski and Jędrzejewska 1996; Wolff 1996).

Currently, there are 32 recorded outbreaks of the multimammate rat in Africa from 1925–2005. *Mastomys natalensis* is the most frequently involved, either alone or, in a few instances, with other *Mastomys* species, or with *Arvicanthis* species. Most outbreaks occurred in East Africa, although a few were in southern Africa and West Africa, with a major outbreak across the Sahel in 1975–6. Much attention has been paid to impacts on maize, rather than other crops such as root crops, so the loss of yield under normal circumstances and in outbreak years is not well documented.

4 Managing rodent pests in maize crops

4.1 Rodent management methods

From time immemorial, rodent pests have been causing alarming losses of both human properties and lives. Inevitably, rodent control is as old as the rodent problem itself. Indeed, this is evidenced by the presence of rat traps in archaeological digs from some parts of Asia (Jackson 1981), and by the fact that Egyptians domesticated cats as early as 2000 B.C. to protect their grains from rodent pest species (Boelter 1990). Rodent control such as hunting remained unscientific until after 1940 when principles underlying modern rodent control technologies such as using synthetic rodenticides as poison were founded following several research works conducted in Europe and USA (Brooks and Rowe 1979). Zinc phosphide was first synthesized in 1740 and first used a rodenticide in 1911 in Italy. In general, rodent control techniques such as natural enemies, cultural techniques and killing by rodenticides only cannot keep rodent outbreaks below damaging levels (Myllymäki 1987) because a prominent resilience capacity can be expected from the high local reproductive rate and the dispersal ability, immigration and survival (Leirs et al. 1994). Farmers in Africa, normally take action if pests are present in large numbers in the fields and storage areas (Makundi et al. 1999). Some farmers may respond to the risk of uncertain pest attack by scheduling prophylactic treatments in which the timing and amount of chemicals are quite independent of actual pest numbers (Myllymäki 1987). The decision is therefore normally taken irrespective of whether the pest will attack the crop (Myllymäki 1987).

4.2 Cultural approaches

A home remedy employs the legume shade tree, *Gliricidia sepium* ('rat killer'). Pounded young leaves or barks, and mixes with cooked rice, maize or other bait, or boils the Giricidia with rice or other cereal grains have been shown to control rats. Bacteria convert chemicals in the leaves to substances similar to brodifacoum (an anti-coagulant used as rat poison). These are less toxic than brodifacoum, so larger amounts must be eaten. Change the bait daily and protect children and pets by placing it in bamboo sections or tins. Planting the legume, for example *Tephrosia vogelii* (commonly known as fish bean), randomly throughout the crop cassava field and along the borders has been reported to control mole rat (Sichilima et al. 2003). This shrub contains rotenone, a fish poison and insecticide, so care should be taken when disposing of it. Mixture of cow dung and pepper placed in the burrows and burnt to smoke out the rodents, pouring one-week-old fermented cattle urine into the burrows to chase away mole rats, or digging deep ditches around crop plantings to stop rodents from tunnelling straight into the field also has been shown effect to control rats.

Mdangi et al. (Submitted) reported that extracts from *Ricinus communis* seed, *Jatropha curcas* and *Capscum chinense* reduce maize seed damage by *M. natalensis*, and its residual effectiveness was observed even after one week (Fig. 5). This result indicates that plant extract of these plant materials has some compounds associated with repellency to *M. natalensis*.

4.3 Chemical control

Generally, management of rodent pests in Africa relies on the ad hoc use of chemical rodenticides (Makundi et al. 1999; Myllymaki 1987). Rodenticides used in this way, however, are rarely economically and ecologically sustainable, and often they are applied only when damage has already occurred (Makundi et al. 1999; Mulungu 2003; Skonhoft et al. 2006). Rodenticide application is not widely practical on individual farms. The success in the use of rodenticides (whether acute or anticoagulants) depends on (i) availability of the required rodenticides (often influenced by available funds for their purchase) and (ii) acceptability of baits formulations to rodents (often influenced by palatability under field conditions. For example, the currently used bait formulation for *M. natalensis* is bromadiolone in cracked maize and sardines. Rice is more acceptable by rodents than maize, but since it is a highly valuable crop the government cannot afford to use it as bait), and (iii) the timing of bait application. This is critical for alleviating damage (Makundi et al. 1999, Mulungu 2003).

Chemical control measures against rodents in Africa continue to be implemented extensively. Most of the countries in Africa, unregistered compounds with acute vertebrate toxicity are commonly used to kill rodents. These poisons are used also as suicide, murder and killing livestock as non-targeted animals. However, acute poisons are often perceived to be more effective at killing rodents than chronic poisons, and changing these misconceptions is one of the major challenges facing experts working to improve rodent management in Africa, where acute poisons are widely used. Fast-acting, acute rodenticides, for example zinc phosphide, is used widely by smallholder farmers (Buckle, 1999), but, in Tanzania, they are supplied mostly free of charge by the government during outbreaks. Till date, however, zinc phosphide has not been registered in Tanzania, but it is strictly used under the supervision of Ministry of Agriculture, Food Security and Cooperative and is not allowed to be sold in open market. The decision to use this toxic compound has been made by the government, as currently there are no other cheap alternative rodenticides to be used during outbreaks. Farmers also favour this compound because its effect is immediately apparent after application. However, the proper application can be a problem under farmer's situation. The compound is supplied as a concentrate, which must be mixed with high-quality cereal baits if it is to be effective, and many smallholder farmers have insufficient resources and knowledge to be able to do this accurately and safely and, therefore, need a close supervision. In fact, a programme for rodent control which is solely a government responsibility would be difficult to implement due to a shortage of manpower, apart from the exorbitant costs involved (Mkondya 1977).

Rodents are well known for being suspicious of new objects (neophobic), a characteristic which is poorly understood or accounted for by smallholders (Myllymäki 1987). Rodents also develop bait shyness (toxiphobia), leading to avoidance of baits used against them following violent reactions to the chemical. In order to avoid bait shyness, more potent anticoagulants such as bromadiolone have been developed. Bromadiolone is effective against species 'naturally resistant' to the first generation anti-coagulant poison (Myllymäki 1987). Anticoagulant rodenticides are probably best for an Integrated Rodent Management (Buckle 1994). Even with an integrated rodent management strategy that uses monitoring systems to target the timing of rodenticides applications, it is felt that the emphasis of such an approach is on control rather than management. Similar concerns have arisen with insect pests (Flint and Bosch 1987) and weeds (Higley and Pedigo 1999).

4.4 Biological control

Biological control of rodents in Africa in general is an almost unexplored area (Vibe-Petersen 2003). The importance of predation in vertebrate prey population dynamics has been debated for many years, particularly in populations exhibiting regular density fluctuations in the northern temperate zones (Hansson and Henttonen 1988; Norrdahl 1995; Krebs 1996; Abrams 2000). Considerably less attention has been directed to the role of predation in tropical rodent population dynamics. Handwerk (1998) investigated the predator–prey relationship of rodents in Egypt, but monitored predators and rodents in areas distant from each other. Leirs et al. (1997) showed that survival of non-reproducing *M. natalensis* is an inverse density-dependent process, an effect that would be predicted if predation is an important mortality factor.

In Tanzania, Van Gulck et al. (1998) reported that raptor activity increased in areas with perch poles and an increased survival of *M. natalensis* in areas excluding avian predators. Vibe-Petersen (2003) investigated the effects of different levels of predation pressure on the population dynamics of *M. natalensis* in maize fields and its consequences on crop damage and maize yield production. The author showed that (i) population growth during the annual increase phase was faster in the absence of predators and peak population size increased, (ii) predators might be a strong driving force for rodent emigration, and (iii) manipulating predation pressure by perch poles and nest boxes did not affect rodent population dynamics directly, but might have an indirect beneficial effect on maize yield by changing the rodents' foraging behaviour.

4.5 Integrated rodent management

Very little work has been done on integrated rodent pest management (IPM) in Africa. In Tanzania, a rodent IPM package for rice crop in Morogoro region has been developed. This package includes: (i) population monitoring before land preparation, (ii) application of rodenticides when population is high, (iii) cleaning or preparation of the farms, (iv) population monitoring and application of rodenticides before planting, (v) reduction of rice bund size to minimize building of nests and burrows,(vi) cleaning of rice bunds, (vii) monitoring population before booting stage and application of rodenticides if the population is still high and weeding, (viii) permanent water buckets along bands for daily trapping of rodents, and (ix) timely harvesting without pilling of harvested rice in the farms (Ngowo 2003; unpublished data). An IPM programme for rodents is not applicable during outbreaks because the mortality may not be high enough to reduce damage while the remaining population often compensates due to better survival and breeding performance (Leirs et al. 1994; Myllymäki 1987).

4.6 Use of early warning signs

Rodent outbreaks, particularly of the multimammate rats *M. natalensis*, are experienced regularly in Africa (Mwanjabe et al. 2002, Bekele and Leirs 1997). A system designed to provide early warning of potential damage must therefore form an integral part of any control strategy (Mwanjabe and Leirs 1997). Research in Tanzania has found that cumulative rainfall of December and January could be used as a predictor for an outbreak 6 months in advance. Furthermore, calculations showed that if rainfall exceeded 366 mm for December and January then control actions would be cost-effective, taking into account the amount of damage that was likely. Davis et al. (2004) discussed how to find the economically optimal cut-off value in such a prediction model, depending on the cost of damage, the cost of control actions and the reduction of damage when control is undertaken.

Also a more mechanistic model was developed that allows simulating populations of *M. natalensis* in Tanzania (Leirs et al. 1997). This model uses recent rainfall and density dependence to predict, monthly wise, how a population of these rodents develops. By including time series of rainfall, it can simulate the population dynamics. Due to the stochastic nature of precipitation, however, it cannot be used for actual forecasting. It does however function well if it is used to find out the conditions to which the population is sensitive or the ways in which interventions could change the population dynamics (Leirs 1999). However, little has been done in other African countries on the predictive model.

5 Summary

Rodents cause serious problems to human communities in Africa as a result of their involvement in the losses of crops through direct consumption of maize grains (Mulungu et al. 2003) and through spoilage (Mdangi et al. 2013). In Africa, damage to maize is largely attributed to *M. natalensis* and *Arvicanthis* spp, and it has been estimated for these rodent species to cause damage up to 80% in maize field (Mulungu et al. 2003). Therefore, an outbreak of *M. natalensis* causes significant impacts on food security at different scales, from the household through to the regional level. Acute effects of rodent outbreaks have been reported over large areas from many localities in Africa, but chronic seasonal damage to agriculture can be even more important in terms of socio-economic impact (Skonhoft et al. 2006). However, in different localities, the Nile rat, *Arvicanthis* spp, African giant rat (*Cricestomys giambianus*), cane rat (*Thryonomys* spp), gerbils (*Gerbillicus* spp), spine mice (*Acomys* spp), stripped grass mouse (*Lemniscomys* spp), crested porcupine (*Hystrix cristata*), ground squirrels (*Xerus* spp), and mole rat (*Tachyoryctes* spp) and *Cryptomys* spp are found. These rodent species are found throughout the maize-growing areas and are also pests of maize, causing serious damage to crops before and after harvest.

Rodent management programmes in Africa have been reactive and have not considered the population ecology of the target species. The strategies used to manage rodents are probably most suited to managing low-density rodent populations and are selected to solve localized rodent problems in certain areas. These include bounty schemes, burning of homes and vegetation, trapping and poisoning. In recent years, new developments in rodent pest management include a system designed to provide early warning of potential damage. An understanding of the population processes that give rise to rodent pest problems provides the framework for evaluating the causes and solutions. Population models for predicting outbreaks have been developed. These have incorporated simulations and aspects of economics in the implementation of control strategies. Simulation based on bioeconomics models have shown that the most economically rewarding strategies differ significantly from current practices of symptomatic treatment when severe rodent damage is noticed in the fields (Skonhoft et al. 2006). Therefore, shifting from symptomatic practices and controlling rodents on a calendar basis can substantially improve the economic conditions for the majority of maize producers in the African context.

6 Future trends in rodent research

6.1 Disease

6.1.1 Haemoparasites

With haemoparasites and other pathogens causing schistosomiasis, borelia, leptospirosis, toxoplasmosis in humans, we need to establish knowledge on their prevalence, mode of transmission, and pathogenicity. More studies need to be conducted on their transmission ecology in Africa continent.

6.1.2 Behaviour of rodents

To establish the social behaviour of species which transmit disease and damage agricultural crops in order to develop sustainable technologies for their management. We need to establish how behaviour affects interaction with people in the transmission of diseases.

6.2 Taxonomy and systematics

We need to conduct research on the evolutionary relationship between species of rodents using molecular systematics. By establishing the phylogenetic relationships, future research will expand the number of species. Further, we need to establish the evolutionary relationships of rodents and the pathogens they carry. There is critical need to establish the phylogenetic relationship of the pathogenic and non-pathogenic arenaviruses found in rodent.

6.3 Population ecology

We need to conduct studies on the role of rodent population dynamics in the transmission of infectious agents (e.g. plague, lassa fever and leptospirosis). Further, critical studies on the transmission ecology of the infectious pathogens harboured by rodents are required.

6.4 Monitoring and modelling rodent populations

Monitoring rodent populations and modelling to develop ecologically based management systems are important research areas. Some species are serious pests, while others harbour and transmit infectious diseases.

6.5 Long-term effects of manipulation of environmental conditions in rodent pest management

In the face of climate change, we need to establish how environmental changes will impact on rodent populations and their consequences on crop damage and disease transmission. We need to answer questions such as: what will be the effects of climate change on rodent populations and rodent-borne disease outbreaks?

6.6 Rodent conservation

Not much is being researched on methods to conserve those rodents which are not pest species. There is a need to establish how habitat fragmentation impacts of species and its effects on human-rodent interactions.

6.7 Rodent management technologies

We need to shift from poison-based rodent management to sustainable non-chemical technologies including those which are ecologically based and environmentally sound.

7 Where to look for further information

Some key resources (web sites, book chapters etc.) are provided below.

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Buckle and Smith (2015): *Rodent Pests and Their Control* (2nd Edition) (Published by CAB International): This is the 2nd edition of the classic book. It has been updated and republished. Available at: http://www.cabi.org/bookshop/book/9781845938178

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