ASSESSMENT OF RODENT DAMAGE TO MAIZE (*Zea mays* L.) IN FIELDS AND STORES AT BEREGA VILLAGE IN KILOSA DISTRICT, MOROGORO, TANZANIA.

BY

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ABSTRACT

This study examined rodent damage to maize in fields and stores and associated losses at Berega village in Kilosa district, Morogoro, Tanzania. The actual rodent damage in two experimental plots (70 x 70 m) and five farmers' fields was assessed at seedling stage and yield loss was calculated. No significant ($p > 0.05$) differences in seedling damage between experimental plots and among farmer's fields was observed. Damage of 13.22 and 14% at population of 4 and 6 individual rodents was observed in experimental plots, respectively and damage range of 30 to 48% at population range of 1 - 9 individual rodents in farmers' fields. The spatial pattern of maize damage distribution was estimated to be random for experimental plots and uniform in four farmer's fields and random in one farmer's field. There was significantly less yield loss in untreated (without rodenticide) compared to treated (with rodenticide) experimental plots ($p < 0.01$) (i.e. 204 kg and 187 kg, respectively). Results showed higher yield loss in treated compare to untreated plot due to larger number of fallen plants hence more rodent infestation. Cob damage differed significantly ($p < 0.001$). In storage experiment, open and closed storage structures were used in the experiment. High significant differences ($p < 0.001$) occurred between different storage structures and between individual household houses. Maize grain damage differed significantly ($p < 0.001$) between storage structures (sacks and cribs). Damage of 34, 8, 25 and 0% was observed in open cribs, closed cribs, open sacks and closed sacks, respectively. There was significant difference ($p < 0.001$) in grain weight loss and contamination level between storage structures and household houses ($p < 0.05$) and higher rodent infestation in open structures placed in earth floor and thatched grass houses. Results suggest that, to

minimize rodent infestation in stored grains improved storage structures should be used.

DECLARATION

I, MDANGI MASHAKA, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that has never been not concurrently being submitted for a higher degree award in any other University.

24/11/2009

(MSc. Candidate) Date

24/11/09

The above declaration is approved Date

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The above declaration is approved Date

(Dr. Massawe, A.W.)

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DEDICATION

Special thanks to my parents Eliud Mdangi and Ester Mdangi who laid the foundation of my education, and to my wife Joyce C. Mdangi for her moral support.

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LIST OF ABBREVIATIONS

%	=	Percentage
<	=	Less than
>	=	Greater than
ARI	=	Agricultural Research Institute
ANOVA	=	Analysis of Variance
CD	=	Coefficient of Dispersion
CMR	=	Capture - Mark - Release
E	=	East
e.g.	=	For example
FAO	=	Food and Agricultural Organization
g	=	gram
GLM	=	General Linear model
ha	=	Hectare
i.e.	=	that is
IPM	=	Integrated Pest Management
kg	=	Kilogram
km	=	Kilometre
m	=	metre
m.a.s.l	=	Metres above sea level
MAFS	=	Ministry of Agriculture and Food Security
S	=	South
SPMC	=	SUA Pest Management Centre

Spp	=	species
SUA	=	Sokoine University of Agriculture
t	=	tonne
USA	=	United State of America
VGLM	=	Visual Generalized Linear Model

CHAPTER ONE

1.0 INTRODUCTION

Maize (*Zea mays* L.) sustains livelihood for more than 500 million people in Africa, Asia and Latin America (Kajuna, 1995). It ranks the third most important cereal crop after rice and wheat (Singh, 1987). In Africa, maize is grown in all Sub–Saharan countries (Kajuna, 1995). In Tanzania, it is one of the major food crops and grows in all regions (Mrosso and Makundi, 2006).

In Tanzania, several factors including pests and diseases, contribute to the low yield in maize production (Mulungu, 2003). Rodent pests cause damage to many crops at pre and post harvest, though some have more varied diets (Taylor, 1968; Leirs, 1992; Leung *et al.*, 1999). Maize is attacked by a range of rodent pest species both in fields and in stores (Makundi *et al.*, 1991). In Tanzania, rodent pests are considered a major impediment to maize production (Mwanjabe, 1993). They contribute to high losses in terms of quantity and quality (Buckle, 1994; Aplin *et al.*, 2003). Rodents cause damage and subsequent losses in maize during the very sensitive young seedling stage and just before harvest (Fiedler and Fall, 1994; Mulungu, 2003).

The types of damage most often caused by rodents to maize crops are: (a) destruction of seeds after sowing and during the first week of growth, (b) damage to the mature crop on the stem and damage to stored crops, and (c) contamination to stored grains through droppings, hairs and urine which results into low market value (Justice and Bass, 1979; MAFS, 1984). Severe rodent damage to crops contributes to food shortage in rural communities of Tanzania resulting in immediate financial loss. In

Tanzania, the extent of rodent damage on maize at seedling stage varies from negligible to over 80% in field (Mulungu *et al.*, 2003). At planting, even moderate rodent damage may hinder late replanting resulting into lower yields (Myllymäki, 1987; Mwanjabe, 1993).

Crop losses caused by rodents in Tanzania is estimated at an average of 15% (Makundi *et al.*, 1991). This would mean a loss of around 382 673 tonnes per year of the actual yield (FAO statistics, 2000). This amount of maize would be enough to feed 2.1 million people for a whole year at a rate of 0.5 kg/day/ person or an estimated value of 42.5 million USD$ (at 11.1 USD$ per 100 kg bag of maize (Mulungu, 2003).

Rodent outbreaks have been reported in many countries where intensive and extensive cultivation is undertaken and in Tanzania rodent outbreaks have been reported in 14 regions, which are; Morogoro, Mbeya, Lindi, Mtwara, Arusha, Tabora, Singida, Dodoma, Iringa, Kilimanjaro, Mwanza, Tanga, Shinyanga and Coat (Mwanjabe *et al.*, 2002). During outbreaks in many parts of Tanzania, rodents present a serious problem to the farmers.

Kilosa district is one of the districts in Tanzania which experiences regular rodent outbreaks that severely affects maize production leading to high losses of maize in fields as well as in stores. Loss of food quality through deterioration, contamination and changes in the composition of nutrients are all important and needs to be better understood and measured (Wilfred and Rolf, 1991). In Tanzania, precise crop damage and loss estimates caused by rodents in fields and in stores are rarely available though obviously they are needed in planning rodent control strategies.

1.1 Objectives

1.1.1 Overall objective

The current study was carried out to assess the infestation of rodents to maize in fields and stores and associated losses occurring in Kilosa district, Morogoro - Tanzania.

1.1.2 The specific objectives

i. to assess crop damage at different crop phenological stages.

ii. to describe spatial pattern and distribution of damage in maize fields.

iii. to estimate losses caused by rodent in stores.

iv. to compare damage in different type of storage structures.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Distribution of Maize

Worldwide, maize (*Zea mays* L.) is one of the most adapted crops and it is spread in the humid tropics (FAOSTAT, 2004). According to FAOSTAT (2004) it is found from north latitude 58^0 to the south latitude 42^0. It is believed to have originated in Central America particularly in Mexico (FAO, 1992). The major producing regions are USA, China, South and Central Africa, Argentina and Brazil. All Sub-Saharan countries of Africa grow maize (Kajuna, 1995).

In East Africa, maize was introduced by the Portuguese as early as 1643 (Ngugi *et al.*, 1988). Maize is grown in all regions of Tanzania (Mrosso and Makundi, 2006) however, the major leading regions for maize production are; Mbeya, Ruvuma, Mara, Rukwa and Iringa (FAO, 2000).

2.2 Maize Production Statistics

Maize is one of the most important crops known to humankind. According to FAOSTAT (2004) the annual global planted area of maize is about 130 million hectares, accounting for 600 million tonnes of grain production, and occupies 35% of global crop production. In 2004, the top ten countries with the highest area planted to maize was 29.8 million ha in USA, 25.4 million ha in China, 12.4 million ha in Brazil, 7.7 million ha in Mexico, 7.5 million ha in India, 4.4 million ha in Nigeria, 3.4 million ha in Indonesia, 3.2 million ha in South Africa, 3.0 million ha in

Romania, and 2.5 million ha in the Philippines, and their respective production shown in table 1.

Table 1: Maize yield of top ten countries in 2004 (Source: http://www.ipni.net)

Top ten countries	Maize production (1000 t)
USA	300
China	140
Brazil	48
Mexico	25
India	25
Indonesia	25
South Africa	25
Romania	25
Nigeria	24
Philipinne	24

In Sub-Saharan Africa, maize is a staple food for an estimated 50% of the population. In East Africa, maize production was greater in Tanzania in 1995, 2000 and 2003 than Kenya and Uganda as shown in the table 2 bellow.

Table 2: Maize production in East Africa (Source FAOSTAT, 2004)

Country	Production in a Year (tones)		
	1995	2000	2003
Tanzania	2 874 400	5 551 160	2 430 000
Kenya	2 699 000	2 160 000	2 000 000
Uganda	91 300	1 096 000	1 200 000

In Morogoro region of Tanzania, maize dominates the production of cereal crops. According to MAFS (2007), the number of house holds growing maize in Morogoro region during the long rainy season in 2002/2003 was 148 561 which is 60% of the total growing households in the region (fig. 1).

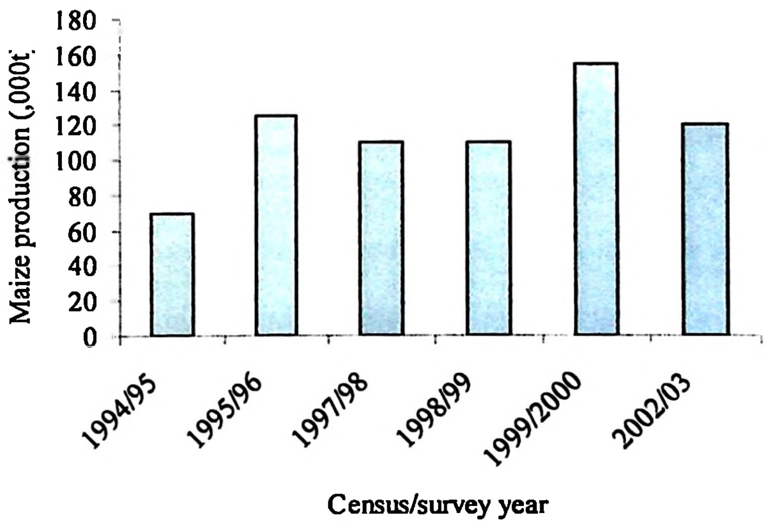


Figure 1: Maize production in Morogoro Region-Tanzania (Source: MAFS, 2007)

2.3 Economic Importance of Maize

Maize is grown mainly for its grains, which may be prepared in a multitude of ways and consumed by humans and livestock (Ngugi *et al.*, 1988). It is an important source of carbohydrate, protein, iron, vitamin B, and sustains more than 500 million people in Africa, Asia and Latin America (Kajuna, 1995). Maize also contributes 60% of calories in the diet (Lyamchai *et al.*, 1997). In Tanzania, it is a major cereal grain and plays an important role in the country's food security and income to smallholder farmers (Lyamchai *et al.*, 1997). Nation wide, it is known to be important crop in alleviating hunger. It is estimated that the annual per capita consumption of maize in Tanzania is 112.5 kg (Mrosso and Makundi, 2006).

2.4 Constraints to Maize Production

Many pests like spotted stem borer (*Chilo partellus* Swinhoe), pink stem borer (*Sesamia calamistis* Hampson), maize stalk borer (*Busseolla fusca* Fuller), white grub (*Phylophaga spp*), maize weevil (*Sitophilus zeamais* Motschuisky), and larger grain borer (*Prostephanus truncates* Horn) attack maize in field and in storage (Mrosso and Makundi, 2006). However, rodents are one of the major sources of pre and post-harvest maize losses (Buckle, 1994).

Worldwide, rodents cause a huge loss of food through direct and indirect damage both in fields and stores (Meyer, 1994). Buckle (1994) reported a crop loss estimate of 7.3% in the entire Penang State of Malaysia and more than 60% both in Philippine and Malaysia. In Tanzania, they are serious agricultural storage pest throughout the country (Makundi *et al.*, 1991). Maize crops are seriously damaged by rodents from planting to harvesting and again during storage.

2.4.1 Rodent damage to maize crop in the fields

Maize is at risk at the time of sowing, soon after germination and from the crop ripening stage onwards, but the crop is not seriously attacked during the vegetative stage (Mulungu, 2003). However, this situation depends on the rodent species involved. In some areas where Cane rats (*Thryonomys* sp.) are present, damage at vegetative stage of maize can be observed (Mulungu *et al.*, 2006).

In Ethiopia, Bekele *et al.* (2003) reported a rodent damage of 9.6% and 12.6% at seedling stage in fenced and unfenced plots, respectively. The species involved were *Mastomys erythroleucus, Arvicanthis dembeensis, Tatera robusta,* and *Mus mohamet.*

In Tanzania, Taylor (1968) found that about 60% of maize was lost due to rodent's damage in Northern Tanzania in the early 1960's while in Chunya district, 35-45% of maize and sorghum crops were being annually damaged by rodents at seedling stage. However, Makundi *et al.* (1991) reported a cereal loss in Tanzania of about 15%. Recently, Mulungu (2003) reported maize damage of over 80% at seedling stage.

2.4.2 Rodent damage to stored maize grains

Damage by rodents to stored maize grains is considered more severe because they eat the germ and discard much of the endosperm (Greaves, 1980). This type of damage reduces maize viability if they are intended to be used as seeds although farmers can still use it for consumption. However, rodent urine and droppings in the maize grain are the source of diseases like Salmonella and Leptospirosis (Machang'u *et al.*, 1997).

In addition, total maize seed depredation occurs. On average, rodents consume about 10% of their body weight of food per day, but consumption varies with size and species of the rodent, and the prevailing climatic conditions (Meyer, 1994). For example, adult Norway rats (*Rattus norvegicus*) of 280 g body weight eat about 28 g of dry food a day (Meyer, 1994). Therefore, a population of 100 adults would consume just over one tonne of dry food a year. This impact of direct consumption can be a major problem in third world countries where food is scarce (Meyer, 1994). In Pakistan, Shafi (1986) reported the storage losses of 1-5% in godowns.

Besides eating, they spoil food by contaminating with feces, urine, or fur (Meyer, 1994). The rodent urine, droppings and hairs reduce the quality of the stored maize grains and therefore, reduced market value of the product. Rodent species like *R. norvegicus* produce about 40 droppings a day (Meyer, 1994). Thus, a relatively small infestation of ten rats would produce sum 146 400 droppings a year. Urine is more difficult to detect, but the same rat infestation (i.e. 10 rodents) will produce 54 litres of urine over the year (Meyer, 1994).

Therefore, the high number of rodents and different species cause a wide range of damage to stored maize grain. Hence, a need for damage and loss assessment becomes very urgent for proper food storage planning to alleviate hunger and maintain the quality of stored maize grains.

2.5 Rodent Pests

2.5.1 Ecology and biology of rodents

Next to humans, rodent are the most successful and abundant mammals on the earth (Wilan, 1992). They are highly adaptable to environmental changes, capable of surviving a range of environmental conditions and rapidly colonize new ecological niches (Fall, 1980). Rodents can survive on the varieties of feeds, including seeds, grains, fruits, animal feeds, and foods of animal origin (Fiedler, 1994). It is this adaptability that makes them difficult pest to manage (Fall, 1980).

Among the pest species, the multimamate rat, *Mastomys natalensis* Smith 1834, the Nile rat, *Arvicanthis niloticus*, Norway rat, *R. norvegicus*, and roof rat, *R. rattus*, are widely distributed in East Africa (Kingdon, 1974). Most rodents live for about one year; they are prolific breeders, multiplying rapidly under favorable conditions. The young are born without hairs on their skin and with closed eyes and ears. They grow very rapidly; the litter size of *M. natalensis* is usually 10 – 13, but can range from 3 - 20 (Leirs, 1992). The female of *M. natalensis* has a gestation period of 21 days but can become pregnant again immediately after giving birth, with young becoming sexually mature at the age of 14 weeks (Kingdon, 1997).When conditions are favourable, breeding can occur in a short interval of time resulting to large number at the end of the breeding season, usually at the beginning of the dry season in Tanzania

(Telford, 1989; Leirs, 1992). The litter size of Norway rat (*R. norvegicus*) and roof rat (*R. rattus*) is 7 – 8 and reaches sexual maturity at 12-16 weeks and house mouse (*Mus domesticus*) litter size is 5 – 6 and sexually mature at 6-8 weeks. They undergo repeated 4-day sexual cycle until they become pregnant (Fiedler, 1994; Kilonzo, 2006).

2.5.2 Rodent outbreaks

In most cases populations are affected by four factors, which are; immigration, birth, death and emigration. In several localities in Tanzania, rodent outbreaks have been reported over large areas (Telford, 1989; Leirs *et al.*, 1989; Leirs *et al.*, 1996; Mwanjabe *et al.*, 2002). Rodent outbreaks cause serious crop damage and can sometimes completely destroy maize fields before the grain matures (Mwanjabe *et al.*, 2002). In years of small rodent outbreaks, damage to agricultural crops may still be considerable (Telford, 1988).

In Tanzania, studies on the population biology of *M. natalensis* clearly show that there is an association between rainfall and breeding (Leirs *et al.*, 1989; Telford, 1989; Leirs, 1992). In Morogoro region of Tanzania, Leirs (1992) observed that rodents breed during the long rains (March-May) and usually start in April (one month after the usual peak of rainfall) and lasting until September. New-borns grow slowly and normally do not mature before the next rainy period. Unless abundant rains appear before March and April the following year, they will be at least six months old before they begin to breed (Leirs, 1992). However, if the short rains are abundant, sub-adult mature and may breed as early as January. Young born in such early breeding seasons grow fast and mature in their third month and this generation starts to breed during the breeding period (Leirs, 1992). This additional generation allows the development of high densities later in the year. Usually abundant rainfall during the first month of the rainy season is a reliable predictor for the occurrence of an outbreak in the following year (Leirs *et al.*, 1996).

2.6. Rodent Management

2.6.1 Management of rodent in fields

Eradication of rodents is difficult and is very expensive, especially for poor countries (Kilonzo, 2006). Rodents move into fields from surrounding fallow land and uncultivated boundaries (donor habitat) (MAFS, 1984). When rodents get into the field, they cause serious problems by destroying seeds after sowing, during the first weeks of growth, and damage mature ears on the stem. However, damage can be minimised by reducing rodent populations to a low level which does not have any harmful economic importance (Kilonzo, 2006). According to Buckle (1999), the control programs of rodent are based on integrated pest management (IPM) technologies involving the use of rodenticides and a combination of various techniques of habitat manipulation. However, few proper IPM schemes have been developed and implemented on a wide scale and long term bases (Buckle, 1999).

2.6.1.1 Field sanitation and ma nagement of surroundings

Rodents require suitable harbourage and breeding sites due to their fear of being exposed to their natural enemies (Kilonzo, 2006). Sanitary measures should therefore be undertaken to keep surroundings and fields clean all the time in order to make the environment unsuitable for harbourage and breeding of rodents. This method of field sanitation includes the following techniques: (a) Removal of fallow patches of land around the field. These patches encourage rodent harbourage close to the crop by providing shelter, (b) Removal of garbage and other materials, which provide shelter and supplementary food resources, (c) Burning the fields before and after harvest to displace the rodent population. Burning after harvest will also eliminate the crop residues and therefore deny the rodent population a potential source of food (MAFS, 1984). However, it has limited use in management of rodents in agriculture over a whole season since it is now clearly understood that some of the major pest species invade regenerating vegetation after fire (De Graaf, 1981). (d) Ploughing and regular weeding helps to reduce the rodent population. According to Massawe *et al.* (2003) deep ploughing destroys the rodent nests and therefore displaces their population, and regular weeding removes an alternative source of food as well as harbourage (MAFS, 1984; Mwanjabe and Sirima, 1993).

2.6.1.2 Timing of the crop

The timing of planting can be manipulated to avoid the peak rodent pest population at sowing as well as at harvesting. It is important when the susceptible stage is not during the peak of the pest population; therefore, it requires a good understanding of the population dynamics of the pest and how it relates to the phenology of the crop (Makundi *et al.*, 2006)

2.6.1.3 Diversionary feeding

This is a technique where by rodents are offered alternative food source which they will prefer over the crop to be protected (Leirs, 2003). This has been tested in orchards and forestry (Sullivan, 1979; Sullivan and Sullivan, 1988) and is now common in sugar beet fields (Pelz, 1989). In such fields, seeds are sown in the soil in long rows, and wood mice, *Apodemus sylivaticus*, simply go along these lines and dig up the planted seeds and by the time these seeds are finished, the targeted plant will have grown to a stage where they are no longer at risk (Leirs, 2003). However, diversionary feeding methods work better if the economic value of the alternative food is sufficiently low compared with the reductive losses that can be realised and the crop to be protected should have relatively high value or when it has to be protected during a short time (Leirs, 2003). In Tanzania, most farmers spread maize bran around the maize fields. This allows rodents to concentrate on feeding maize bran than the planted maize seeds (Mulungu, L.S. personal communication, 2008).

2.6.1.4 Biological methods

Biological control has been tried in some areas using the following techniques:

(a) Control of fertility: Singleton and Redhead (1991) outlined this approach in Australia using a hepatic nematode (*Capillaria hepatica*) as parasites in house mice. It was observed that the number of litters produced and young weaned over three months were reduced. This parasite affects the host birth and death rates. However, the authors stress on the need for multidisciplinary studies and a sound knowledge of the ecology of the pest to be controlled if this method is to be of practical use.

(b) Biological control using vertebrate predators: In method, 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 (a) population growth during the annual increase phase was faster in the absence of predators and peak population size increased, (b) predators may be a strong driving force for rodent emigration, and (c) manipulating predation pressure by perch poles and nest boxes did not affect rodent population dynamics directly, but may have an indirect beneficial effect on maize yield by changing the rodents' foraging behavior.

However, one of the theoretical problems with using vertebrate predators as biological control is that their generation time is substantially longer than that of their prey and therefore the numerical response of predator populations is insufficient to keep up with rapidly changing prey populations (Smith, 1994).

2.6.1.5 Trapping

A large proportion of rural population in East Africa has made use of different, locally produced traps to control rodents and managed to reduce rodent numbers (Kilonzo, 1984). Trapping is the preferred method of killing or capturing rodents to replace chemical control in areas of high risk or environmental sensitivity (Smith, 1994). However, it is not an effective strategy for outbreak species like *M. natalensis* (Makundi *et al.*, 2006). It is effectively only for small populations of rodents, particularly sub-terranian species such as mole rats (Makundi *et al.*, 2006). This is due to a limit on the number of rodents that can be trapped (usually one per trap)

(Smith, 1994). Also it requires the effort to set and check them. Greaves (1982) recommends that the number of traps used should be two to three times the estimated numbers of rodents present. Trapping success can be improved by placing baited traps near runs and at other locations where there are clear signs of rat activity.

2.6.1.6 Chemical control

Chemical control using approved rodenticides have been used to control rodents, particularly during outbreaks. The fast-acting, acute rodenticides are still much used by tropical smallholders (Buckle, 1999). In Tanzania, Zinc phosphide is the most widely used acute rodenticides compared to anticoagulants (Makundi *et al.*, 2006). According to Makundi *et al.* (2006) the use of acute rodenticides in Tanzania is widespread because it is relatively cheap and effective. It is made available in large quantities through government channels. However, the acute rodenticide has disadvantages over anticoagulant because it results in the development of bait shyness to rodents. Although anticoagulants do not cause bait shyness, farmers do not accept them because of delayed death of rodents (Makundi *et al.*, 2006). Observation by Greaves (1994) shows that anticoagulants can also result into widespread behavioural resistance to rodents therefore increases cost in terms of the need to use the more potent compounds, sometime for periods longer than normal and in greater quantities.

The recommended concentration of acute rodenticides has been demonstrated by Rennison (1976) on farms in the United Kingdom where 2.5% concentration were applied and resulted into an average level of control of 84% of *R. norvegicus*.

According to Adhikarya and Posamentier (1987) the recommended concentration of Zinc phosphide for field use varies from 1% to 5%. The baits are applied in small piles of 20 – 50 g at an interval of 5 – 20 m in a field (Adhikarya and Posamentier. 1987; Mwanjabe and Leirs, 1997).

In Tanzania, acute rodenticides are only recommended for use under proper supervision in farms far from homestead at a concentration of 2% (Kilonzo, 2006). The rate of application may be varied, both by the weight of bait used and the distance between bait points in order to accommodate different pest infestation densities. In this study the hypothesis tested was that, application of rodenticide in maize fields before planting lowers rodent density hence increase maize yield.

2. 6.2 Manage ment of rodent in stores

The duration of stored grains at the village level extends from the end of the harvest season to the begging of the next season. According to Makundi *et al.* (1991) storage of maize grains at village level ranges from 3 – 12 months. Like in other countries, in Tanzania maize grains are stored for the following four basic reasons, which are: (a) to provide food to the farm household and where applicable supplement feed for livestock from one harvest season to the next, (b) to provide carry-over food in case of crop failure and natural disasters, (c) to service marketing and trading system from rural to national level, and (d) to retain seed stock for planting the next crop (Wilfred and Rolf, 1991).

During time of storage, rodent infestation can cause economic losses (Makundi *et al*., 1991). In Tanzania, the common traditional storage structures and practices used to store maize include: (a) containers (woven sacks, pots, "vilindo") made of tree barks, animal skin, or reeds, (b) cribs ("Vihenge") (Mphuru and Maro, 1975), (c) storage in the house ("Chanja"), and (d) open air storage (Wilfred and Rolf, 1991). However, these structures are unprotected and therefore, they can provide an abundant food source for certain species of rodents. Under such conditions, rodent numbers can increase markedly to very high levels within a short period, leading to severe losses in the post–harvest period (Makundi *et al*., 1991).

To control rodents in stores, a range of rodent control strategies have been described (Makundi *et al*., 1991; Makundi *et al*., 1999). Most methods used to control rodent damage in stores are aimed at reducing the accessibility of the crop to rodents. The range of methods include: (a) use of rodent proof storage structures, (b) clearing the surroundings of the stores, (c) the use of poison, and (d) the use of traps. Rodent proof storage structures are structures which have tight fitting doors, no holes leading into the store, and where the crib "*kihenge*" type of structures are used, they must be raised at least a metre from the ground and the poles are also rodent proofed using galvanized conical flaps to prevent rodent climbing into the store (Makundi *et al*., 2006). Most of Tanzanian farmers, however, use storage structures which are not protected from rodents.

Clearing the surroundings of the stores helps to remove spillage and other source of food which attract rodent to the vicinity of the store (MAFS, 1984; Makundi *et al*., 2006). It also discourages rodents building nests close to the store houses, the removal of weeds, dense vegetation, bushes and tree branches to a distance of at least 5 m may also be applied (Makundi *et al.*, 2006). The use of rodenticides, acute and chronic (anticoagulant) rodenticides can be used in stores, hence they lower the population of rodents in stores resulting in lower grain damage. The use of traps and trapping has also been described (Makundi *et al.*, 1991). However, this is only effective when rodent population is low (Smith, 1994). The hypothesis here is that, improved storage structures may reduce rodent damage to stored maize grains.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location and duration

The study was carried out at Berega village in Kilosa district, Morogoro region, Tanzania during the cropping and storage season of 2007/2008. The village is within Magole division. It is located at 840 m.a.s.l at 6^0 10'S; 37^0 5'E. It is about 105 km from Morogoro town at the right side to Dodoma and has 10 hamlets (Fig. 3). The study was carried out from October 2007 to April, 2008 for damage assessment on stored maize grains and from January to June, 2008 for maize crop damage assessment in fields.

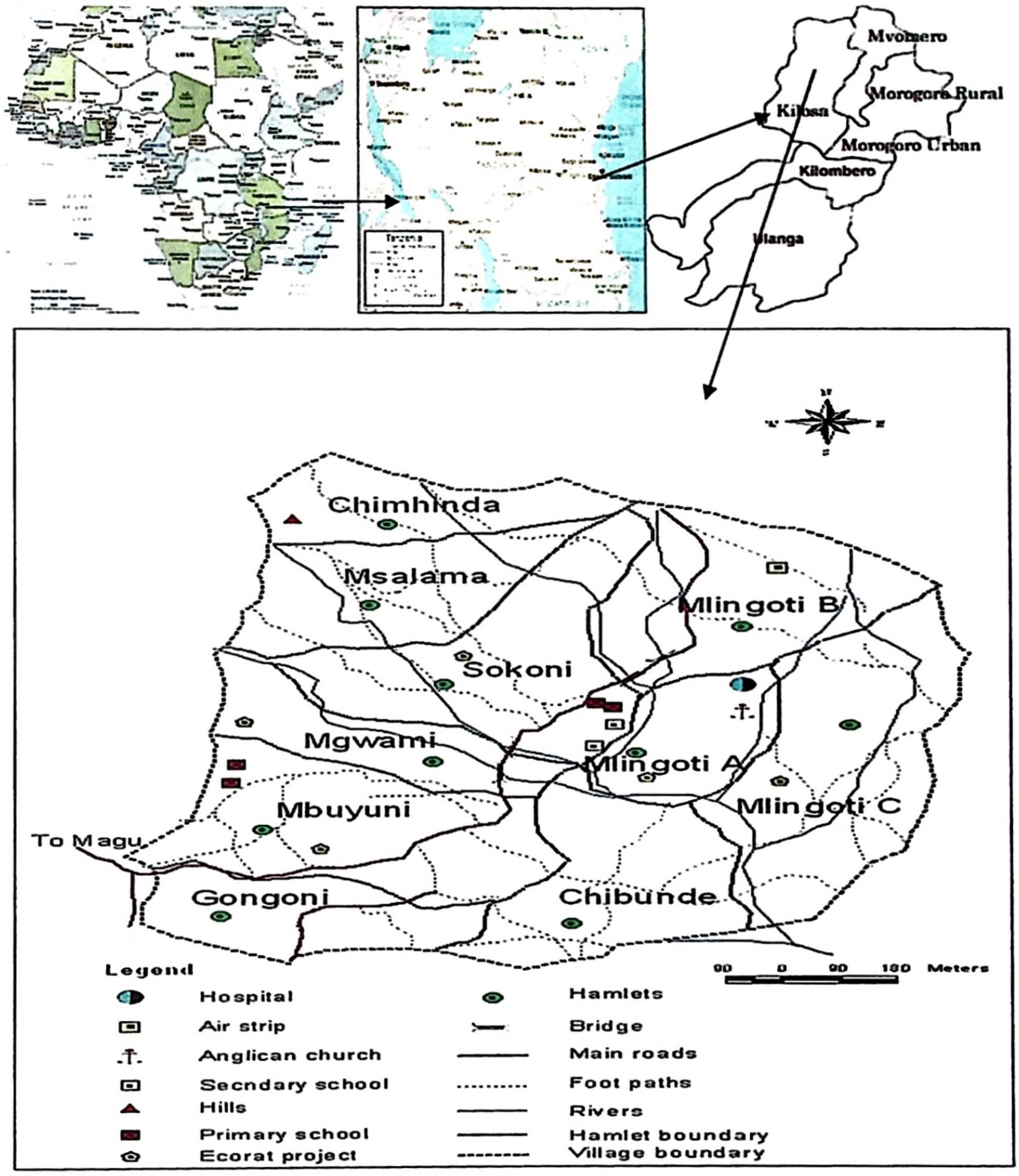


Figure 2: A map showing the location of the study areas in Berega village, Morogoro Tanzania (i.e. Berega village has 10 hamlets and 5 study sites are shown as the location for the Ecorat project)

3.1.2 Climate

The area has a single wet season in which the rainfall starts in November and extends to April/May, although variation may occur from year to year. The mean annual rainfall is 600 - 900 mm (Mrosso, 2004).

3.1.3 Land use

The village has a population of 4915 people. The land allocated for crop production is about 1450 ha and the residential and livestock land is currently not measured. The main crop grown as staple food is maize. During the study period, several crops were cultivated with the largest land occupied by maize. The respective areas (in brackets) for different crops were maize (769.6 ha), cassava (182.8 ha), beans (91.2 ha), velvet beans (198.8 ha), simsim (20.0 ha), cotton (20.0 ha), sunflower (60.0 ha), pigeon pea (107.2 ha) and sweet potato (35.0 ha).

3.2 Pre-harvest Experiment

3.2.1 Rodent abundance in experimental plots and farmers fields

Two experimental plots of 70 m x 70 m were established and five farmer's fields were selected for rodent trapping. Plots were placed at a distance of over 100 m from each other to avoid movement of rodents from one plot to the other. The average movement distance of *M. natalensis* has been reported to be 100 m (Leirs, 1992). In both experimental plots, population monitoring was done before maize planting, at seedling stage, and at maturity stage. In farmer's fields trapping was done only at seedling stage. Before planting, one experimental plot was saturated with rodenticide (Bromadiolone) for rodent management for seven consecutive days using 2 kg/acre of rodenticide as a recommended rate and the other plot was not baited. Traps were placed 10 m apart within and between rows where each plot had seven lines with seven trapping stations (Fig. 3).

Each trapping station was identified by coordinates A to G, and numbered 1 – 7. A total of 49 Sherman – live traps were used and baited with peanut butter. Traps were set in the evening and inspected every morning around 0900 hours for two consecutive nights. The trapped rodents at the first day were marked by toe clipping and released at point of capture; during the second catch. They were recorded as old or new for the newly caught animals and released.

The rodent abundance was determined using Petersen's method (Krebs, 1999) as:

$$N = \frac{CM}{R} \quad \text{[1]}$$

where;

N = population size

C = total number of individuals in the second day sample

M = number of individuals marked in the first sample

R = number of individuals in the second sample that were marked.

Petersen's method was used to estimate rodent abundance in each experimental field (treated and untreated). It was the best method in this study because only two trap nights were conducted. The assumptions for Petersen method to be used, which are (a) all animals had the same chance of being caught in a sample, (b) marking animals could not affect their catchability, (c) animals did not lose marks between the two sampling periods, and (d) all marks were reported on discovery in the second sample. According to Krebs (1999) Petersen's method is based on single episode of marking animals, and a second single episode of recapturing individuals.

1G	2G	3G	4G	5G	6G	7G
1F	2F	3F	4F	5F	6F	7F
1E	2E	3E	4E	5E	6E	7E
1D	2D	3D	4D	5D	6D	7D
1C	2C	3C	4C	5C	6C	7C
1B	2B	3B	4B	5B	6B	7B
1A	2A	3A	4A	5A	6A	7A

Numbers 1 – 7 = Trapping lines

Letter A – G = Trapping stations.

Figure 3: Schematic map showing trapping stations used in experimental plots and farmers fields.

3.2.2 Damage assessment

3.2.2.1 Estimates of damage at seedling stage in experimental plots

After land preparation, plots were planted with maize (Situka m-1 variety) obtained from Agricultural Research Institute (ARI) Ilonga. Three seeds were planted per hole, at a spacing of 90 x 75 cm as a standard planting space. Damage assessment was carried out at seedling stage (that is 10 days after planting). The actual rodent damage was counted by recording the number of emerged seedlings (out of three planted maize seeds) in each hole per field. Maize seeds were pre tested for germination percentage (Barts *et al.*, 1985) the results showed that 98% of seeds germinated.

Percentage damage at seedling stage was calculated using the formula adopted from Mwanjabe and Leirs (1997) and further elaborated by Mulungu (2003).

$$D = \frac{d}{(u+d)} \times 100 \qquad [2]$$

where;

D = percentage damage

d = missing seedlings

u = total number of seedlings not missing

3.2.2.2 Estimates of damage at seedling stage in farmer's fields

Five untreated farmer's fields of 70 x 70 m were randomly selected one each from five hamlets for comparison with the damage from experimental plots. After land preparation, local varieties of maize were planted. Three maize seeds were planted per hole following farmer's practices at the study area. In each field, sampling was done in five quadrants having four sides of 10 x 10 m in size where one sample was taken from the centre and other four samples were from the quadrants at the periphery of the field as shown in Figure 5. One quadrant had 148 holes at a space of 90 cm x 75 m which could have an estimated 444 plants when three maize seeds are sown. In each quadrant, damage assessment was done by recording the emerged seedlings out of three planted seeds in each planting hole. The mean damage of five quadrants in a field was considered as damage of the whole field. The percentage crop damage was calculated using the formula (equation 3) above.

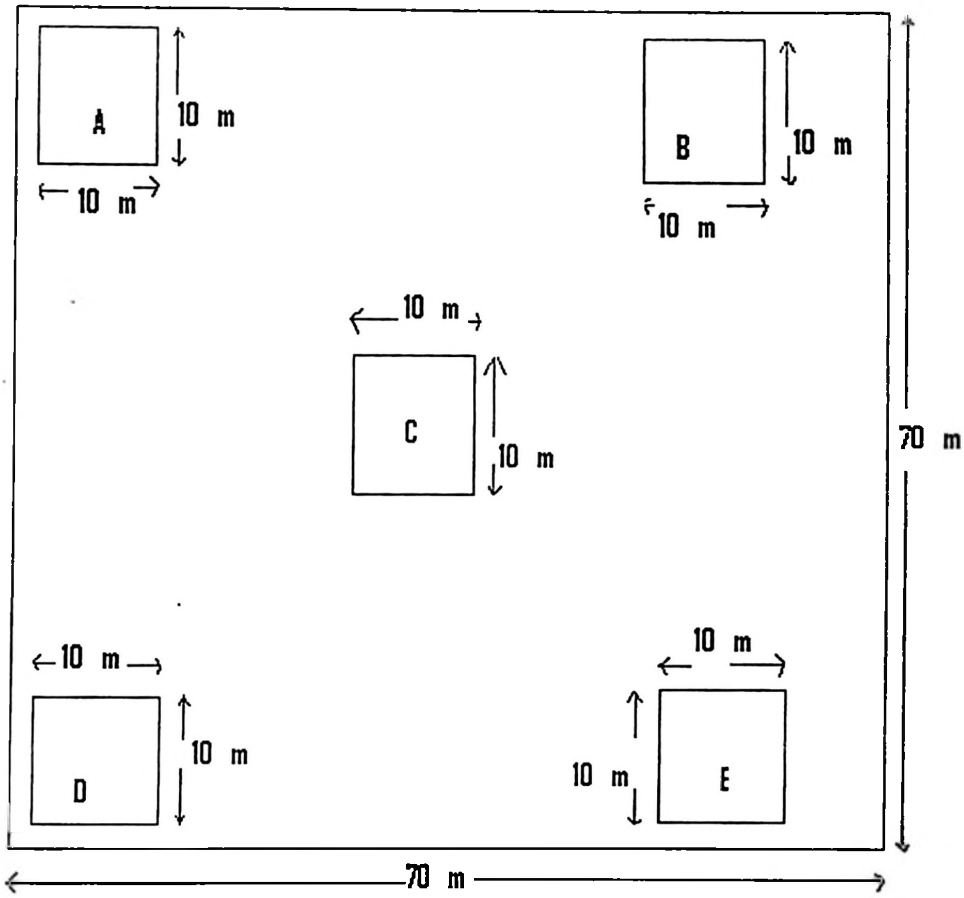


Figure 4: Schematic map showing five quadrants (A-E) in farmers' fields sampled for damage assessment at seedling stage.

3.2.2.3 Damage distribution pattern

The distribution pattern of damage in experimental plots and farmers fields were calculated using the formula adopted from Kranz (1993).

$$CD = \frac{s^2}{\bar{x}} = \frac{\dfrac{\sum\left(x-\bar{x}\right)^2}{n-1}}{\dfrac{\left(\sum x\right)}{n}} \quad \text{..................................[3]}$$

where,

CD = Coefficient of dispersion

S^2 = variance

X = general mean of damaged seedling per plot.

n = number of observations.

When CD is greater than 1 the damage is aggregated; CD of less than 1 the damage is uniform and when CD is equal to 1 the damage is random. For the farmer's fields. each stratum was calculated differently and the mean was calculated. The mean value of CD was recorded as CD for that particular farmer's field.

3.2.2.4. Estimates of damage proportion at maturity stage

The ears were examined for damage by rodents on upright and fallen maize stems where longitudinal and circular ear damage was observed. Longitudinal ear damage occurred when the missing kernels were along the length of the ear. In circular ear damage, missing kernels were in a ring form around the ear. Measurements taken on each ear were the length of ear, length of damaged portion and radius for circular damage (Plates 1 and 2). For both cob damage, the proportion damage was calculated:

(a) Longitudinal cob damage

For longitudinal cob damage (Plate 1), the proportion damage was calculated as the ratio of the area of the damaged portion (i.e length of the damaged portion x width) and the area of the ear. It was assumed that the shape of the ear is similar to that of cylinder. Therefore, the area is equal to (*pi* x radius x length) of the ear, which was the length of the fully developed kernels on the ear from bottom to top (i.e. *pi*rL). All measurements were in centimeters. The formula used therefore was

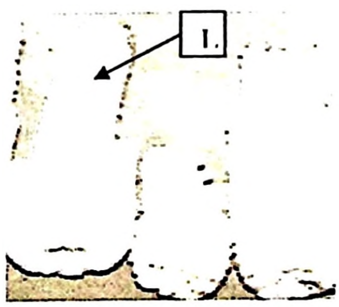
$$P = \frac{a}{A} \qquad [4]$$

where;

P = damage proportion

a = area of the damaged portion (Length x width) cm^2

A = area of ear (*pi*rL) cm^2



Key. L; longitudinal

Plate 1: Maize cob damaged longitudinally by rodents

(b) Circular cob damage

For circular ear damage (Plate 2), the damaged portion was calculated as the ratio of the length of damage (i.e the average of the shortest and the longest length of portion damaged) and the length of the ear as shown bellow.

$$P = \frac{L1}{L2} \qquad [5]$$

where:

P = damage proportion

L1 = length of damaged portion (cm)

L2 = length of the ear (cm), which was the length of the fully developed kernels on the ear.

The damaged portion of ears per field was calculated as the total damaged portions and the number of ears in the field.

Key: C; circular

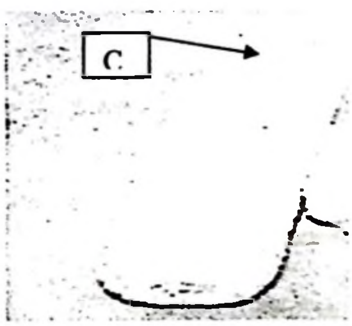


Plate 2: Maize cob damaged by rodent in a circular form

3.2.3 Yield loss

At maturity stage; individual plots were harvested and the ears were kept separately. all cobs were counted and grouped into two categories, damaged and undamaged cobs. The maize was threshed, cleaned by hand winnowing, and sun dried and weighed using standard farmer's practices. The weight was adjusted to a common moisture content of 15.5% in order to maintain uniformity in all fields using the following formula as described by Moyal (1998) and this was taken as the actual yield for the plot.

$$Y = [(100 - k)/(100 - 15.5)] * j \qquad [6]$$

where:

Y = adjusted weight (kg) of the sample at 15.5% moisture content

k = moisture content of the sample. and

j = weight of the sample

The potential yield for the plot in the absence of rodent damage (w_o) was calculated as described by Mulungu (2003)

$$Wo = a_o\, T \qquad [7]$$

where:

w_o = potential yield in absence of rodent damage

a_o = mean actual yield of unattacked plant in kg (was calculated as the average yield for all plants that were completely free of rodent damage at harvesting time)

T = total number of seeds planted, with 98% germination:

The yield loss during maturity was calculated by using a difference between mean actual yields per unattacked cobs and yield of attacked cobs as shown bellow.

$$L = Yu - Ya \qquad [8]$$

where:

L = mean yield loss at maturation

Yu = mean yield of unattacked cobs

Ya = mean yield of attacked cobs

Yield loss due to rodent in relation to damaged cob per field (LOS_R) was computed as described by Mulungu (2003):

$$LOS_R = Y * T \qquad [9]$$

where,

LOS_R = grain loss (kg)

Y = mean loss/ damage cob (kg)

T = total damaged cob in a sample

And total yield loss (LOS_T) was calculated using the formula shown bellow:

$$LOS_T = LOS_P + LOS_R \qquad [10]$$

where,

LOS_P = yield loss due to rodent attack of seedlings

LOS_R = yield loss during maturity stage due to cob damage

3.3. Storage Experiment

3.3.1 Population of rodents in farmer's houses

Five hamlets were selected for rodent trapping; in each hamlet one house was selected randomly for rodent trapping. Eight traps were set per house (three box traps and five Sherman traps). Three box traps were kept inside the house each at the corner, two traps at the corners in the bed room and one in sitting room (Fig. 5). These traps were aimed to capture domestic rodents. Five sherman traps were set outside at the surroundings of the house (Fig. 5.) 10 m from the house in order to capture peridomestic rodents. All traps were baited with peanut butter before trapping. Trapping was done monthly for three consecutive nights for a period of six months. Trapped animals were identified to species level following the guideline from Kingdon (1997).

The monthly percentage trap success was determined using a formula adopted from Telford (1989).

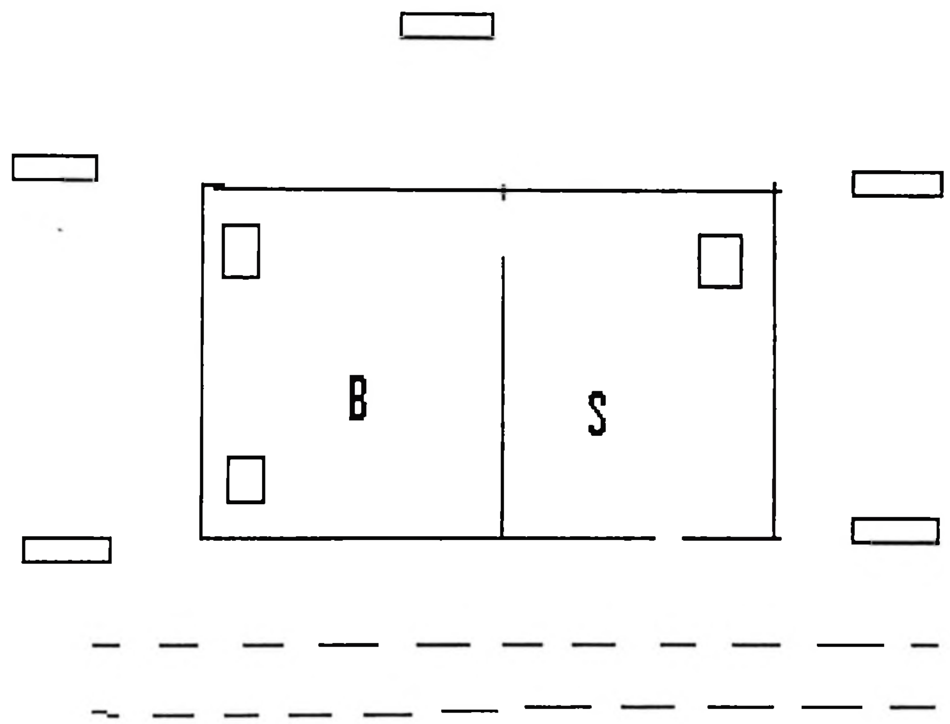
$$X = \frac{N}{TN} \times 100 \qquad [11]$$

where;

X= percentage trap success

N = total number of animals trapped

TN= total number of traps set per three nights



Key:

B; Bed room

S; Sitting room

☐ Box trap, ▭ Sherman trap, == Road

Figure 5: A schematic diagram showing a house and how traps were set

3.3.2 Post – harvest damage assessment

In the study village, five hamlets were selected randomly and six farmers were selected from those hamlets for the post - harvest experiment. A known amount (90 kg) of dried maize grains (moisture content 15%) was stored in farmer's stores for a period of six months. Maize grains were treated with insecticide viz; Actellic Supper

Dust prior to storage for insect pest control as a normal farmer's practice. A factorial experiment was used. Two storage structure (cribs and sacks) and two types (open or closed structures) were used. Each treatment was replicated three times, i.e. three farmers used sacks (1 closed; 1 open in each storage) and the other three used cribs (1 closed, 1 open in each storage). For storage in sacks, two sacks were kept in a storage house where one sack was left open resembling the farmer's situation in the village and the other sacks was enclosed in wire mesh (control) to protect maize grains from rodent damage (Plate 3).

For storage in cribs, six cribs were constructed in three different houses, two cribs in each house. Three cribs were left open and the other three were (closed) to protect them from rodents. No rat guards were used in the crib (Plate 4). Sampling was done consecutively for six months at an interval of once per month. Sampling from each storage structure was done monthly using a 0.25 kg container to sample four times, making a total of one kilogram of maize (Mulungu, L.S. personal communication. 2008). Samples were taken from the middle and the periphery in each storage structure. After every sampling the remaining maize grains were reweighed.

The sampled maize grains were separated into two groups, viz. damaged and undamaged seeds. In each group grains were counted and weighed. The percentage grain damage and weight loss were calculated using the formula adopted from Buckle (1994).

$$\% \; Damage = \frac{a}{b} \times 100 \qquad [12]$$

where,

a = damaged grains in a sample

b = total number of grains in a sample

Weight loss of grains was calculated using the formula

$$Weight \; loss = Wu - Wd \qquad [13]$$

where,

Wu = weight of undamaged grains

Wd = weight of damaged grains

Plate 3: Open and closed sacks in farmer's house

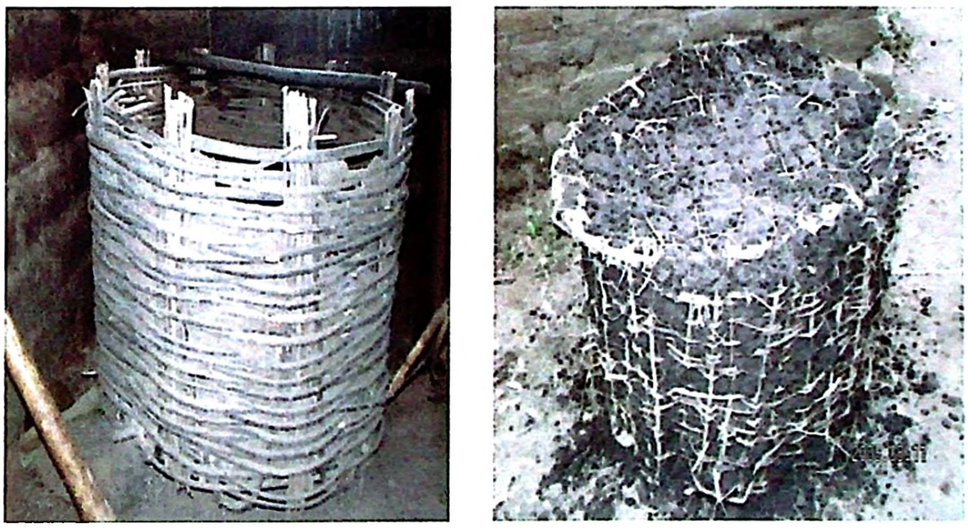


Plate 4: Open and Closed crib in farmer's house.

3.3.3 Contamination of stored maize grains

Samples taken each month were also used for assessment of contamination. The number of rodent droppings in a sample was counted. A scale of contamination was developed using five classes (Table 3).

Table 3: Scale for stored maize grains contamination.

Class	Description	Number of droppings
1	No contamination	0
2	Slight contamination	1 – 10
3	Moderate contamination	11 – 20
4	Highly contamination	21 – 50
5	Severe contamination	>50

3.4 Data Analysis

3.4.1 Pre–harvest crop loss

To test damage of maize crop at seedling stage, percentage cob damage and proportion of cob damage in the two experimental fields (treated and untreated) were done using the General Linear Model (GLM) available in statistical analysis system (SAS, 1990) and mean separation was done using Tukey's stundentised range (HSD) test.

3.4.2 Determination of rodent damage distribution pattern

The rodent damage data (actual damage at seedling stage) were used to determine damage distribution and to establish the variance – to – mean ratio (s^2/mean). The variance to mean ratio was calculated as the coefficient of dispersion (CD) as shown in equation 3 above. The calculated CDs from different fields were grouped to either random, aggregate or uniform damage and compared.

3.4.3 Post–harvest crop loss

Damaged maize grains from different storage structures were used to find out the percentage damage and maize grain weight loss. Statistical analysis using General Linear Model (GLM) Factorial ANOVA was performed in STATISTICA to establish percentage maize grain damage and weight loss due to rodents.

3.4.4 Contamination of stored maize grain

The data for rodent contamination of stored grains were modeled in STATISTICA (VGLZ – Visual Generalized Linear Models) using the ordinal multinomial distribution and logit as a link function. The outcome is the cumulative probability expected in each level ordered in their natural order: in level 1 the analysis calculates the expected proportion in level 1. In level 2 the expected proportion in level 2 + expected proportion in level 1, in level 3 the expected proportion in level 3 + expected proportion in level 2 + expected proportion in level 1. The outcome presents intercepts (baseline probabilities) for each level (except for the last level. which always will be 100%) (Mutoh, 2000).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Field Experiment

4.1.1 Crop Damage assessment

4.1.1.1 Crop damage at seedling stage

A damage of 13.22%± 3.03 was observed in treated and 14%± 3.99 in untreated maize plots at a population of 4 and 6 rodents, respectively. However, there were no significant differences in damage between plots (t = 13.22%± 3.03, 4%± 3.99, p = 0.08). The observed crop damage in the treated plot rejects the hypothesis. The reason could be due to rodent recolonization from nearby farmer's fields which were surrounded by non crop land. According to Fiedler (1994) and Leung *et al.* (1999), non crop lands provide breeding sites where rodents can establish nests during breeding season resulting in population increase and therefore higher crop damage. However, various studies show that the population density may be reduced immediately after applying rodenticide, but the remaining population compensates with better survival and breeding performance (Singleton *et al.*, 1999; Myllymäki, 1987). The percentage compositions of total capture (in brackets) of the two rodent species observed in experimental plots at seedling stage were *M. natalensis* (75%) and *Gerbilliscus vicinus* (25%).

In farmer's fields, a damage of 30% - 48% was observed at a population of 1 to 9 rodents. There were no significant differences between fields (F = 2.50, df = 4, 16, p = 0.08). However, damage in farmer's fields was high compared to damage in experimental plots. This difference may be due to the fact that most farrmer's fields are surrounded by non crop land which provides harborage to rodents. Crop damages in farmers' fields were similar to those reported by Taylor (1976) in Chunya district, where a damage of 35 – 45% of maize and sorghum crops was observed. This may be due to similar farming practices among farmers. Farmers at Berega village grow maize crop in small plots surrounded by non crop land and bushes (i.e mosaic fields). These create a favourable environment for rodents to multiply due to ample food and shelter. Greaves (1982) and Mwanjabe (1993) reported that maize in fields surrounded by bushes were more prone to rodent attack than fields with clean surroundings. In this study, the habitat around the experimental plots was clear without bushes. Three rodent species and their percentage captures in bracket were obtained in farmer's fields at seedling stage *M. natalensis* (76%), *G. vicinus* (20%) and *Lemniscomys* sp (4%).

4.1.1.2 Crop damage at maturity stage

Rodent damage to mature cobs was observed in all experimental plots. There was significantly higher cob damage observed on treated (4 ± 0.01) compare to untreated plot (2 ± 0.01) ($F = 70$, $df = 1, 9$, $p < 0.001$). This was due to severe attack by rodents to fallen plants. Plants were felled as a result of termites attack. Funmilayo and Akande (1977) reported that termites' attack at crop maturity stage is a prelude to considerable crop loss by rodents. In all experimental plots, the level of damage was low compared to those reported by Funmilayo (1976) in Nigeria (14.8%), Key (1990) in Kenya (5.4%) and Mulungu (2003) in Tanzania (3.31%). This may be due to difference in rodent species and abundance. In this study *M. natalensis* and *Arvicanthis neumanni* were observed to cause damage. Key (1990) observed that in

Kenya, ground squirrels (*Xerus sp)* were involved in crop damage at maturity stage. Everad (1966) observed Cane rat is the rodent species involved in maize crop damage in Nigeria. Observation made by Massawe (2003) show that, the common field rodent pest species in Tanzania are; Multimammate rat (*M. natalensis*), Nile rat (*Arvicanthis spp*), Gerbils (*Gerbilliscus vicinus*) and Striped grass rat (*Lemniscomys spp*). These species have similar ecological requirements, as the animal of grassland, and under natural conditions, they feed on grass or grass seeds and insects (Kingdon, 1997). There was significantly higher cob damage proportion in untreated plot (0.053 ± 0.02) compare to treated plot (0.031 ± 0.02) ($F = 340.31$, $df = 1, 9$, $p < 0.001$).

4.1.3 Rodent damage pattern and distribution

In the current study, temporal damage distribution of maize occurred at seedling and at maturity stage. At seedling stage, the spatial rodent damage was random in all experimental plots as shown in Table 4. Plots had similar habitat of being clear without bushes on all sides. However, Mulungu (2003) indicated that the spatial damage distribution is clumped in some area of the field surrounded by non crop land. Four farmer's fields were uniformly damaged and one farmer's field was randomly damaged as shown in Table 2. The uniform damage distribution in farmer's fields was probably due to presence of bushes on all sides which increase the area for food availability and breeding site (Taylor, 1972; Cheson, 1981; MAFS, 1984). Taylor (1972) reported that the distribution of rodent damage in field crops shows a strong edge effect. Key (1990) defined the term "edge" as an area of potential refuge such as a perimeter fence, a terrace bank or a path of non crop land.

Table 4: Damage pattern and distribution of maize seedlings in experimental plots and farmer's fields

Experimental plots	Calculated CD	Damage pattern
Treated	1.0	Random
Untreated	1.0	Random
Farmer's fields		
1	0.7	Uniform
2	0.6	Uniform
3	0.4	Uniform
4	1.0	Random
5	0.5	Uniform

Note that, when CD is greater than 1 the damage is aggregated; if CD is less than 1 the damage is uniform and when CD is equal to 1 the damage is random.

4.1.4 Yield losses

Rodents cause damage not only at planting, but also afterwards when the crop is ripening and at maturity. The effect of rodent attack to maize crop leads to less crop yield (Mwanjabe *et al.*, 2002; Mulungu, 2003). Walker (1990) defined yield loss as a negative term and points that yield reduction, yield gap or preventive losses are alternative terms for the samething.

In this study, there was significantly higher yield loss in treated compare to untreated plot (204.2, and 187.2 kg/ plot± SD = 12.2, respectively) ($F = 30.67$, $df = 1, 1$, $p <$ 0.003). The higher yield loss in treated plots could be due to accessibility of rodents to fallen plants caused by termites, although the effect of termites to maize was not assessed in this study. The normal maize yield per hectare is estimated to 1200 kg to 1500 kg provided the climatic condition is conducive. In this study, the overall yield was 500 kg and 450 kg in treated and untreated plots, respectively. Other than rodent pests, rainfall contributed to low maize yield though was not assessed. Mulungu (2003) observed that the amount of rainfall during the 10 days after planting is more important than the total in a planting month. Therefore, these data suggests that for rodent control to be achieved properly, other factors like termite problem should be taken into consideration. The rodent species observed in maize fields at maturity stage were *M. natalensis* and *Arvicanthis sp* at a density of 10 animals/plot.

Crop loss was much more serious at planting compared to the maturity stage. This could be due to cumulative effect and foraging behavior of rodents (Meyer, 1994). It is observed that a rodent consumes 10% of their body weight per day depending on size and species of rodents (Meyer, 1994). Therefore, a rodent of 80 g may need to consume 8 g which is equivalent to visit eleven times to a cob of 90 g where by the whole row of maize crop seedlings will be damaged for a rodent to get the same weight (8 g).

4.2 Post – harvest Experiment

4.2.1 Damage of stored maize grains

The damage assessment in stored maize grains indicated that, there was significanlyt higher damage in cribs compared to sacks (F =20.34, df=1, 60, p < 0.001) (Fig.6 and Table 5). The reason for higher damage in cribs was due to rodents having easy accessibility to cribs. In this study, open and closed structures had different damage. There was significantly higher damage in open structures compared to closed structures ($p < 0.001$) (Fig. 6 and Table 5). These results suggests that, although closed cribs can be used to store maize grains, there is a need to use rat guards at its poles to avoid easy rodent accessibility. The low level of damage in closed sacks was associated with no accessibility by rodents.

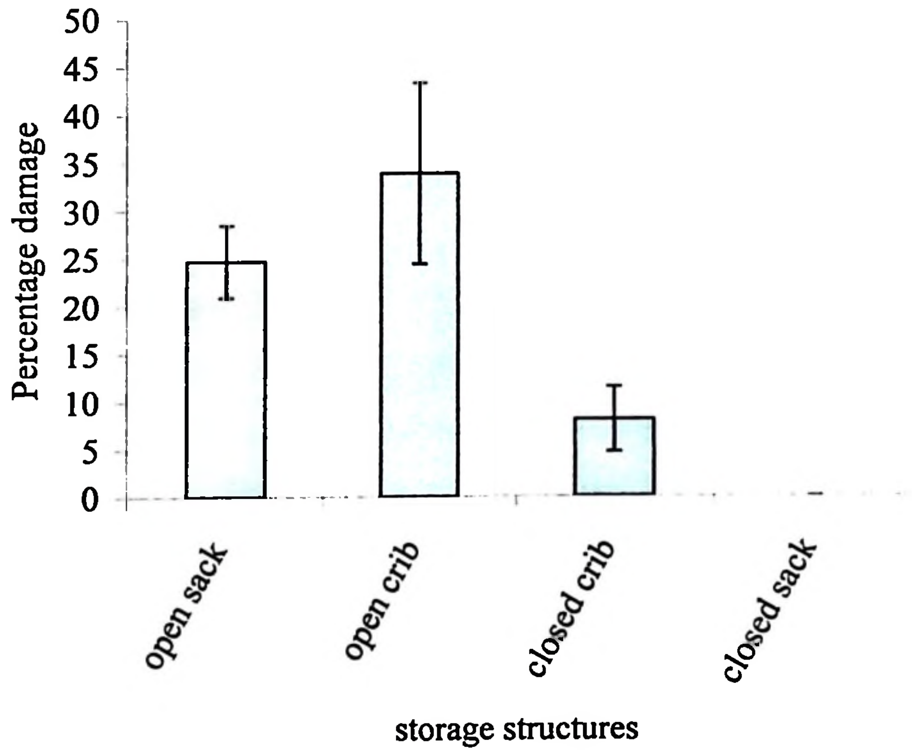


Figure 6: Percentage damage (± SE) of stored maize grains in open and closed storage structures.

Table 5: General Linear Model Factorial ANOVA showing storage structure and treatment effect on stored maize damage in different farmers during the storage season 2007/2008.

Source of variation	Df	MS	F	P
Farmer	2	3591.16	54.16	<0.001
Structure	1	1348.80	20.34	<0.001
Treat	1	11516.81	173.69	<0.001
Farmer*structure	2	7882.61	118.88	<0.001
Farmer*Treat	2	808.63	12.20	<0.001
structure*Treat	1	5.59	0.08	0.772
Farmer*structure*Treat	2	3381.80	51.00	<0.001
Error	60	66.31		

Damage of maize grain was not observed in closed sacks among all storage structures in farmers' houses in the study village. However, there were significant differences in grain damage between different household types ($p < 0.001$) (Table 5). The highest damage was observed in farmer number 2 and farmer number 3 with cribs and sacks, respectively (Fig. 7). The reason could be due higher rodent population as a result of difference in type of storage house, kind of habitat around the houses and spillage of other food sources in storage houses. In this study, farmer number 2 and number 3 had their houses thatched with grasses and were surrounded by bushes and probably the reason why damage was high in those houses and farmer 1 had the house thatched with iron sheets and their surrounding was clean (Personal observation). In the study area, *R. rattus* was very common and a trap success of 6.3% - 14% was achieved. According to Kilonzo (2006) the commonest storage

6.3% - 14% was achieved. According to Kilonzo (2006) the commonest storage rodent pests are; the roof rat (*R. rattus*), Norway rat (*R. novergicus*) and house mouse (*M. musculus*). However, where the grains are stored outdoors in dry weather, *M. natalensis* may also cause damage (Fiedler, 1994).

MAFS (1984) pointed out that to prevent rodents from jumping onto the storage structures, rat guards should be fixed on the supporting pole of one metre above ground. In order to reduce high numbers of rodents in houses, MAFS (1984) suggest that, farmers should use the following methods: (a) keep an area around the house clean and free of vegetation, (b) do not pile firewood and other things by the walls, (c) maintain the house by blocking holes in the walls with small stones and mud or clay, (d) plaster the walls so that the surface becomes smooth, (e) make doors fit tight, (f) clean up inside houses and remove piles of things not in use, (g) always keep food in closed containers like tins and clay pots covered with sheet metal lids and put something heavy on top, and (h) use locally made traps or other traps if available.

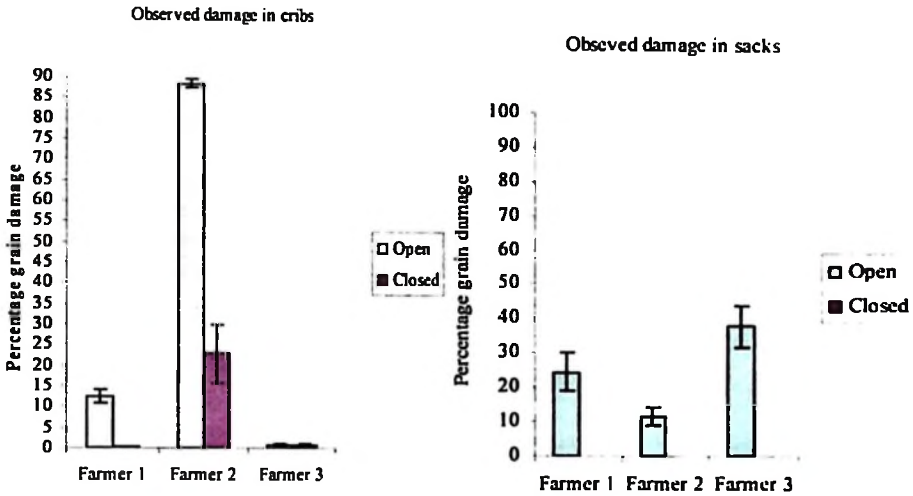


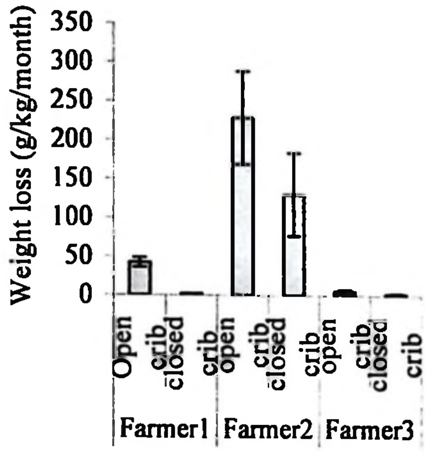
Figure 7: Damage of maize grains in different farmers with 3 cribs and 3 sacks

4.2.3 Maize grains weight loss

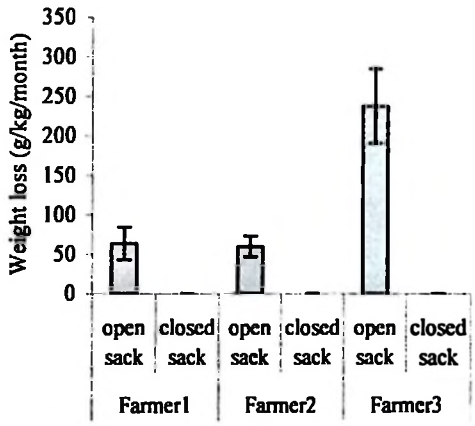
In this study, there was significantly less maize grain loss between open and closed storage structures (F = 22.45, df = 1, 60, p < 0.001), Fig. 8 and Table 6). There were no significant differences in maize grain weight loss between storage structures (cribs and sacks) (F= 0.2, df = 1, 60, p = 0.68). However, no grain weight losses were observed in closed sacks because they were properly protected from rodent attack.

In general, weight loss of maize grains was high in open compared to closed structures (Fig. 8). Maize grains in open structures were accessible to rodents compare to closed structures. However, the type of storage house, the kind of habitat around the houses, and spillage of other food sources in storage houses had major effect on rodent population (Personal observation) hence higher maize grain weight loss. There was more maize grain weight loss in household number 2 and household number 3 with cribs and sacks, respectively (Fig. 8). Though this was not assessed, it was observed that those farmers with their houses thatched with grasses, surrounded by bushes and spillage of other food sources in storage houses had higher rodent population (Personal observation).

The estimated mean weight loss was 240 g/kg/month in open cribs, 140 g/kg/month in closed cribs and 260 g/kg/month in open sacks equivalent to 20 kg/tonne/year, 11.7 kg/tonne/year and 21.7 kg/tonne/year, respectively. However, the weight loss is low compared to the feeding capacity of rodents reported by Meyer (1994) that, rodents need to consume 10% of their body weight depending on size and rodent species, and with prevailing climatic condition and that an adult Norway rat (*R. norvegicus*) eats about 28 g of dry food a day. The observed rodent species in the study area was *R. rattus* at a trap success of 6.3% - 14%. According to Nowak (1999) *R. rattus* consumes about 15 g/day of food and 15 ml/day of water. Therefore, given a trap success in the study area a loss of 16.8 kg to 37.8 kg would be expected for the whole storage time of six months.



(a)



(b)

Figure 8: (a and b). Weight loss (g/kg/month) of maize grains in open and closed storage structures.

Table 6: General Linear Model Factorial ANOVA showing storage structure and treatment effect on stored maize weight loss in different farmers during the storage season 2007/2008.

Source of variation	Df	MS	F	p
Repl	2	35068.0	5.94	<0.05
Structure	1	1021.3	0.17	0.68
Treat	1	132903.6	22.49	<0.001
Repl*structure	2	120549.8	20.41	<0.001
Repl*Treat	2	9522.5	1.61	0.21
Structure*Treat	1	28119.7	4.76	0.03
Repl*structure*Treat	2	35649.0	6.03	< 0.05
Error	60	5908.3		

4.2.4 Contaminations of stored maize grains

Rodents cause indirect damage and spoilage to maize crop through contamination (with their droppings, urine, hair and other body parts), which leads to deterioration and enhance susceptibility to fungal and bacterial infestations during storage period (Gregory, 2002). Rodent droppings contaminate stored maize as shown (Plate 5) below.

Plate 5: Maize grains contaminated by rodent droppings

The results show that, there was significantly higher contamination level in open compared to closed structures ($p < 0.001$) (Fig. 9 and Table 7). Maize grains in household with open structures were highly contaminated compared to household with closed structures. Closed sacks had proper protection from rodent attack. Household number 1 and number 2 with open cribs, Household number 1 and number 3 with open sacks and household number 2 with closed cribs had slightly higher contamination (Fig. 9). However, maize grain contamination was not observed in closed sacks.

The study shows that the greater number of grains damaged the higher the contamination. However, this depends on the rodent species involved. In the study area *R. rattus* was the main pest species in stores. Meyer (1994) observed that rodent species like *R. norvegicus* produce about 40 droppings a day, where a relatively small infestation of ten rats would produce total of 146 400 droppings a year. Similarly, it has been reported that within six months, one pair of *M. musculus* can eat more than two kilograms of food and deposit about 18,000 droppings (Alberta Agriculture Food and Rural Development, 1996).

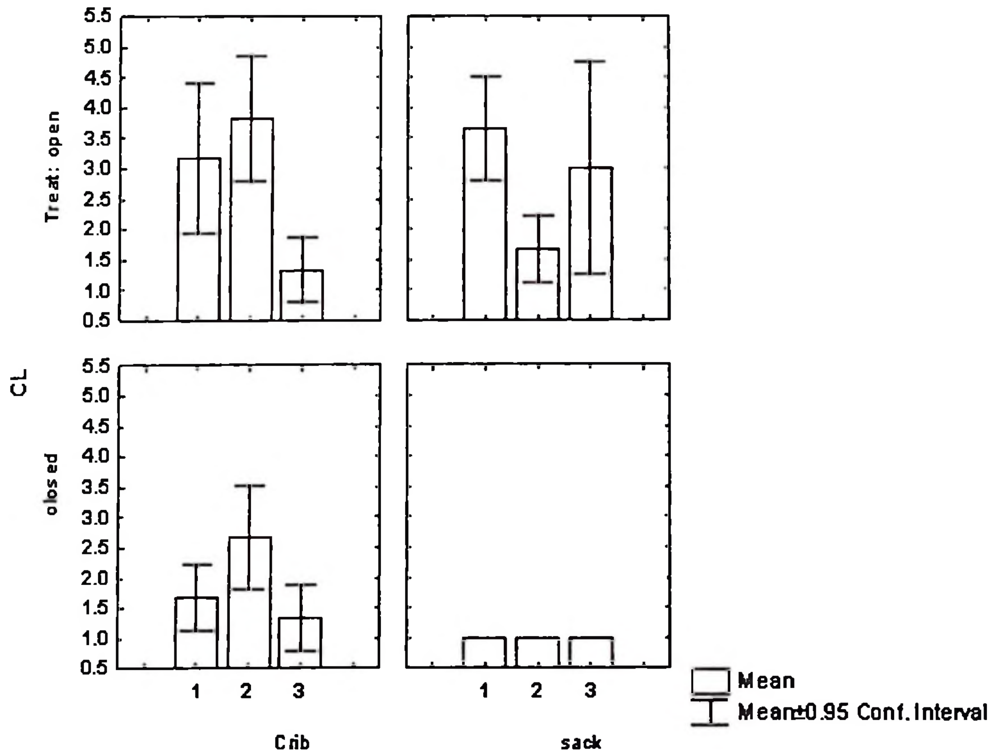


Figure 9: Contamination of maize grains in open and closed storage structures. (CL: is Contamination Level and number 1 -3 are households)

Table 7: Visual Generalized Linear Model ANOVA showing storage structure and treatment effect on contamination of stored maize grains in different farmers during the storage season 2007/2008

Source of variation	Level of effect	Column	Estimate	Standard	Wald	P
Repl	1	5	-0.75	0.26	8.24	<0.05
Repl	2	6	-1.06	0.26	16.78	<0.001
Structure	Crib	7	-5.33	0.18	879.32	<0.001
Treat	Open	8	- 6.11	0.20	932.32	<0.001
Repl*structure	1	9	0.48	0.25	3.60	0.06
Repl*structure	2	10	-2.12	0.35	36.45	<0.001
Repl*Treat	1	11	-1.02	0.29	12.22	<.001
Repl*Treat	2	12	0.57	0.26	4.84	0.028
Structure*Treat	1	13	5.13			
Repl*structure * Treat	1	14	0.20			
Repl*structure * Treat	2	15	-0.49			
Scale			1.00	<0.001		

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSIONS

A full understanding of rodent damage to crops is vital to the design of effective management strategies. The present study has shown that, rodent population and rodent damage to maize crop at seedling was slightly higher in untreated compared to treated experimental plots although the differences were not significant. The hypothesis which states that rodenticides application can reduce the rodent damage hence high yield is rejected. This is because the damage observed at seedling was similar in both treated and untreated plots.

Maize seedling damage was also observed in farmers' fields, however damage was high in fields which was not clear and surrounded by non crop lands compared to experimental plots, which was clear though surrounded by fallow lands. In the storage experiment, results show that the highest maize grain damage, weight loss and contamination were observed in open storage structures (sacks and cribs) and closed cribs in all households. This accepts the hypothesis which states that improved storage structures may reduce rodent damage to stored maize grains. In this study no damage was observed in closed sacks because rodents had no access to the sacks. There was higher rodent incidence in grains stored in cribs compared to open sacks. Although closed sacks showed better control of rodent damage to stored maize grains, it is more expensive for farmers to implement. Visual observation indicated that farmers with houses thatched with grasses and are surrounded by patches of bushes, had their stored maize grain received greater damage compared to those houses with galvanized iron sheets and clean surroundings.

5.2 RECOMMENDATIONS

(1) Farmers in Berega village are advised to clean fallow lands surrounding their fields so as to remove the site for rodent breeding.

(2) Because closed sacks did not show any rodent damage, it is recommended that farmers in Berega village should use closed sacks for maize storage.

(3) Other studies should be carried out to cover the whole year rather than only for six months.

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APPENDICES

Appendix 1: Maize grains damaged by rodent