RESPONSE OF RICE YIELD TO RAT DAMAGE IN IRRIGATED RICE (*Oryza sativum* L.) IN MVOMERO DISTRICT, MOROGORO, TANZANIA.

PHLORENTINPHILIP LAGWEN

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN CROPSCIENCE OF SOKOINE UNIVERSITY AGRICULTURE. MOROGORO, TANZANIA.

2016

ABSTRACT

Rodents often damage crops throughout the growing season, from germination to harvest, thus making it difficult to understand its cumulative effects for crops such as rice that are able to partially compensate. This study examines response of rice yield to rat damage in farmer's fields and simulated rat damage in irrigated and rain-fed rice (*Oryza sativum* L.) in Morogoro, one of Tanzania's granary areas. The study was conducted at Hembeti village in Mvomero district from September, 2012 to July, 2013 where variety TXD 306 was used. Two field experiments; viz: farmers' managed rice field and rodent simulation damage were conducted. The experimental design for farmer's field study was split plot laid in Completely Randomized Design (CRD) and a split-split plot layout in a Randomized Complete Block Design (RCBD) with three replications for simulation rat damage experiment. Five damage levels (i.e. cuts at 0%, 10%, 20%, 25% and 50%) at different rice growth stages (i.e. transplanting, vegetative and maturity) and seasons (i.e. dry and wet) were carried out for later experiment. Results show that there were no significant differences in rodent abundance between seasons and crop growth stage in farmer's managed rice fields. *Mastomys natalensis* was the most abundant rodent pest species while *Grammomys dolichurus* was found in small proportions. Higher yield was recorded during the wet season compared with the dry season. Yield loss was observed during all cropping stages for all levels of simulated rat damage for wet and dry season crops, with significant compensation noted at the transplanting stage. Damage above 10% stem cut and at vegetative and maturity stage resulted in significant reductions in rice yield. Grain yield was highly and positive correlated with number of panicles per plant and panicles m^{-2}, filled grains per panicle, percentage grain fill and 1000 grain weight.

DECLARATION

I, Phlorentin P. Lagwen, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is the result of my own original work and it has been done within the period of registration and that it has neither been submitted nor being concurrently submitted any other institution.

Signature…………………….

Phlorentin P. Lagwen

MSc. Candidate. Date …………………

Signature……………………

Prof. L.S Mulungu.

Supervisor   Date…...……………

COPYRIGHT

ACKNOWLEDGMENTS

I would like to express my gratitude to all those who supported me toward the completion of this study. Special thanks are given to Almighty God for giving me good health and taking care of me during doing my research and writing of this work.

I wish to express my heart-felt thanks to my supervisor, Prof. L.S. Mulungu for the guidance, constructive criticism, tireless close supervision and encouragement. His direction and patience in going through my work made this study successful. I am also grateful to Prof. B.S Kilonzo for perusing and advice on constructive changes.

Further thanks extends to ZARDEF for the financial support during my research work, my fellow colleagues in the Master of Crop Science course (2011/2012) and to all those who have made possible in one way or another in the completion of this work.

Finally, I am highly indebted to my beloved wife Lydia Mhoro and my daughter Vanessa and son Robert for their patience, understanding and encouragement during the period of my entire study. May God bless all.

DEDICATION

This work is dedicated first to my late father Philip and my mother Sabina, brothers and sisters who tirelessly laid the foundation for my education. Also it is dedicated to my wife Lydia, my lovely daughter Vanessa and my son Robert for their moral support throughout the study period. However, this work could not be possible without my supervisor Prof. L.S. Mulungu for his care and assistance from early stage of the study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

%	Percent
/	Per
<	Less than
>	Greater than
±	Plus or minus
^0C	Degree Celsius
ANOVA	Analysis of Variance
cm	Centimeter
DSA	Days After Sowing
e.g.	For example
EIL	Economic Injury Level
et al	And others
FAO	Food and Agricultural Organization
g	Gram
GDP	Gross National Product
Ha	Hectare
i.e.	That is
IPM	Integrated Pest Management
IRRI	International Rice Research Institute
Kg	Kilograms
m	Metre
m.a.s.l	Metres Above Sea Level
m^2	Metre square
MAFS	Ministry of Agriculture and Food Security

mm	Millimeter
MMT	Million Metric tones
MT	Metric tone
N	North
Prof.	Professor
S	South
SD	Standard Deviation
ssp	Species
SUA	Sokoine University of Agriculture
t	Tone
tha^{-1} or t/ha	tone per hectare
USA	United States of America
Vs	Versus
ZARDEF	Zonal Agricultural Research Development Fund

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Rice (*Oryza sativa* L.) is one of the most important cereal crops in the world (Banwo, 2006). It is the second highest produced grain worldwide, after maize (FAOSTAT, 2013). It constitutes staple food providing 20% of the world's dietary energy supply (FAO, 2004) compared to wheat (19%) and maize (5%) (FAO, 2005). Apart from being rich in dietary energy supply, rice is a good source of thiamine, riboflavin and niacin (FAO, 2005). Worldwide the crop is grown in Asia, West Africa, North America, Central and East Africa, South and Central America, Australia and United States of America (Worldwide rice production, 2011).

Tanzania is an agricultural based country and its economy depends on agriculture, which accounts for more than one-quarter of GDP, provides 85% of exports, and employs about 80% of the work force (The World Factbook, 2013). Crop production to a large extent is by subsistence, where most farms range between 1 and 5 acres and are dominated by mixed cropping system. However, rice is an exception, it is produced under typical monocultural system (Lwezaura *et al*., 2011; Kihupi, 2011). The system can further be subdivided into three agro-ecosystems namely rainfed lowland (74%), rainfed upland (20%) and irrigated lowland (6%) (Kanyeka, 1994). Production of the crop is exclusively for human consumption unlike maize and wheat which are sometimes used as fodder (Ministry of Agriculture of Kenya, 2008). Large amount of the rice consumed in Tanzania is produced from five regions, namely Mbeya, Shinyanga, Mwanza, Morogoro and Tabora (Kadigi, 2003). Average production ranges between 1 and 1.5 t/ha (ECARRN, 2006; RLDC, 2009) which is actually lower than that of Africa (2.2 t/ha) and that of the world (3.4 t/ha) (FAO, 2000).

Despite the low average production, the crop is also vulnerable to pests such as rodents (Mulungu *et al*., 2013) which, according to Singleton (2010), are animals that have continually gnawing incisor teeth and no canine teeth. They can cause damage in crop fields from planting throughout harvest and storage. In Tanzania, damage reduces both quantity and quality of the crop yield (Fiedler, 1994). Damage to crops by rodents is largely attributed to Multi-mammate mouse, *Mastomys natalensis*, Smith 1834 and Nile rat, *Arvicanthis* sp. (Safianu and Robert 2004; Mulungu *et al*., 2013). According to Mulungu *et al*. (2010) and Makundi *et al*. (1991), the Multi-mammate mouse in particular, poses the greatest risk to the crops. This species is economically the most important rodent pest in Sub Saharan Africa and is an indigenous commensal rat (Fiedler, 1988).

The types of damage imposed by rodents to field crops include the destruction of seeds after sowing and damage of the stem of a mature crop (Mulungu *et al*., 2003a). The Regional Agriculture and Fisheries Information Division (2008), named various categories of cereal crops losses resulting from rodent damage in the fields as seed removal and consumption, seedling cutting, weight loss arising from total grain predation at crop ripening and maturity, and loss of viability of seeds due to removal of the embryo from the seed. Each season a large proportion of potential crop yield is lost due to rodent infestation (Mwanjabe *et al*., 2002).

According to Singleton *et al*. (1999), rodents are considered as an inevitable pest and hence left without constant control, thus enabling them to produce and occasionally reach an outbreak levels. In areas with rice crop, rodent outbreaks have been reported to cause severe crop losses and food shortages (Zehrer, 1998 in Singleton *et al*., 1999) and of all, the irrigated rice suffers the greatest damage (Singleton *et al*., 1999; Sixbert, 2013). Studies to determine amount of damage by rodents have been reported in different parts of

the world (Lavoie *et al.*, 1991; Meerburg *et al*., 2009; Sixbert, 2013). For example, in Philippines, about 90% rat damage has been estimated in fields (Fall, 1977). In Asia, pre-harvest rice losses were estimated to be between 5 and 10% (Singleton, 2003a; Singleton *et al*., 2005; Meerburg *et al*., 2009) while in Madagascar, the overall annual losses were estimated to be 62,500 tons of rice paddy or 40,000 tons of marketable rice (Singleton *et al*., 1999). In Bangladesh, Poche *et al*. (1981) reported that the later the damage occurs due to rodent pests, the greater the yield losses except for the <10% damage at tillering where rice was able to compensate for yield loss.

In Africa, Safianu and Robert (2004) reported yield losses of rice in Nigeria to be 12.6% in 1991 which is nearly three times higher than that of 1990 (4.8%). Sheyo (2010) estimated rat damage on famers' rice fields in Tanzania during wet season to be 5% while Sixbert (2013) reported 12% rodent crop damage during the dry season and 6% during the wet season. Mulungu *et al*. (2013) reported that rodent population was higher during dry season in comparison with wet season. Little information, however, exists on which level of rodent damage and on the growth stage, at which the crop can compensate for rodent damage hence little impact at small holder farming scale in Tanzania. Therefore, there is a gap in information pertaining to rodent damage levels and crop growth stage(s) at which implementation of control measures becomes most economical in irrigated rice agrosystems.

1.2 Objectives

1.2.1 Overall objective

The overall objective of this study was to investigate the impact of both natural and simulated rat damage to rice grain yield in irrigated lowland rice production area.

1.2.2 Specific objectives

i.   To establish rodent species composition at different rice crop growth stages especially at seedling, vegetative and maturity.

ii.   To assess the rodent population dynamics in a different rice crop growth stages (i.e. seedling, vegetative and maturity).

iii.   To estimate the effect of different damage levels at different rice growth stages on farmer's fields

iv.   To determine the critical rice growth stage(s) where control measures will be most economical.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Background Information

2.1.1 The rice plant

Cultivated rice is generally considered as an annual grass plant, although in the tropics it can survive as a perennial, producing new tillers from nodes after harvest (ratooning) (NARI, 2001). The life span of this plant varies among varieties and between climates (Shao *et al*., 2001). The plant possesses the following important features; roots, stem, tiller, leaf and panicle (Fig 1). It can grow in a variety of environment preferably semi-aquatic environment (Lwezaura, 2011).
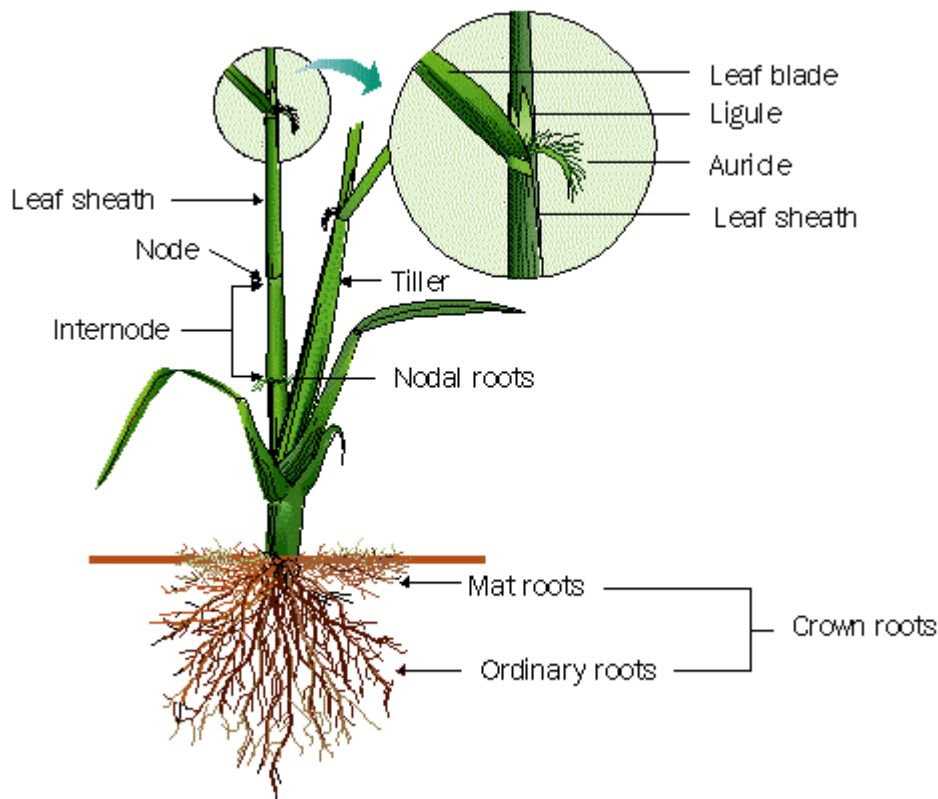
Figure 1: The rice plant

Source: Haifa (2014).

2.1.2 Nutritional value of rice

Rice is primarily a high energy calorie food (FAO, 2005). It is high in carbohydrate in the form of starch, which is about 72 - 75 percent of the total grain composition and it has a protein content of around 7 percent which is actually lower than that of wheat (Anjum *et al.*, 2007). The nutritive value of rice protein (biological value = 80) is much higher than that of wheat (biological value = 60) and maize (biological value = 50) or other cereals (Nuss and Tanumihardjo, 2010). Rice contains many minerals just like other cereals and a large portion of these minerals are located in the pericarp and germ (Srilakshmi, 2005). The phosphorus content of rice is high (about 4%) and is in the form of phyticacid (Nagel, 2010) and also contains some trace elements and enzymes (Srilakshmi, 2005).

2.1.3 Distribution of rice

Rice is grown in more than a hundred countries, with a total cultivated area in 2009 of approximately 158 million hectares, producing more than 700 million tons annually (470 million tons of milled rice) (IRRI, 2012). It is cultivated between 53^0 and 40^0S latitude (Ali *et al.*, 2012). The crop grows in a wide range of environmental conditions as it possesses efficient air passage system (shoot to roots). According to Chang (1976), rice originated from supercontinent of Gondwanaland which later broke and drifted to form Africa, Antarctica, Australia, Malagasy, South America and Southeast Asia.

2.1.4 World production statistics for rice

Rice has gained more popularity in recent years. According to FAOSTAT (2013), in 2012, the world annual planted area of rice was about 163 million hectares, accounting for rice grain production of about 71 million tons. In 2011, the top ten countries leading in rice production were as per table 1 below.

Table 1: Rice yield of the world leading top ten countries in 2011

County	Rice production (MMT)
China	202.6
India	155.7
Indonesia	65.7
Bangladesh	50.6
Vietnam	42.3
Thailand	34.5
Burma	32.8
Philippines	16.6
Brazil	13.4
Cambodia	8.7

Source: http://faostat.fao.org/site/339/default.aspx

In 2012, the contribution of Africa to the worlds' rice production was only 3.8% (FAOSTAT, 2013). In East Africa, Tanzania ranks the first by producing 1.8 million tons followed by Uganda 212000 tons and Kenya 122465 tons (FAOSTAT, 2013).

2.1.5 Rice varieties grown in Tanzania

Tanzania grows numerous varieties of rice ranging from traditional local rice varieties which descended from seed imported by Arab traders before 1960s (RLDC, 2009), to the new improved varieties produced by National Research Stations (Ngwediagi *et al*., 2009). The local varieties are more preferred by the local people and are characterized by long maturation period and low yielding ability (Bill and Melinda Gates Foundation, 2012). The improved varieties possess high yielding traits and have short maturing duration. However, their adoption by farmers is not much promising due to their low aroma

(Coulson and Diyamett, 2012). The improved rice varieties and their days to maturity includes Supa and IR 54 which takes 93-100 days, IR 22 (120-134 days), Dakawa (75-85 days), TXD 85 (98-102 days), TXD 88 (86-95 days) and TXD 306(100-102 days) (Ngwediagi *et al*., 2009).

2.1.6 Significance of rice in Tanzania

Rice is an important cereal grown as food and income generating crop in Tanzania. The crop is a mostly preferred food than maize (Mghase *et al*., 2010) and according to Shayo *et al*. (2006) reported that about 60 percent of the country population consumes it. Kayeke *et al*. (2010) reported that the crop has been ranked as a national strategic crop on the basis of area under cultivation, production and consumption. The annual per capita consumption of milled rice shows gradual increase from year to year, example in 1970s it was 15 kg (FAO, 2002), and rose to 25.4 kg in 2007 (MAFS, 2009).

The consumption preference is, among others, influenced by grain size, color, taste/flavor and the cooking attributes while aromatic rice varieties are more preferred to non-aromatic. An example of the aromatic rice in Tanzania is the Super and SARO (TXD 306) while the non-aromatic is IR64 (Ngwediagi *et al*., 2009).

The daily caloric intake for rice in Tanzania for the year 2009 was 154 kcal/person/day and accounts for a share of 8% for country daily caloric intake (Minot, 2010). This value is expected to ascend in the near future as the consumption of rice is linked to rise in income compared to other any factors.

2.1.7 Rice production trend in Tanzania

Tanzania rice production has been increasing year after year (Coulson and Diyamett, 2012). For example, in the past ten years (2002 - 2011), rice production rose from 985 metric tons to 2248 metric tons and area under rice production rose from 566000 hectares in 2002 to 1119000 hectares in 2011 (FAOSTAT, 2013). Production projection by agro-ecological condition for the year 2013 and 2018 are as per table 2.

Table 2: Paddy production and yield by agro-ecological conditions

	Rain-fed upland		Rain-fed lowland		Irrigated	
Year	2013	2018	2013	2018	2013	2018
Area (000'ha)	21	31	374	274	290	390
Yield (000't)	1	1.6	1.5	2	3	3.5
Production (000't)	21	50	561	548	870	1365

Source: MAFS 2009

Increase in rice production as predicted in table 2 above is not solely associated with increase in rice production per area but also to increase in area under rice production.

2.2 Constraints Facing Rice Production in Tanzania

In Tanzania, rice is grown almost in all regions but with varying degrees of importance. However, production of the crop has been faced with a number of constraints which include biotic and abiotic factors such as drought and soil fertility. The biotic factors include weeds, insect pests, diseases and rodent pests. It has been reported that pests such as rodents are increasingly contributing to rice yield losses in rice fields (Singleton *et al*., 1999).

2.2.1 Crop loss due to rodent pests

Rodents, particularly rats, substantially cause damage to rice fields (Singleton, 2010a). They eat rice seeds and seedlings, gnaw tillers, damage plants, and feed on grains (Reissig *et al*., 1985; Brown and Singleton, 2000). The level or severity of damage is not uniform throughout growth stages of the crop instead it tends to be more concentrated at some growth stages (Sixbert, 2013). At planting, for example, rodents may dig up and eat the planted rice seeds in nurseries or in fields which are directly planted, and consequentlynecessitates repeated late replanting (Mwanjabe, 1993; Makundi *et al*., 1999; Brown *et al*., 2006) and ultimately result in lower yield (Taylor, 1968; Myllymäki, 1987; Mwanjabe, 1993; Mulungu, 2003).

At vegetative stage, rats cut rice tillers while growing and use for building their nests (Gergon *et al*., 2008) and eat (Reissig *et al*., 1985). Damage can be severe during the dry season and cuts are normally seen at the base (Jahn *et al*., 1999; Sixbert, 2013). At maturity, rodents attack both milky and mature grains (Mulungu *et al*., 2006; Sixbert, 2013). In Asia, an estimated rodent damage of 5% to 10% was recorded prior to rice harvest in 1999 (Singleton, 1999). In Indonesia, rodent pests, primarily the rice field rat (*Rattus argentiventer*), are the most important pre-harvest pests causing annual losses of rice crops by 17% (Jacob *et al*., 2002). In Vietnam, My Phung and Brown (2011), reported rodent damage on rice to increase from 2.1% (in the first rice crop, winter-spring), to 3.8% in the second (Summer-autumn) rice crop and reached 6.6% in the third (autumn-winter) rice crop and caused yield loss of 15%. In Western Kenya, Taylor (1968) reported rodent associated losses of maize, wheat and barley to be 20%, 34 - 100% and 34%, respectively during rodent outbreak periods.

During the 1989/90 cropping season, in Tanzania, a total yield loss of 48% in maize, sorghum, paddy, and pulses was reported and attributed to seed depredation by rats

(Mwanjabe *et al.,* 2002). According to Makundi *et al*. (1991), the annual pre-harvest loss of maize in Tanzania is estimated to reach 15%. Mwanjabe and Leirs (1997) and Mulungu *et al*. (2003b) reported that maize damage at sowing and seedling stages could range between 40 and 80%, depending on cropping seasons and location. Furthermore, in 1998, rodent pests were reported to destroy over 352173 acres of various grain crops in Lindi region (Mwanjabe *et al*., 2002). In irrigated rice, in Morogoro region, Tanzania, Sixbert (2013) reported that crop damage by rodent pests during the dry season was 11% and that such damage resulted into yield loss of 12% which is enough to feed about, 7568 people/year. The author, also reported that during the wet season, rice crop damage was 6% and it resulted into yield loss of 4.75%, an amount which is enough to feed about, 2996 people/year.

2.2.2 Symptoms of rat damage on rice crop

Rat damage on rice crop in fields is easily observed where a large number of tillers are cut, but it can go unnoticed when damage is low. In rice nurseries, rats simply chop down the young seedlings and also feed on the endosperm (Plantwise, 2014; IRRI, 1990). Rats will feed on the freshly sown seeds as well as on pre-germinated grains. In severe cases, nurseries have to be re-sown (Makundi *et al*., 1999).

At the maximum tillering to booting stages of the rice plant, the tillers are gnawed near the base, and the heart of the developing buds and heads are eaten (Regional Agriculture and Fisheries Information Division, 2008). In the late flowering and grain-filling stages, rats make oblique cuts (usually 45° on the rice stalks carrying the inflorescence) (Sudarmaji *et al*., 2003). After severe rat damage (depending on rodent species involved and its feeding habit, i.e. nocturnal or diurnal, the field may be left with border plants ('stadium' effect) (Islam *et al*., 1993) or the centre plants ('edge' effect) (Sheyo, 2010). Under very high rat

infestation and depredation all the rice plants are attacked and the crop is totally destroyed (Fayenuwo *et al*., 2007).

2.2.3 Rodent pest species

Worldwide there are almost two thousands species of rodents, but only a limited number of them cause problems in agriculture (Leirs, 2003). The pest status for these rodent species varies from one region to another. In Indonesia for example, the *Rattus argentiventer* is a major pre-harvest pest causing damage to crops in every planting season (Singleton and Petch, 1994). In Australia, three rodent species, namely *Mus domesticus* (house mouse), *Rattus rattus* (black or roof rat) and *Rattus norvegicus* (Norway rat) are considered as pests, but the house mouse is the most important agricultural pest (Singleton *et al*., 2003b). According to Fiedler (1994), more than 70 rodent species in Africa, are considered as pests but only a few are agricultural pests.

In Tanzania, there are more than 21 rodent pest species, the main ones being *M. natalensis, Arvicanthis nairobe* (Nile rat)*, Rattus rattus* (House/roof rat)*,* and *Mus musculus* (Fiedler, 1994; Makundi *et al*., 1991; Mulungu *et al*., 2010). Most of these species belong to family Muridae (Kilonzo, 2006). Of these, *M. natalensis* causes more agricultural damage than any other rodent pest species (Stenseth *et al*., 2003, Sixbert, 2013) and it is the most abundant and serious pest of rice (Mulungu *et al*., 2013; Sixbert, 2013). The species occurs in fallow and cultivated lands ranging from sea level to an altitude of 2000 m above sea level (Msangi, 1968). It feeds on a variety of crops and on average an adult *M. natalensis* rat can consume, up to 10% of its body weight of cereal per day (Kilonzo, 2006). During rodent outbreaks which occur occasionally and during population densities exceeding 1000 animals/ha (Leirs, 1995), damage and economic losses are considerably higher than in years with low population densities (Mulungu *et al*., 2003a).

2.2.4 Population dynamics of rodent pests

Population dynamics of rodents is an important key for planning successful rodent control strategies (Sheyo, 2010). It has been reported that positive relationship between inhabitants and crops damage exist (Advani and Mathur, 1982; Sheikher and Jain, 1997). The availability of food in terms of quantity, quality and preference and habitat in any place at a time determines the prevalence and dominance of any pest species.

In sub-Saharan Africa, background information on field rodents revealed *Mastomys* genus as the most dominant, with *M. natalensis* ranking first (Mwanjabe and Leirs, 1997). It is well established now that rodent population fluctuate seasonally (Kilonzo, 1994; Lalis *et al*., 2009; Sheyo, 2010; Mulungu *et al*., 2013). Hansson (1998) reported that such fluctuations are due to several factors, a combination of which may result into different responses depending on the environment. Oosthuizen and Bennett (2009) reported that populations of small mammals like rodents are influenced by food availability, plant cover, rainfall and environmental conditions. Zhang *et al*. (2010) reported that occasional population outbreak of *Lasiopodomys brandtii* (Brandt's vole) in the grassland of Inner Mongolia and (*Microtus forti*) (Yangtze vole) in the rice fields of Dongting lake region of southern China, respectively, were associated with the combination of intrinsic and extrinsic (mainly rainfall) factors.

In Morogoro, Tanzania, *M. natalensis* breeding has been reported to be positively correlated with short rains (Leirs, 1995; Kilonzo, 2006). Similarly, Massawe *et al*. (2011) reported that population densities of *M. natalensis* in the area is high during and after the short rains, and consequently coincides with the most susceptible phenological stage of crops.

In Bangladesh the lesser bandicot rat (*Bandicota bengalensis*) and the greater bandicot rat (*Bandicota indica*) are of high economic importance and reportedly cause great losses to ripening cereals (Sultana and Jaeger, 1992). In East Asia, the active reproductive period of *Rattus tanezumi* seems to follow rice growth stages (Singleton *et al*., 2005), with a peak of breeding during the generative period (booting to ripening) rather than the vegetative period (Miller *et al*., 2008). Similar findings have been reported by Lam (1983) and Murakami *et al*. (1990) who observed correspondence of the breeding season of *R. argentiventer* with the reproductive stage of rice crop.

Singleton *et al*. (2010b) summarized causes of rodent outbreaks and named three categories, viz; outbreaks triggered by masting (including bamboo and beech forest) which is an multiannual event triggered by flowering and masting of bamboo species or other plants and which is not influenced by either climate or farming system; changes in abiotic conditions (e.g. seasonal or unusual rainfall and major climatic events such as *El Nino*) which occur irregularly and rodent populations rapidly respond to the peaks in increased food availability; and changes in cropping systems where the outbreaks are driven directly by delayed or asynchronous planting often associated with calamitous weather events, or an increased intensity of cropping per unit area, which is connected to both climatic events and market forces.

In irrigated rice systems in Tanzania, Mulungu *et al*. (2013) reported that *M. natalensis* population varied with habitat and months where Fallow land had higher abundances of rodents than rice fields. The highest abundance was observed during the dry season from July to October. The authors further observed that *M. natalensis* is sexually active throughout the year in the study area and it reaches the highest level when rice is at the maturity stage, suggesting that breeding is highly influenced by the presence of rice crop in both seasons.

2.2.4 Yield loss in rice crop

Yield can be defined as an interaction of assimilation rate, leaf area, duration of the grain filling period and movable assimilates in vegetative organs available for grain production (Walker, 1987), or it can be considered as a measurement of the amount of crop that was harvested per unit of land area. Yield can be affected by a number of factors and the effect may be positive or negative. Negative or decrease in yield is what accounts agricultural losses. Losses usually occur at any stage of crop growth or storage but cumulative effect can be measured at harvest for pre harvest losses and on sales or during consumption or at any end use for post-harvest losses (Cheaney and Jenning, 1975; Taherzadeh and Hojjat, 2013). Losses, even in modest amounts, may greatly affect individuals, entire community or even the whole society. In the less developed countries any significant loss in yield may precipitate economic chaos and in some cases famine (Wiese, 1982). In most of the time, agriculture losses are attributed to either or in combination by bad weather, diseases like fungus or virus attack, and pests like weeds, insect and vertebrates pest (Sarkar *et al*., 2013). The extent of loss depends on crop growth stage, level of damage inflicted on crop, feeding habit of the pest and the extent of a bad weather. In case of rice crop to rodent pests, they usually attack the crop throughout its growing period (Islam and Hossain, 2003). Judenko (1973) reported that damage which occurs at early growth stages can be compensated completely by the plant. In the other hand damage at maximum tillering cannot be compensated for that much and usually result into significant yield reduction (Sebastian, 2006). Cuong *et al.* (2002) examined the effect of rodent damage at different stages of rice growth and found that when damage occurs at the seedling stage (15 − 20 DAS) of rice, the plant was able to compensate for the effect; but at tillering (35 - 40 DAS) and booting (55 - 60 DAS) stage, there were no compensation effect. The condition may be more serious when damage occurs at the maturity stage as it is generally considered to result into a total yield loss and the reason for this being insufficient time for

compensation to occur (Islam and Hossain, 2003). It is known that farmers usually forego damages to some extent but it is advisable to keep pest out of reach of rice in the later stages (i.e. vegetative through maturity).

2.2.5 Relationship between rodent density and crop losses

Proper knowledge on the relationship between rodent pest density and crop loss (damage and yield loss) is an essential element in planning a sound management package (IRRI, 1990). The idea behind this concept lies on the population of rodents and the resultant yield loss. The later varies between crop types and within crop varieties depending on the ability of the crops to compensate for damage. This idea can be extended more and lead into calculation of Economic Injury level (EIL). The EIL is more about pest population in relation to cost of imposing control measures (Fishel *et al*., 2001). Various reports on the relationship between rodent abundance and crop damage presents varying observation depending on a crop type, crop growth stage and pest involved (Fielder and Fall, 1994; Mulungu *et al*., 2003b). In this case Cuong *et al.* (2002) reported that rodent damage to rice crop is strongly associated with rodent density and yield is negatively correlated with rodent density. Singleton and Brown (2000) established a relationship between rodent abundance and damage in four different crop types and reported positive relations for wheat and soybeans, and unclear trend for rice and maize. Poche *et al*. (1982) and Lefebvre *et al*. (1989) described a linear relationship in wheat and Mulungu *et al*. (2003) described both sigmoid and linear relationship in maize is possible. In simple terms, linear and sigmoid relationship between rodent abundance and damage, means little or significant compensation by the crop to damage or injury respectively (Brown *et al*., 2006). In terms of rodent management, sigmoid relationship describe that any decrease in rodent density will results in a proportionally higher decrease in damage, especially if rodent density moves from above to below the threshold value. Some of the established

threshold values for rodent management in rice include that of Kishore and Rao (2010) in Kumar *et al*. (2013) through simulation study and reported 4% tillers damage as an Economic Threshold Level for rodents in irrigated paddy fields. In Indonesia, where Rice rats (*R. argentiventer*) pose a serious problem, an action threshold of 25% damaged rice hills were set for farmers to start poison application (Van Elsen and van de Fliert, 1990).

2.3 Rodent Pest Management

The history of rodent pest management in Tanzania goes back as early as 1912 when rodent (*M. natalensis*) outbreaks were reported in Rombo district in Kilimanjaro region (Lurz, 1913). Studies on population characteristics of this species showed irregular population explosions and most of outbreaks occurred during the dry season and last through the planting season of October-February (Telford, 1989; Mwanjabe and Sirima, 1993). In the past, most of the control measures used in then were localized (Mulungu *et al*., 2010). With technological advancement and population growth, several changes took place and at present, rodent control options can be grouped into two basic approaches: the lethal or non-lethal or preventive approach (Mulungu *et al*., 2010).

2.3.1 The lethal or population reduction approach

This approach involves the use of toxicants, traps and biological control (Witmer *et al*., 2012). Rodenticides and traps are known to provide immediate effect to the problem and are often considered to be the most practical, economical and effective method of combating rodents (Pest control newsletter, 2009). The biological method always requires a period of time before it become stable and provides substantial results (Bale *et al*., 2008).

2.3.1.1 Chemical control (Toxicants)

Poisoning of rodents with rodenticides is a commonest and most preferred method in Tanzania (Ngowo *et al*., 2005). Both chronic (anticoagulants) and acute rodenticides are available and effective against most rodent species in the country (Kilonzo, 2006). The most known and widely used acute rodenticide in the country (even by smallholder farmers) is Zinc phosphide (Buckle, 1999). Zinc poisoning is mediated by phosphine, which is thought to act by inhibiting cytochrome C oxidase (Coşkun *et al*., 2012). In Tanzania, this rodenticide is supplied by the government during outbreaks and is strictly used under the supervision of Ministry of Agriculture, Food Security and Cooperative (MAFC) and it is not allowed to be sold in open markets. Sometimes anticoagulant toxicant such as Bromodialone is used at low population density. The mechanism of action of anticoagulants is based on their ability to decrease the endogenous formation of reduced vitamin K. It appears that the compounds inhibit vitamin K epoxide reductase. Reports on the efficacy of rodenticide use under field conditions include that of Saikia and Borah (2015) who used zinc phosphide (2.0%) followed by bromadiolone (0.005%) as cake 10 days after, under field condition against field rodents in *boro* and *sali* rice at panicle initiation and milky stage and recorded a reduction of 91.70 and 84.47% in live burrow, of 60.22 and 45.23% trap index and of 74.91 and 70.18% cut tillers at panicle initiation stage and 87.87 and 82.79% live burrow, 60.36 and 41.16% trap index and 72.87 and 67.43% cut tillers at milky stage in both *boro* and *sali* rice, respectively. Sahni and Prabha (2012) tested the efficacy of Zinc phosphide (two concentration, 1% and 2%) and bromodioline 0.005% (1st and 2nd day) on rodent population management and reported 86.91% against 79.76% control for 2% and 1% zinc phosphide, respectively and 96.77 against 98.83% for bromodioline in the 1st and 2nd day, respectively.

However, managing rodent pests on a broad scale using lethal methods is not an appropriate long-term strategy given their extraordinary breeding capacity and high mobility. Moreover, environmental, animal welfare and ethical concerns regarding the use of poisons has decreased the acceptance of mortality methods in recent times. Another reason for avoiding lethality is that it may promote a strong selective pressure for resistance to the chemical (Smith and Greaves, 1986). Other management strategies have been reported to overcome some of the inadequacies of using poison as a conventional control.

2.3.1.2 Trapping

Trapping is a method of rodent control that has been used over a period of time (Fitzwater and Prakash, 1989). While it is expensive because it is time consuming, it has its uses to remove small numbers of rodents or in place of toxins in areas where poison cannot be used safely (Loven and Williams, 2010). Traps are preferred by some people because it effectively provides you with a visual result i.e. dead rodent! The success of trapping depends on the person using them. When using traps leave the traps unset until the bait has been taken at least once, as this reduces the chance of creating trap shy rodents (Vantassel and Ferraro, 2005).

Several trapping methods are available, depending on the intended result. Spring-loaded "snap" traps are the most common means of killing rodents by farmers in different areas in Tanzania (Taylor *et al*., 2012; Mulungu *et al*., 2011; 2012). Live traps are designed to capture rodents in a cage, but not kill the animals; rodents caught in live traps are either released for biological studies or removed from the container and killed separately (Mulungu *et al*., 2012; 2013; 2015). Some farmers use glue boards to catch and immobilize rodents who walk over them but should be lighter rodent species such as *Mus* spp or juvenile rodents (Loven and Williams, 2010).

However, different trapping nights yield different information, especially on trapping numerically rodent species dominance over all species present. Three-night trapping sessions, conventionally used by most researchers, should be reliable for testing the relative densities of numerically dominant species but may not detect all rodent species present especially for rare species in area. Similarly, different trapping methods yield also different information. For example, Weihongi *et al.* (1999) reported that trap grids appeared to be better than trap lines for detecting the presence/absence of rodent species when two species coexist and one appears subordinate to the other. The authors reported that on trap lines the trapping rate of rats was consistently high for five of the first six nights. On trap grids the trapping rate was variable on all nights with the first mice being caught on the third night. Example of rats control using traps include that of Borah and Baglari (2014), who tested the efficacy of two traps namely bamboo and Sherman traps on *B. banglensis* in maximum tillering, panicle initiation and flowering for boro and Sali rice seasons in India and reported bamboo traps to be more efficient.

2.3.1.3 Biological methods

Biological control has been defined as the action of biological organism to maintain another organism at a lower average density in relation to than it would attain in their absence (Singleton and Petch, 1994). This method involves the use of predators, parasites, pathogens and reproductive inhibitors against rodents. There is a growing demand, particularly in developing countries, for rodent control strategies that either has less reliance on chemical rodenticides or promotes better use patterns resulting in lower costs for control, minimal risk of contamination of produce and reduced non-target risks (Bomford, 1990). This demand is driven by three main factors. One is the high cost associated with the persistent use of rodenticides prior to or during the growing of each rice crop. The second is the environmental concerns associated with using chemical

rodenticides given their ability to cause both primary and secondary poisoning of a wide range of species of mammals and birds (UNEP, 2014). The third is the domestic and international marketing requirements for clean agricultural produce that is produced in an environmentally-friendly and sustainable manner (Altieri and Nicholls, 2005).

(i)   Predators

The predators of rodents include cats, jackals, foxes, owls, hawks, and snakes. Examples of predators use in rodent management include; the use of cats in domestic and snakes and owls in field situation (Singleton *et al*., 2003b). Barn Owls have been used as pest control agents of rodents since 1982, and even earlier in Malaysia (Newsome, 1990). Predations upon rodents by natural predators considerably decrease rodent numbers, consequently lowering crop damage and eliminating the need for less benign methods. The effectiveness of this method depends much on feeding behavior of the predator in place. For example, Whitaker and Dattatri (1986) reported that a captive snake feeds on one rodent in every three days and Neelanarayanan (1997) observed that the barn owl consumes 1-6 rodents/night with an average of 2 individuals of rodents/day.

It is obvious then, a predator like snake alone cannot impose enough predatory pressure to rodents who are mostly fast breeders. For barn owls, provision of nesting sites and T-shaped perching poles in the field encouraged their predatory activity (Neelanarayanan, 1997). It has been reported that successful predator to prey management program involved the introduction of barn owl in rice fields could in turn reduced crop loss from as much as 12% to less than 2% within a year of its implementation (Hafidzi *et al*., 1999). However, decline in rodent population in areas with predators will causes predators to leave the area (Rao, 2002).

Petersen *et al*. (2003) investigated the effects of different levels of predation pressure on the population dynamic of *M. natalensis* in maize field and its consequences on crop damage and maize yield production. The control showed that manipulating predation pressure by patch poles and not boxes did not affect rodent population dynamics directly, but may have an indirect beneficial effect on maize yield by changing rodent foraging behavior. However, sometimes it is not the case. For example, the result of predator attraction against predator exclusion study carried out in Denmark and a similar study carried out in Tanzania indicated that, the study done in Denmark showed divergent results while the one in Tanzania showed positive effect on petch pole and nest box use on the crop yield. Despite of that there was no further effect from control on the rodent population indicating that the predators affects the foraging behavior of the rodent pest species.

(ii)   Parasites and diseases

Research on rodent-parasite interactions can be viewed from two principal perspectives. These are: first, analysis and manipulation of the host-parasite relationship in the wild to better understand the natural situation; and second, exploitation of pathogenic effects of parasites for a practical purpose in rodent control (Singleton and Petch, 1994). Microparasites (viruses, bacteria and protozoans) therefore, play an important regulatory role in rodent population dynamics (Singleton and Redhead, 1990). Bacteria such as *Salmonella* has been found to be effective against rats in Europe but is a potential health risk to livestock and humans which is a major challenge to this approach to rodent control (Singleton and Redhead, 1990).

Recently, the potential of an endemic virus was highlighted (Feore *et al*., 1997). It was reported that, for example an endemic apicomplexan protozoon, *Sarcocystis*

singaporensis, could be used for population control of rodents. *Sarcocystis singaporensis* frequently occurs in rodents in Southeast Asia (O'Donoghue *et al*., 1987; Jaèkel *et al*., 1997) and has been found to be host-restricted (Zaman, 1976; Jaèkel *et al*., 1999; Jaèkel *et al*., 2005). In Southeast Asia, it uses snakes (*Python reticulatus*) and rodents of the genera Rattus and Bandicota to maintain its lifecycle. It has been reported that sporocysts containing sporozoites, the stages which are infective for rats, can be obtained in large quantities from the snake host (Jaèkel *et al*., 1999). Its potential as a biocontrol agent was recognized (Zaman, 1976; Wood, 1985) because this normally is a pathogenic parasite induces a fatal pneumonia in rodents once infection with sporocysts exceeds a certain threshold.

According to Boonsong *et al*. (1999), infection of rats is usually followed by two rounds of asexual multiplication inside endothelial cells of various organs; a process by which merozoites are formed. Later, about one month after infection, merozoites eventually invade the muscles to form characteristic cysts (so-called sarcocysts) in muscles which contain a third stage, the bradyzoite. Bradyzoites are infective for pythons once the snake preys on rodents and so the cycle is continued (Lampel *et al*., 2012).

However, Singleton (1994) reported that biological control using macro- or micro-parasites is a promising for rodent control. The largest impediment to progress is the identification of a control agent which is sufficiently pathogenic, high transmission rate and is target specific. It has been therefore reported that the best prospects for the biological control of rodents lie with agents that reduce fertility rather than increase mortality. The development of immuno-contraception using a virus as a vector is preferred

as the most promising generic approach for the biological control of rodent pests (Chamber *et al*., 1999).

There are two ways in which animal/rodents could be infested: fertility control using either a non-infectious agent delivered in non-toxic oral baits, or infectious viruses as carriers of an infertility agent (Singleton, 1994). In both cases the aim is to vaccinate the animal by delivering an antigen (a reproductive protein) that generates an immune response, with antibodies in the female host blocking fertilization (Rhodes and Moldave, 2002). This immunocontraceptive approach is potentially highly species-specific, is considered humane and is likely to be cost effective in the long term. Fertility control aims to reduce a specific population size by reducing the number of young produced and recruited into the population. In Punjab (India), Triptolide was tested on *Bandicota bengalensis* where 0.25% and 0.20% of triptolide was able to inhibit reproduction of male and female rats, respectively (Deng *et al*., 2011; Dhar and Singla, 2013; Singla *et al*., 2013; Dhar and Singla, 2014).

2.3.2 The non-lethal or preventive measures

The non-lethal or preventive measure involves habitat manipulation or cultural practices, exclusion/fencing and use of repellants.

2.3.2.1 Cultural practices and/or habitat manipulation

The agronomic practices employed by farmers in raising crops in the fields plays great role in reducing rodent population. Rao (2002) reported that deep ploughing, bund trimming and other land preparation measures reduce the carrying capacity of the habitats and Massawe (2003) reported that deep cultivation using tractor reduce rodent population as compared to slash and burn cultivation system. White *et al.* (2003) reported a significant reduction in damage for fields adjacent to manipulated habitats as compared to

fields near un-manipulated habitats. Activities such as weeding and burrow digging also deprive rodents' shelter and alternative food sources. Sharma and Rao (1989) reported a decline in rodent infestation in rice fields through reducing bund dimension. Christopher *et al.* (1984) reported a reduction in rodent habitation in animal/human dwellings, stores and godowns as the result of periodic removal of garbage and nesting material.

2.3.2.2 Exclusion/fencing

This method involves setting of barrier to prevent rodents from reaching the area of concern. It is mostly practiced in smaller areas or in valuable crops like seedbeds and research plots (Fielder and Fall, 1994). Inchaurraga (1973) used galvanized sheet barrier in South American rice field to obtain a 5 tha^{-1} yield compared to a 2 tha^{-1} in unprotected plot.

Rodent-Proofing in houses whenever possible is a critical step in controlling rodents. This could be through making it impossible for them to gain entry to the house. It has been reported that fences which relied on the use of barriers that exceeded the physical capability of the rodent pests were reliable (Day and MacGibbon, 2007).

2.3.2.3 Use of repellants

The use of repellants in rodent management explores the knowledge of predator odours avoidance and dietary poisoning to a large extent. According to Masol *et al*. (1994), the behavioral defense of pest against dietary poisoning and on semiochemical influences their feeding. Voznessenskaya *et al.* (2003) reported pregnancy block due to stress and failure to implant blastocysts and also reduce in litter sizes at parturition during pregnancy, when female rodents were exposed to the odour or urine of strange males or cat respectively. Voznessenskaya *et al.* (1992) reported the exposure to predator odour to cause disruption of the oestrous cycle. Voznessenskaya *et al.* (2003) reported reduced

reproductive outputs as the result of exposure to diets, specifically urine products derived from meat diets; and urine from rats housed in a crowded condition. From studies, responses showed striking similarities in terms of reproduction aspect and MacNiven *et al*. (1992), explained the magnitude of the effects to vary between species and between strains.

In Tanzania, Ngowo *et al*. (2003) evaluated two compounds i.e. thiram and cinnamamide treated in maize seeds and reported that these two compounds excel over no treated maize seeds in both laboratory against *M. natalensis* and fields against rodent pest species.

2.4 Integrated pest management

Despite significant advances in our knowledge of the biology and control of rodents in agriculture, rural and urban situations, the rodent problems continue to persist unabated with occasionally devastating effects (Mulungu *et al*., 2010; Singleton *et al*., 2010b). The integrated pest management is not a single pest control method but, rather, a series of pest management evaluations, decisions, and controls (FAO, 2010). Establishing a proper IPM requires a well arranged step-wise approach;

2.4.1 Establishment of action thresholds

Before taking any rodent pest control action (Singleton *et al*., 2005), IPM must first set an action threshold, a point where rodent pest populations or environmental conditions indicate that rodent control action must be implemented (Fishel *et al*., 2001). Sighting a single rodent in the field does not always mean implementation of the control measure (Stenseth *et al*., 2003; Brown and Singleton, 2006). The level at which rodent pests become an economic threat is very critical in determining pest control decisions.

2.4.2 Monitoring and identifying pests

Not all small mammals require control (Singleton *et al*., 2005). IPM programs work to monitor for rodent pests and identify them accurately, so that appropriate control decisions can be made in conjunction with action thresholds. The monitoring and identification process works to remove the possibility of pesticides use when they are not really needed or the use of wrong kind of pesticide.

2.4.3 Prevention

As a first line of pest control, IPM programs work to manage the environment to prevent rodent pests from becoming a threat (FAO, 2010). In an agricultural crop fields, this may mean improving field sanitation, use of trap crops, use of pitfalls or use of repellants (Nyambo, 2009). These control methods can be very effective and cost-efficient and present little or no risk to people or the environment.

2.4.4 Control

This could be taken as rodent management once monitoring, identification, and action thresholds indicate that pest control is required, and preventive methods are no longer effective or available (Marsh *et al*., 2013). IPM programs then evaluate the proper control method both for effectiveness and risk. Effective, less risky pest controls are chosen first, including highly targeted chemicals or mechanical control, such as trapping or weeding (Gacheri, 2012). If further monitoring, identifications, and action thresholds indicate that less risky controls are not working, then additional pest control methods would be employed (Pierce *et al*., 2012). Broadcast application of non-specific pesticides is a last resort.

It is apparent from literature that there are 21 rodent pest species in Tanzania (Mulungu *et al*., 2006). Much of the crop losses have been attached to *M. natalensis*. In rice crop, the rat is said to impose much of the damage during maturity stage. It is important to see how

the relationship of rice crop to any existing rodent pest during other pheological stages. The issue of rodent management especially in Tanzania is based much on rodenticide use thus requires more detailed study on the effect of damaged levels and crop growth stages at which farmers can apply control strategies.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The experiments were conducted at Hembeti village (06°16′S, 37° 31′E) from mid-October 2012 to June 2013 in farmers' fields in Mvomero district, Morogoro region, Tanzania (Fig. 2). The district has a typical tropical climate with bimodal rainfall. The long rainy season ranges from mid-February to May and the short rainy season from November to December. The remaining months of June to October are dominated by dry period. The altitude ranges from 380 to 520 meters above sea level (m.a.s.l.) with an annual rainfall of 1,500 - 2,000 mm, and the temperature ranges from 15 to 29°C. Rice is the major crop in the area and farmers produce this crop twice yearly. The first cropping calendar is in the wet season from January to June and the second one is in the dry season from July to December/January, which purely depends on irrigation. Water for irrigation originates from surrounding mountains (Nguu mountains) and flows through local canals which later open to nearby farms. Land preparation and transplanting are done in January and July for wet and dry seasons, respectively. The crop reaches physiological maturity in May and November, and farmers harvest in June and December/January for wet and dry seasons, respectively. The Booting stage is in April and October for wet and dry seasons, respectively. During the remaining months (February and March for wet season and August and September for dry season) the crop is at vegetative growth stage.
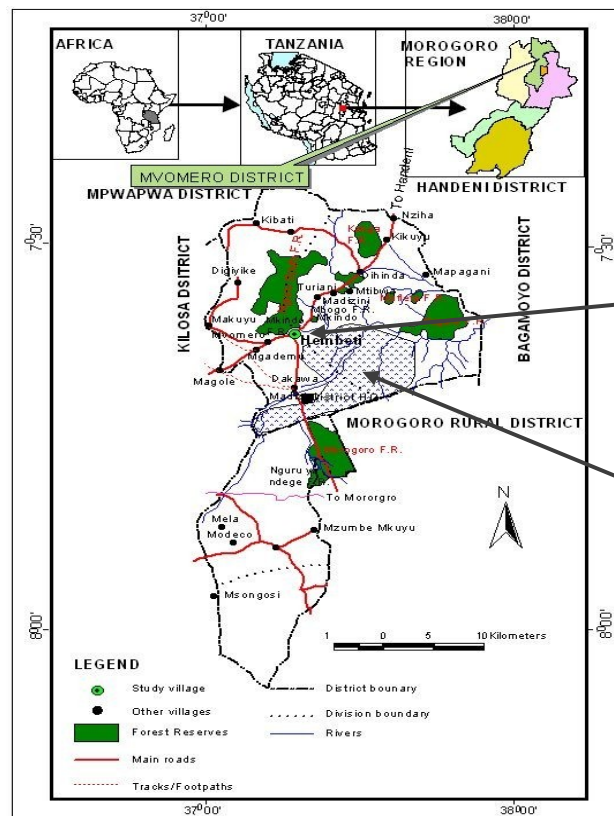
Figure 2: Map showing location of the study area: Wet and dry season crops are grown in the same area highlighted as the irrigated zone.

Source: Mulungu *et al*. (2013)

3.2 Experimental Materials

The experimental material used for both seasons (dry and wet) was rice SARO (TXD-306) variety. This variety was chosen and used because it was the dominant rice variety grown in the area (MAFS, 2009, MAFS, 2011). The variety can grow in lowland rain-fed and irrigated ecosystems and (MAFS, 2011), has high tillering ability (30 – 50 tillers/plant), high yielding potential (8 – 10 tha^{-1}and 4 - 6.5 tha^{-1} in research station and farmer's fields, respectively), and has semi aromatic property. Ngwediagi *et al*. (2009) reported the variety to mature in 120 DAS compared to 180 DAS for the local rice varieties (MAFS, 2011).

3.3 Experimental Design

Two experiments were conducted, viz; farmer's managed rice fields and simulated rodent damage experiments.

3.3.1 Farmer's managed field experiment

3.3.1.1Experimental design and layout

The experiment was conducted at farmer's rice field in Hembeti village and was laid out in split plot in Completely Randomized Design (CRD). Factor A was seasonal effect while factor B was crop growth stages. The experiment aimed at estimating crop losses and rodent population densities. Two farmers' fields of 70 x 70 m in area (approximately 0.5 ha) each were set for removal trapping. These two rice fields were at a distance of at least 100 m apart, which is above movement range of rodents (Mulungu *et al*., 2015) and hence prevents the latter from moving from one field to another. As such, each population from respective fields was independent. Each field (grid) consisted of 7 parallel lines, spaced 10 m apart and each line was marked with 7 trapping stations at a distance of 10 m apart, thus totaling 49 traps per grid. Trapping stations were identified by co-ordinates 1-7 lines (y-axis) and A-G trapping stations (x-axis) according to Sutherland (1996).

3.3.1.2 Trapping frequency and handling of captured rodent

The study was designed to cover three main rice growth stages, viz. transplanting, vegetative, and crop physiological maturity during the dry and wet seasons (Table 3) for comparison in changes of the characteristics of the rodent pest species. Forty nine snap traps and 49 Sherman LFA Live traps (H. B. Sherman traps, Tallahassee, FL, USA measuring 9.5 x 9 x 23 cm) were used in each field. The two types of traps were arranged in alternating order in each grid line. The two different types of traps were mainly used to increase trap efficacy on various small mammal species available in the area (Barnett and

Dutton, 1995; Ling-Ling, 1997).Trapping was done for three consecutive nights at each crop growth stage. Traps were baited with peanut butter mixed with maize bran (Neal, 1984), placed at appropriate stations and inspected every morning at around 0900 hrs. The captured rats were collected and identified to genus or species level, following established taxonomic nomenclature (Kingdon, 1974). Before repositioning, the traps were cleaned with dettol detergent soap to remove old baits and dropping(s), and re-baited with fresh bait. The trapped rodents were euthanized with diethyl ether and their external morphological features were examined and recorded according to Nagorsen and Peterson (1980). These involved studying the reproductive conditions of both males and females including position of testes (scrotal or abdominal) and epididymal gybernacula (externally visible or not) in males; and vagina (perforated or closed), visibly pregnant or not, and nipples size (small or swollen due to lactation) in females. Males were considered to be sexually active when externally seen to be at scrotal position and the gybernacula was visible, while sexually activeness in females was demonstrated by presence of perforated vagina and the swollen nipples due to lactation, or visible pregnancy and through perpation.

Table 3: Rodent trapping plan in rice fields for wet and dry season

| Crop growth stage | Seasons | |
	Dry	Wet
Transplanting	12 - 14 October, 2012	21 - 23 March, 2013
Vegetative	9 - 11 November, 2012	18 - 20 May, 2013
Maturity	6 - 8 January, 2013	23 - 25 June, 2013

3.3.1.3 Crop damage assessment

Crop damage assessment was conducted during the three different crop growth stages, viz: transplanting, vegetative, and maturity stages. The fields were surveyed by walking across to visualize the distribution of rodent damage. The fields were divided into three strata depending on the damage intensity, i.e. light, medium, and heavy damage based on the ratings of 0 - 25, 26 - 50 and >50% rodent damage, respectively. Within each stratum, a quadrant of 25 x 25 cm was selected randomly. The proportional contribution of each stratum in the crop field was determined by visual estimates of how much the stratum occupy relative to the total field. The sample size was determined by ensuring each category of crop damage is represented by 2 - 5 samples and a mean for crop damage from each stratum was calculated.

3.3.2   Rodent damage simulated experiment

3.3.2.1 Experimental design and layout

The experiment was set at farmer's field in Hembeti village and was organized as a split-split plot in a Randomized Complete Block Design (RCBD) with three replicates. Field of 18 x 29 m with blocks of 13.0 x 8.0 m, and within each block, a plot of 2 x 2 m with paths of 0.5 m was used. Fourteen (14) days old seedlings were planted at a distance of 20 x 20 cm spacing interval with one seedling per hill. The main plot factor considered was season (wet and dry). The sub-plot factor was growth stages (seedling, vegetative and maturity) while sub-sub plot factor was the damage levels (0, 10, 20, 25, and 50% of stems cut in a plot). Within each of the five damage level plots, three of the sub-plots were randomly assigned, one for each growth stage. Simulated rat damage was done separately at the three growth stages, i.e. transplanting, vegetative and maturity at 14, 45 and 110 days after sowing (DAS), respectively. Stems to be cut were chosen at random and each stem was cut from 3 to 5 cm above the ground surface (Appendix 1) using scissors at an oblique angle (45°) to mimic rat damage characteristic (Poche *et al.,* 1979).

3.3.2.2 Crop Management Practices in Rice Fields

Crop management in the study area followed farmer's common practices and calendar. The rice seeds were first raised in a nursery for two weeks then transplanted in the seedbed in mid-October, 2012 and March, 2013 for dry and wet seasons respectively. SARO (TXD-306) rice variety was used and planted at a distance as described in section 3.3.2.1. Weeds management involved the use of a selective post-emergency herbicide, 2, 4-D Amine (32 DAS), for the control of broad leaved weeds followed by hand weeding (40 DAS) for the remaining weeds which did not respond to the herbicide. Nitrogen fertilizer in the form of Urea at a rate of 80 kgN/ha was applied in split applications, viz; at early stage of tillering (44 DAS) and during panicle initiation (60 DAS). In order to curtail possible rat damage during the experiment, the area was kept continuously baited with chronic rodenticide (Bromadiolone) put in long bamboo poles (50 cm long x 10 cm diameter) placed at each baiting station, set at 10m from one another, and supplied with 2grams of the bait per station. Bait was replaced every 96 hours (four days).

3.4 Data Collection and Processing

3.4.1 The farmers' managed rice fields experiment

Rodents abundance, expressed as percentage trapping success or rodent abundance index [number of rodents caught divided by total number of effective trapping nights multiplied by 100] (Aplin *et al*., 2003), rodent species composition per rice growth stage (i.e. the ratio of number of a particular species to the total number of captured rodents in a particular habitat at each rice growth stage multiplied by 100), crop damage and its intensity (i.e. the ratio of tillers cut to the total number of tillers multiplied by 100 and damage intensity in each field was grouped as light and medium damages), number of rice plants per sampling point per rice growth stage (i.e. total number of plants either damaged or undamaged at transplanting, vegetative and maturity rice growth stages in a 25 * 25 cm quadrant) were recorded.

At harvest, quadrants from strata with similar damage intensity and the undamaged field portion were separately cut, tied in bundles, sun dried for one day, threshed locally with eucalyptus sticks, sun-dried again for 4 days. Moisture content was measured with a grain moisture meter (Multi Grain Moisture Tester (MT-PRO), Sparex Ltd), and the crop from each quadrant was weighed to the nearest 0.1 g and adjusted for variable moisture content using the following formula:

$Y = [(100-k)/ (100-12.5)] \times j$

where, Y = adjusted weight of sample, k = percentage moisture content of the samples as determined by moisture meter, and j = initial weight of the sample

Total observed or actual yield (Yo) was obtained by the summation of yield from quadrants and the remaining field after sampling for farmer's fields. The potential yield (Yp) was obtained by taking the actual/observed yield (Yo) multiplied with the ratio of number of undamaged stems or tillers (n) per quadrant divided by number of damaged stems/tillers (n) and the mean production value for each of the damage intensity was calculated. Yield was converted into tonnes per hectare based on each quadrant area of 0.0625 m².

3.4.2 The simulated rodent damage experiment

At harvest, the rice plants in each plot were cut and processed in each quadrants by measuring the number of panicles per plant, number of seeds per panicle, number of panicles per metre square, number of filled grains per panicle, percentage filled grains and 1000 grain weight were recorded. Numbers of panicles per plant, seeds per panicle, cut/uncut tillers were recorded at maturity before plants were harvested. Panicles from each plot were bulked, threshed and grains weight together with their moisture content recorded.

A total of 10000 seeds (N) were taken in three repeats, and socked in water-salt solution with specific gravity 1.06, followed by counting the floats i.e. unfilled grains (u) to determine the percentage filled grains (f). Filled grains were dried and 1000 grains weight was determined through counting and weighting using precision balance. Each time the grain weight was taken, the transformation to 14% moisture condition was done. Yield was converted into tonnes per hectare based on each plot area of 4 m^2.

3.5 Data analysis

3.5.1 Farmers managed rice field experiment

Data collected from this experiment were subjected to the two way analysis of variance (ANOVA) (GenStat (15th Edition); following statistical model;

$$Y_{ijk} = \mu + \beta_i + A_j + \delta_{ij} + B_k + AB_{ik} + \varepsilon_{ijk} \quad \text{.. (i)}$$

Where: Y_{ijk}= Response level, μ = General effect or general error mean, β_i = Block effect, A_j = Main plot effect, δ_{ij} = The main plot random error (Error a), B_k = Sub-plot effect, AB_{ik}= Interaction effect between the main plot and the subject, and ε_{ijk}= Sub-plot random error effect (Error c)

3.5.2   Simulated rodent damage experiment

Data were subjected to analysis of variance (ANOVA) using the split-split plot model, and the Least Significant Difference (LSD$_{0.05}$) test procedure with parameters of season, growth stage, damage level and their interactions. Analysis was carried out using GenStat (15th Edition). Two statistical models were used in the analysis as follows:

$$Y_{ijk} = \mu + \beta_i + A_j + \delta_{ij} + B_k + AB_{ik} + \varepsilon_{ijk} \quad \text{.. (ii)}$$

Where: Y_{ijk}= Response level, μ = General effect or general error mean, β_i = Block effect, A_j = Main plot effect, δ_{ij} = The main plot random error (Error a), B_k = Sub-plot effect, AB_{ik}=

Interaction effect between the main plot and the subject, and ε_{ijk}= Sub-plot random error effect (Error c) and

$$Y_{ijkm} = \mu + \beta_i + A_j + \delta_{ij} + B_k + AB_{ik} + \omega_{ijk} + C_m + AC_{jm} + BC_{km} + ABC_{jkm} + \varepsilon_{ijkm}\text{..............} \text{ (iii)}$$

Where: Y_{ijkm}= Response level, μ = General effect or general error mean, β_i = Block effect, A_j = Main plot effect, δ_{ij} = The main plot random error (Error a), B_k = Sub-plot effect, AB_{ik}= Interaction effect between the main plot and the subject, ω_{ijk} = Subject error (Error b), C_m = Sub-subplot effect, ABC_{jkm} = The three way (Factors A* B* C), and ε_{ijkm}= Sub-sub-plot random error effect (Error c) will be used to test the treatment effects on the indices calculated as described by Montgomery (2004).

The first (ii) and second (iii) models were used to conduct Analysis of Variance (ANOVA) for split plot and Split-split plot arrangements, respectively.

CHAPTER FOUR

4.0 RESULT

4.1 Farmers' managed rice field experiment

4.1.1 Species composition

During the study period, a total of 166 rodent individuals were captured in the study area making 18.8% trap success in 882 trap nights. Rodent species in the study area comprised of *M. natalensis* (Appendix 2) and *Grammomys dolichurus*. Of these, *M. natalensis* was most dominant (>96.97%) in both seasons and all growth stages (Table 3). More individuals were trapped during transplanting than in other crop growth stages (Table 3).

Table 4: Rodent species composition per rice growth stages

Growth stages	Species	Number of rodents	Percentage contribution
1. Transplanting	*Mastomys natalensis*	95	100
Total		95	100
2. Vegetative	*Mastomys natalensis*	38	100
Total		38	100
3. Maturity	*Mastomys natalensis*	32	96.97
	Grammomys dolichurus	1	3.03
Total		33	100
Grand total		166	100

4.1.2 Rodent abundance

There was no significant difference in terms of rodent abundance between season (F= 0.00, df = 1, 4, p = 0.95), crop growth stages (F = 1.53, df = 2, 4; p = 0.32) and interaction of season and crop growth stages (F = 0.17; df = 2, 4; p = 0.85). At transplanting stage, rodent population abundance was relatively higher than at vegetative and maturity stages across the seasons (Fig. 3). Similarly, relatively higher rodent population abundance was observed in dry than in wet season (Fig. 3).
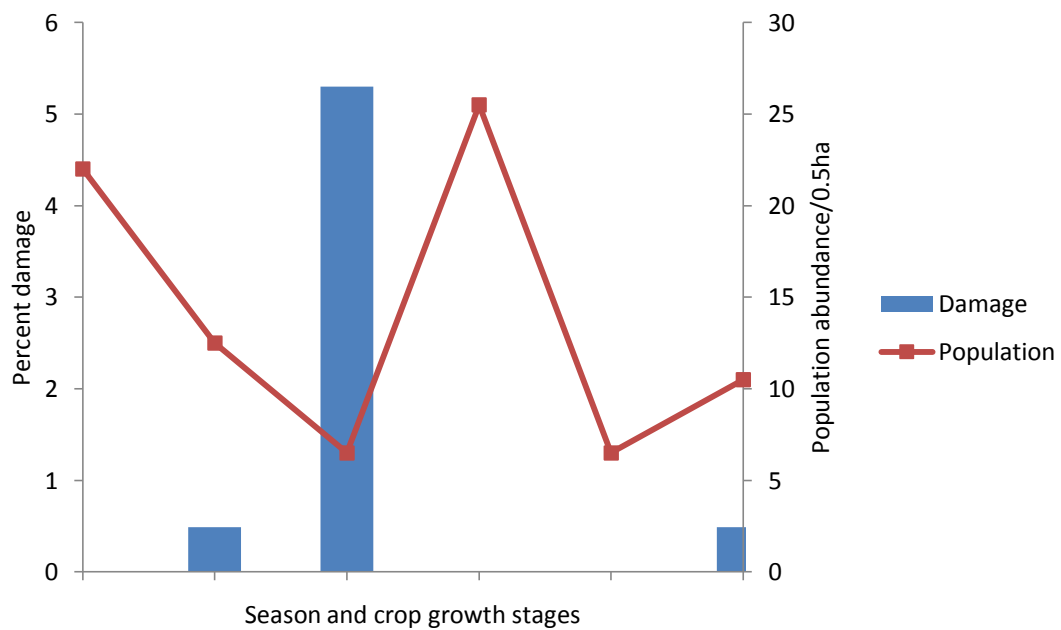
Figure 3: Relationship between percentage damage, rodent population abundance, seasons and crop growth stages

4.1.3 Effect of rodent abundance on crop losses (i.e. damage and yield losses)

4.1.3.1 Crop damage

Highly significant differences between seasons (F = 87.14, df = 1, 4, p = 0.001), crop growth stages (F = 94.42, df = 2, 4, p = 0.000), and interaction (F = 68.83, df = 2, 4, p = 0.001) were observed on rodent crop damage. The damage was significantly higher in dry (12.07%) than in wet seasons (0.85%). High rodent damage was recorded at maturity crop

growth stage (18.10%) as compared to vegetative (1.28%) and transplanting (0.00%) crop growth stages despite the high rodent population in the last two crop growth stages. In terms of interaction, the interaction between dry season and maturity crop growth stage had the highest rodent damage than other interactions (Fig. 4). Similarly, the interaction between dry season and vegetative crop growth stage and interaction between wet season and maturity crop growth stage produced the same rodent damage value but both had higher rodent damage than the interaction between dry season and transplanting, wet season and transplanting, and wet season and vegetative crop growth stage (Fig. 4).
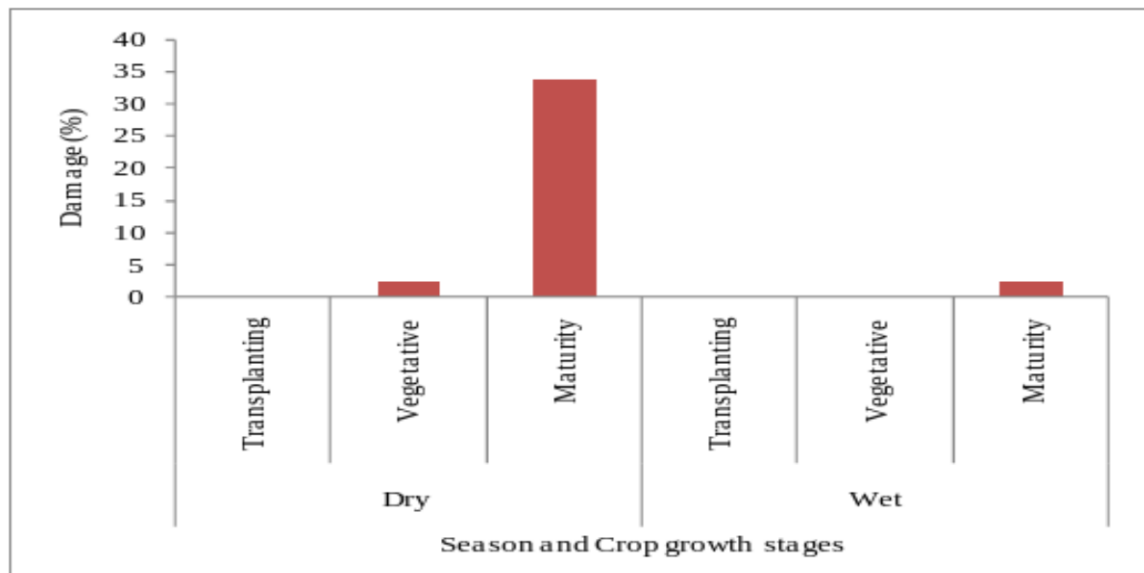
Figure 4: Interaction between season and crop growth stages

4.1.3.2 Yield loss

There was no significant difference (F = 15.63; df = 1, 1; p = 0.16) between seasons in terms of yield losses. However, there was relatively higher yield loss during dry (5.02%) than during wet seasons (0.75%).

4.1.3.3 Relationship between rodent population abundance and crop damage

In this study, rodent population abundance followed a decreasing trend towards maturity when higher rodent damage was observed (Fig. 3). During the transplanting crop growth stage of rice in both dry and wet seasons, there was higher rodent population abundance than during other crop growth stages where no rodent damage was observed (Fig. 3). Between seasons, the vegetative crop growth stage of the dry season had higher rodent damage than the transplanting crop growth stage in both seasons.

Rodent damage recorded during vegetative and maturity rice growth stage in dry season ranged from 2.5% to 33.7% as compared to 2.5% recorded at during maturity growth stage in the wet season. The recorded rodent damage at maturity growth stage corresponds to losses equivalent to 5.02% and 0.75% in dry and wet seasons respectively. Extrapolation of grain yield loss from the actual grain yield (Yp) gives grain yield loss of 0.18 tha^{-1} and 0.04 tha^{-1} for dry and wet seasons respectively. Based on average yield, Tanzania could lose between 50 – 80 kgha^{-1} in dry season and 1 – 10 kgha^{-1} in wet season.

4.2 The simulation experiment

4.2.1 Effect of season, rice growth stage, damage levels and their interaction

4.2.1.1 Grain yield

Season, growth stage and damage levels showed significant differences for each factor on mean yield (Table 5). Average yield for the wet season was higher than dry season (wet season = 2.98 t/ha vs. dry season = 2.29 t/ha, LSD$_{0.05}$ = 0.07, p < 0.001). Mean yield at transplanting (2.83 t/ha), vegetative (2.58 t/ha) and maturity (2.49 t/ha) growth stages were also highly significant different (LSD$_{0.05}$ = 0.08, p< 0.001) with transplanting stage ranking first with higher yields. The average yield at damage levels was 3.08, 3.11, 2.51, 2.38 and 2.09t/ha for 0, 10, 20, 25, and 50%, respectively (LSD$_{0.05}$ = 0.10, p< 0.001). Damage at 10% stem cut yielded higher than other damage levels. Interactive effects

between season and damage level (Table 6) and growth stage and damage level (Table 7) were also observed. No other interactive effects among parameters were noted. Observed differences by season, growth stage and damage level were statistically confirmed by LSD tests performed after the multifactor ANOVA (Table 8).

Table 5: Multi-factor ANOVA on rice crop yield (t/ha) showing significant effects of season, growth stage and damage level on average yield

Source	DF	Sum of squares	Mean squares	F
Rep stratum	2	0.29110	0.14555	5.93
Residual	58	1.42310	0.02454	
Total	89	9.98332		
Season	1	2.51351	2.51351	10.00^{***}
Growth stage	2	2.36746	1.18373	48.24^{***}
Damage levels	4	10.27010	2.56752	104.64^{***}
Season * Growth stage	2	0.04946	0.02473	1.01^{NS}
Season * Damage levels	4	1.75310	0.43827	17.86^{***}
Growth stage * Damage levels	8	1.04821	0.13103	5.34^{***}
Season * Growth stage * Damage levels	8	0.26729	0.03341	1.36^{NS}

Note: * = interaction, *= P ≤ 0.05, ** = P ≤ 0.01, *** = P ≤ 0.001, ^{NS} = Not significant different at P < 0.05

Table 6: Interactive effects between season (dry or wet) and damage level on rice yield (t/ha)

Interaction (season & damage level)	Mean yield t/ha
Dry * 0	2.21 b
Dry * 10	2.69 d
Dry * 20	2.25 b
Dry * 25	2.14 b
Dry * 50	1.87 a
Wet * 0	3.46 e
Wet * 10	3.54 e
Wet * 20	2.80 d
Wet * 25	2.67 d
Wet * 50	2.42 c

Note: * = interaction

Season = Dry (Irrigated rice), Wet (Rain-fed rice)

0 – 50% = Damage levels (stem cuts at different levels)

Mean separation was done using LSD and means followed by the same letter are

not significantly different from each other

Table 7: Interactive effects between rice growth stages in both (dry and wet) season and damage level on rice yield (t/ha)

Interaction (growth stages & damage level)	Mean yield t/ha
Transplanting * 0	2.79 de
Transplanting * 10	3.40 g
Transplanting * 20	2.87 e
Transplanting * 25	2.68 d
Transplanting * 50	2.39 c
Vegetative * 0	2.82 de
Vegetative * 10	3.06 f
Vegetative * 20	2.44 c
Vegetative * 25	2.26 bc
Vegetative * 50	2.12 b
Maturity * 0	2.89 ef
Maturity * 10	2.87 e
Maturity * 20	2.27 bc
Maturity * 25	2.27 bc
Maturity * 50	1.91 a

Note: * = interaction

Growth stages = Transplanting, Vegetative and Maturity

0 – 50% = Damage levels (stem cuts at different levels)

Mean separation was done using LSD and means followed by the same letter are not significantly different from each other

Table 8: Effect on average rice crop yield (t/ha) through simulated rodent damage when different percentages of rice tillers have been cut at different crop growth stages in different seasons (dry or wet)

Interaction	Mean yield t/ha	Interaction	Mean yield t/ha
Dry * Transplanting * 0	2.20 def	Wet * Transplanting * 0	3.37 mno
Dry * Transplanting * 10	2.90 kl	Wet * Transplanting * 10	3.90 p
Dry * Transplanting * 20	2.60 hij	Wet * Transplanting * 20	3.14 lm
Dry * Transplanting * 25	2.53 hi	Wet * Transplanting * 25	2.82 jk
Dry * Transplanting * 50	2.08 cde	Wet * Transplanting * 50	2.71 ijk
Dry * Vegetative * 0	2.16 de	Wet * Vegetative * 0	3.48 no
Dry * Vegetative * 10	2.67 hijk	Wet * Vegetative * 10	3.45 no
Dry * Vegetative * 20	2.17 de	Wet * Vegetative * 20	2.71 ijk
Dry * Vegetative * 25	1.87 abc	Wet * Vegetative * 25	2.66 hijk
Dry * Vegetative * 50	1.80 ab	Wet * Vegetative * 50	2.44 fgh
Dry * Maturity * 0	2.25 efg	Wet * Maturity * 0	3.53 o
Dry * Maturity * 10	2.49 ghi	Wet * Maturity * 10	3.25 mn
Dry * Maturity * 20	1.97 bcd	Wet * Maturity * 20	2.56 hi
Dry * Maturity * 25	2.02 bcde	Wet * Maturity * 25	2.53 hi
Dry * Maturity * 50	1.72 a	Wet * Maturity * 50	2.11 cde

Note: * = interaction

Mean separation was done using LSD andmeans followed by the same letter are not significantly different from each other (ANOVA with $LSD_{0.05}$, $P < 0.05$).

4.2.1.2 Interaction between rice crop growth stages and stem tillers cut levels

Interaction between crop growth stages, stem tillers cut levels and seasons was observed on mean percent yield loss (Fig. 5). The interaction between crop maturity and stem tillers cut (Appendix 1a - d) in both seasons has higher effect to yield losses compared to interaction between transplanting and stem cut levels in both seasons (Fig. 5).
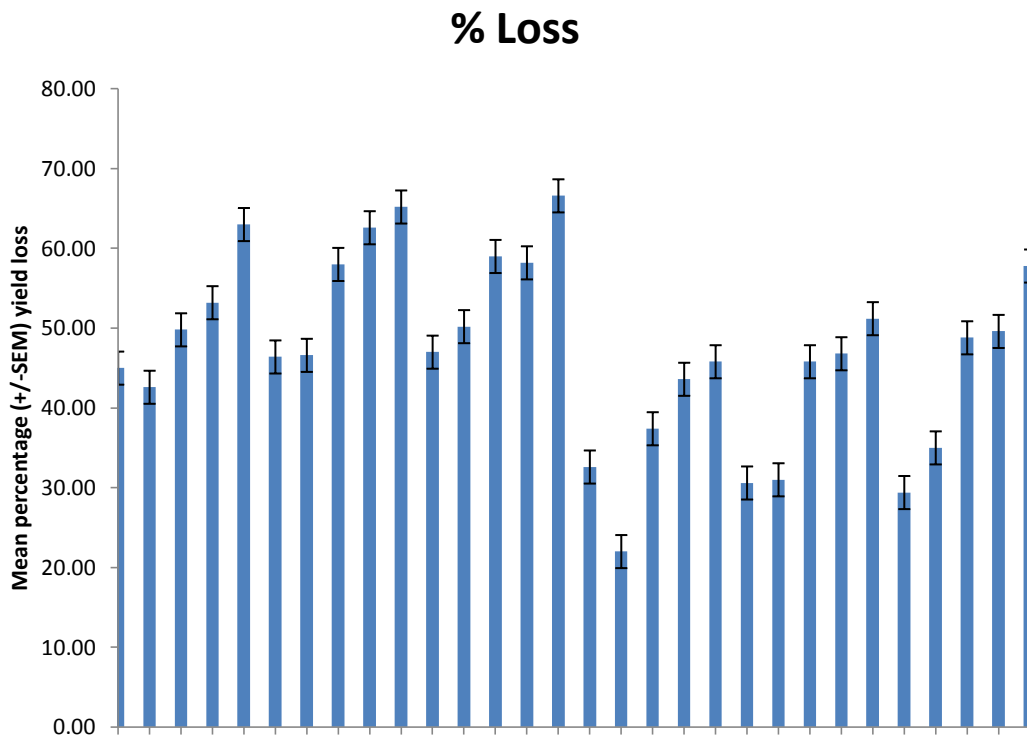
% Loss

Figure 5: Yield loss observed due to simulated rodent damage by cutting rice tillers at different percentages of each crop area at three different growth stages over two cropping seasons.

From these results, the compensatory ability of rice to re-grow new tillers is most apparent at the transplanting stage in the wet season where all percentage damage levels have approximately the same effect on yield loss. Percentage loss is observed to be generally higher in the dry season, at the maturity stage and among the higher rates of damage, particularly at 25% (Appendix 1c) and 50% (Appendix 1d).

4.2.1.3 Yield components

The effect of season, growth stage, damage level and their interaction showed significant difference for each factor on number of panicles per plant, number of seeds per panicle, number of panicles per m^2, number of filled grains per panicle, percentage filled grains and 1000 grain weight (Table 9).

4.2.1.3.1 Number of panicles per plant

Higher average number of panicles per m^2 for the wet season than the dry season was recorded (wet season = 25.78 vs dry season = 21.11; $LSD_{0.05}$ = 0.47, p < 0.001). There were significant difference in mean number of panicles per plant at transplanting (24.50), vegetative (23.40) and maturity (22.43) growth stages ($LSD_{0.05}$ = 0.58, p < 0.001). Of all the three crop growth stage, transplanting produced higher average number of panicles per plant than vegetative and maturity. The average number of panicles per plant at damage level was 23.78, 23.44, 23.31, 22.94 and 22.44 for damage levels of 0, 10, 20, 25, and 50%, respectively ($LSD_{0.05}$ = 0.75, p < 0.001). When comparing the difference in mean number of panicles per plant between damage levels, control treatment over performed twenty five and fifty percent damage levels. Interactive effects between season and damage level (Table 10), season and growth stage (Table 11) and growth stage and damage level (Table 12) were also observed. No other interactive effects among parameters recorded were noted. The effects of the interactions among season, growth stage and damage level were also observed (Table 13).

Table 9: Multi-factor ANOVA on rice yield components showing significant effects of season, growth stage and damage level on average yield components

Source	DF	Mean squares					
		Number of plants per m^2	Number of panicles per plant	Number of spikelets per panicle	Number of filled grains per panicle	Percentage grain fill	1000 grain weight (g)
Rep stratum	2	2750.1	0.08	112.9	75.48	37.36	0.7590
Residual	58	402.4	1.25	104.0	44.13	24.12	0.1660
Total	89						
Season	1	120853.40***	490.00***	9351.60***	122.50^{NS}	1652.54***	24.52***
Growth stage	2	3912.80***	32.08***	1337.50***	400.31***	26.65^{NS}	3.10***
Damage levels	4	4446.50***	12.25***	1194.50***	3384.93***	216.79***	93.62***
Season*Growth stage	2	7448.00***	4.90*	1.50^{NS}	110.80^{NS}	16.96^{NS}	7.19***
Season*Damage levels	4	1115.10*	8.14***	461.80**	122.92*	95.87*	1.49***
Growth stage*Damage levels	8	1635.00***	5.84***	224.70*	96.48*	41.31^{NS}	1.85***
Season*Growth stage*Damage levels	8	3339.60***	4.91***	58.70^{NS}	99.72*	28.66^{NS}	1.09***

Note: * = interaction, * = $P \leq 0.05$, ** = $P \leq 0.01$, *** = $P \leq 0.001$, ^{NS} = $P < 0.05$, NS = Not significant at $P < 0.05$

Table 10: Interactive effect between growth stages and stem cut levels on rice yield components for both dry and wet season

Growth stage * stem cut (%)	Number of panicles per plant	Number of panicles per m^2	Number of filled grains per panicle	Number of seeds per panicle	Grain fill (%)	1000grains weight (g)
Transplanting * 0%	23.33 bcd	574.30 ab	194.50 f	228.30 g	85.29 efg	25.93 ijk
Transplanting * 10%	25.67 e	612.30 d	190.00 f	227.50 g	84.46 d,e,f,g	27.29 m
Transplanting * 20%	23.50 cd	622.50 d	171.20 cd	214.70 cdef	80.01 abcde	24.50 gh
Transplanting * 25%	23.50 cd	606.50 cd	170.00 cd	224.00 efg	76.14 a	22.14 d.e
Transplanting * 50%	24.00 d	564.70 ab	167.20 bcd	221.80 efg	75.56 a	21.27 bc
Vegetative * 0%	24.33 d	574.50 ab	195.50 f	228.30 g	85.73 fg	25.85 ij
Vegetative * 10%	23.50 cd	605.5 cd	180.00 e	218.50 defg	82.90 cdefg	26.70 lm
Vegetative *20%	24.33 d	559.00 a	166.70 abcd	213.20 cdef	78.54 abc	24.22 g
Vegetative * 25%	22.67 bc	570.50 ab	161.00 ab	206.20 abc	78.41 abc	22.82 ef
Vegetative * 50%	22.17 ab	574.2 ab	165.00 abc	194.50 a	85.28 efg	20.61 ab
Maturity * 0%	23.67 cd	570.30 ab	196.80 f	224.70 fg	87.72 g	28.84 no
Maturity * 10%	21.17 a	604.80 cd	174.00 de	212.70 cde	82.33 bcdefg	26.10 jkl
Maturity * 20%	26.00 e	559.00 a	161.00 ab	212.30 cde	76.71 ab	24.59 gh
Maturity * 25%	22.67 bc	583.70 bc	166.30 abcd	209.30 bcd	79.38 abcd	22.42 de
Maturity * 50%	21.17 a	561.50 ab	159.00 a	198.50 ab	80.67 abcdef	20.18 a
Grand mean	23.44	582.90	174.54	215.60	81.28	25.61
CV (%)	4.80	3.40	3.80	4.70	6.00	1.80
SEM	0.46	8.19	2.71	4.13	2.01	0.19
LSD	1.29	23.18	7.68	11.70	5.68	0.53

Note: * = interaction, Growth stages = Transplanting, Vegetative and Maturity, 0 – 50% = Damage levels (stem cuts at different levels), Numbers in columns followed by same letter(s) are not significant different at P < 0.05 according to Fisher's unprotected LSD test.

Table 11: Interactive effect between season (dry or wet) and growth stage on rice yield components

Season * Growth stage	Number of panicles per plant	Number of panicles per m^2	Number of filled grains per panicle	Number of seeds per panicle	Grain fill (%)	1000grains weight (g)
Dry * Transplanting	22.40 b	577.60 b	175.70 b	233.20 d	75.41 a	24.23 b
Dry * Vegetative	20.60 a	530.30 a	172.10 ab	222.50 c	77.64 a	24.04 ab
Dry * Maturity	20.33 a	530.80 a	172.30 ab	222.00 c	77.92 a	23.83 a
Wet * Transplanting	26.60 d	614.50 c	181.50 c	213.30 b	85.17 b	28.48 e
Wet * Vegetative	26.20 d	623.10 c	175.10 ab	201.80 a	86.71 b	26.91 d
Wet * Maturity	24.53 c	620.90 c	170.50 a	201.00 a	84.80 b	26.18 c
Grand mean	23.44	582.9	174.54	215.60	81.28	25.61
CV (%)	4.80	3.40	3.80	4.70	6.00	1.80
SEM	0.29	5.18	1.72	2.61	1.27	0.12
LSD	0.82	14.66	4.86	7.40	3.59	0.33

Note: * = interaction, Season = Dry (Irrigated rice), Wet (Rain-fed rice), 0 – 50% = Damage levels (stem cuts at different levels), Numbers in columns

followed by same letter(s) are not significant different at P ≤0.05 according to Fisher's unprotected LSD test.

Table 12: **Interactive effect between season and stem cut levels on rice yield components**

Season * stem cut (%)	Number of panicles per plant	Number of panicles per m^2	Number of filled grains per panicle	Number of seeds per panicle	Grain fill (%)	1000grains weight (g)
Dry * 0%	21.33 ab	543.20 b	191.80 d	232.70 de	82.44 b	25.87 e
Dry * 10%	20.56 a	564.10 c	177.70 b	236.70 e	75.12 a	26.69 f
Dry * 20%	21.78 b	545.30 bc	166.70 a	226.00 cd	73.96 a	24.43 d
Dry * 25%	20.67 a	558.00 bc	168.00 a	223.90 cd	75.16 a	22.46 b
Dry * 50%	21.22 ab	520.60 a	162.80 a	210.20 b	78.27 ab	20.69 a
Wet * 0%	26.22 de	602.90 d	199.40 e	221.60 c	90.05 c	28.75 h
Wet * 10%	26.33 e	651.00 e	185.00 c	202.40 ab	91.35 c	29.29 i
Wet * 20%	27.44 f	615.00 d	165.90 a	200.80 ab	82.88 b	27.43 g
Wet * 25%	25.22 d	615.8 d	163.6 a	202.4 ab	82.73 b	26.57 f
Wet * 50%	23.67 c	613.00 d	164.70 a	199.70 a	80.79 b	23.92 c
Grand mean	23.44	582.90	174.54	215.60	81.28	25.61
CV (%)	4.80	3.40	3.80	4.70	6.00	1.8
SEM	0.37	6.69	2.21	3.37	1.64	0.15
LSD	1.06	18.93	6.27	9.55	4.63	0.43

Note: * = interaction, Season = Dry (Irrigated rice) Wet (Rain-fed rice), 0 – 50% = Damage levels (stem cuts at different levels), Numbers in columns followed by same letter(s) are not significant different at $P < 0.05$ according to Fisher's unprotected LSD test

Table 13: Interactive effect between seasons (dry or wet), crop growth stages and stem cut levels on rice yield components

Season * Growth stage * stem cut (%)	Number of panicles per plant	Number of panicles per m^2	Number of filled grains per panicle	Number of seeds per panicle	Grain fill (%)	1000grains weight (g)
Dry *Transplanting *0%	20.67 bcd	548.70 cde	193.30 jkl	233.70 gh	82.75 defgh	25.93 ijk
Dry *Transplanting *10%	23.00 efg	572.00 efg	183.70 ij	247.70 h	74.23 abc	27.29 m
Dry *Transplanting *20%	23.33 fg	602.70 ghij	170.00 cdefg	222.30 efg	76.61 abcde	24.50 gh
Dry *Transplanting *25%	23.00 efg	642.00 k	164.70 abcde	233.70 gh	70.48 a	22.14 de
Dry *Transplanting *50%	22.00def	522.70 abcd	166.70 bcdefg	228.70 fg	72.99 a	21.27 bc
Dry *Vegetative *0%	21.33 cde	541.30 bcde	191.70 jk	235.00 gh	81.57 cdefg	25.85 ij
Dry *Vegetative *10%	20.67 bcd	565.30 ef	177.00 fghi	234.00 gh	75.64 abcd	26.70 lm
Dry *Vegetative *20%	21.33 cde	522.00 abc	166.30 bcdef	227.00 fg	73.29 ab	24.22 g
Dry *Vegetative *25%	19.00 ab	507.00 a	162.00 abcd	219.30 cdefg	73.88 abc	22.82 ef
Dry *Vegetative *50%	20.67bcd	516.00 abc	163.70 abcd	197.00 a	83.81 efgh	20.61 ab
Dry *Maturity *0%	22.00 def	539.700 abcde	190.30 jk	229.30 fg	83.01 defgh	25.84 ij
Dry *Maturity *10%	18.00 a	555.00 de	172.30 defgh	228.30 fg	75.49 abcd	26.10 jkl
Dry *Maturity *20%	20.67 bcd	511.30 ab	163.70 abcd	228.70 fg	71.98 a	24.59 gh
Dry *Maturity *25%	20.00 bc	525.00 abcd	177.30 ghi	218.70 cdefg	81.12 bcdef	22.42 de
Dry *Maturity *50%	21.00 cd	523.0 abcd	158.0 ab	205.0 abcd	78.02 abcde	20.18 a
Wet *Transplanting *0%	26.00 ijk	600.0 ghi	195.7 kl	223.0 efg	87.84 fghi	28.72 no
Wet *Transplanting *10%	28.33 l	652.7 k	196.3 kl	207.3 abcde	94.69 i	30.45 p
Wet *Transplanting *20%	28.67 l	642.3 k	172.3 defgh	207.0 abcde	83.41 defgh	28.36 n
Wet *Transplanting *25%	24.00 gh	571.0 efg	175.3 efghi	214.3 bcdef	81.80 cdefg	28.23 n
Wet *Transplanting *50%	26.00 ijk	606.7 hij	167.7 bcdefg	215.0 bcdef	78.14 abcde	26.62 klm
Wet *Vegetative *0%	27.33 kl	607.7 hij	199.3 kl	221.7 efg	89.89 hi	28.69 no
Wet *Vegetative *10%	26.33 jk	645.7 k	183.0 hij	203.0 abc	90.17 hi	29.15 o
Wet *Vegetative *20%	27.33 kl	596.0 fgh	167.0 bcdefg	199.3 ab	83.79 efgh	27.30 m
Wet *Vegetative *25%	26.33 jk	634.0 jk	160.0 abc	193.0 a	82.94 defgh	26.23 jkl
Wet *Vegetative *50%	23.67 fgh	632.3 ijk	166.3 bcdef	192.0 a	86.74 fghi	23.18 f
Wet *Maturity *0%	25.33 hij	601.0 ghi	203.3 l	220.0 defg	92.42 i	28.84 no
Wet *Maturity *10%	24.33 ghi	654.7 k	175.7 fghi	197.0 a	89.18 ghi	28.26 n

Table 13 cont…..						
Wet *Maturity *20%	26.33 jk	606.7 hij	158.3 ab	196.0 a	81.45 cdefg	26.62 klm
Wet *Maturity *25%	25.33 hij	642.3 k	155.3 a	200.0 ab	77.63 abcde	25.24 hi
Wet *Maturity *50%	21.33 cde	600.0 ghi	160.0 abc	192.0 a	83.32 defgh	21.96cd
Grand mean	23.44	582.9	174.54	215.6	81.28	25.61
CV (%)	4.8	3.4	3.80	4.7	6.0	1.8
SEM	0.646	11.58	3.84	5.85	2.835	0.2634
LSD	1.827	32.78	10.86	16.55	8.027	0.7456

Note: * = interaction

Season = Dry (Irrigated rice), Wet (Rain-fed rice)

0 – 50% = Damage levels (stem cuts at different levels)

Numbers in columns followed by same letter(s) are not significant different at P ≤0.05 according to Fisher's unprotected LSD test.

4.2.1.3.2 Number of spikelet per panicle

The average number of spikelet per panicles for the dry season was higher than those recorded during wet season (dry season = 225.90 vs. wet season = 205.40; $LSD_{0.05}$ = 4.27 p < 0.001). For the three growth stages, the mean number of spikelet per panicle at transplanting (223.30), vegetative (212.10) and maturity (211.50) growth stages were highly significant different ($LSD_{0.05}$ = 5.23, p < 0.001) with transplanting ranking the first with higher mean number of spikelets per panicle. The average number of spikelets per panicle at damage levels was 227.10, 219.60, 213.40, 213.20 and 204.90 for damage levels of 0, 10, 20, 25, and 50%, respectively ($LSD_{0.05}$ = 6.76, p < 0.001). Damage level of 0% produced higher average number of spikelets per panicle than damage levels 20, 25 and 50%. Interaction effects between season and damage level (Table 10), season and growth stage (Table 11) and growth stage and damage level (Table 12) on number of spikelets per panicle was also observed. No other interactive effects among parameters were noted (Table 13).

4.2.1.3.3 Number of panicles per metre square

Average number of panicles m^{-2} for wet season was higher than for the dry seasons (wet season = 619.5 vs dry season = 546.20, $LSD_{0.05}$ = 8.46, p < 0.001). For, growth stages, the mean number of panicles per plant at transplanting (596.10), vegetative (576.70) and maturity (575.90) growth stages were highly significant different ($LSD_{0.05}$ = 10.37, p < 0.001) with transplanting ranking the first. The average number of panicles per m^2 at different damage level was 573.10, 607.60, 580.20, 586.90 and 566.80 for damage levels of 0, 10, 20, 25, and 50%, respectively ($LSD_{0.05}$ = 13.38, p < 0.001). 10% damage produced more tillers than other damage levels indicating that removing tillers increases spaces between and within the plant as the result the plant translocate its resources and produces more tillers to counteract the damage. . Significant interactive effects between

season and damage level (Table 10), season and growth stage (Table 11) and growth stage and damage level (Table 12) on number of panicles per m^2 were also observed (Table 13).

4.2.1.3.4 Number of filled grains per panicle

No significant difference on the average number of filled grains per panicle for wet and dry season (wet season 175.71 vs dry season 173.38, $LSD_{0.05}$ = 2.80, p > 0.05) was observed. However, on growth stages, the mean number filled grains per panicles at transplanting (178.57), vegetative (173.63) and maturity (171.43) growth stages were highly significant different ($LSD_{0.05}$ = 3.43, p < 0.001) and was higher at transplanting. The average number of filled grains per panicle at damage level was 195.61, 181.33, 166.28, 165.78 and 163.72 for damage levels of 0, 10, 20, 25, and 50%, respectively ($LSD_{0.05}$ = 4.43, p < 0.001). Zero percent damage had more grain filling percentage than other treatments. The 10% damage ranked the second after zero percent damage but there were no significant difference in higher (20, 25 and 50%) damage levels. The interactive effects between season and damage level (Table 10), season and growth stage (Table 11) and growth stage and damage level (Table 12) on the number filled grains per panicles were also observed (Table 13).

4.2.1.3.5 Percentage grain fill

The average percentage grain fill for the wet season was higher than that of the dry season (wet season = 85.56 vs dry season = 76.99, $LSD_{0.05}$ = 2.07, p < 0.001). There were no significant difference ($LSD_{0.05}$ = 2.54, p > 0.05) between mean percentage grain fill for transplanting (80.29), vegetative (82.17) and maturity (81.36) growth stages. The average percentage grain fill at damage level was 86.25, 83.23, 78.42, 77.98, and 80.50 for damage levels of 0, 10, 20, 25, and 50%, respectively ($LSD_{0.05}$ = 3.28, p < 0.001). Higher average percentage grain fill was observed at zero percent damage level. The significant

interactive effects between season and damage level (Table 10), season and growth stage (Table 11) and growth stage and damage level (Table 12) on the percentage grain filling were also observed. No other interactive effects among parameters were noted (Table 13).

4.2.1.3.6 1000 grain weight

The average grain weight for 1000 grains for the wet season was higher than that of the dry season (wet season = 27.19 g vs. dry season = 24.03 g, $LSD_{0.05}$ =0.19, $p < 0.001$). For the three growth stages, the mean percentage of 1000 grains weight at transplanting (26.35 g), vegetative (25.47 g) and maturity (25.01 g) growth stages were also highly significant different from each other ($LSD_{0.05}$ =0.24, $p < 0.001$). The average 1000 grain weight at damage different level was 27.31, 27.99, 25.93, 24.51 and 22.30 for damage levels of 0, 10, 20, 25, and 50%, respectively ($LSD_{0.05}$ = 0.30, $p < 0.001$). Significant interactive effects between season and damage level (Table 10), season and growth stage (Table 11) and growth stage and damage level (Table 12) on 1000 grain weight were also observed ANOVA (Table 13).

4.2.2 Partial correlation between yield and yield components

Grain yield in rice is a complex attribute and is the eventual expression of its individual components. Table 14 presents the partial correlation coefficients between rice yield and yield components. The highly significant ($P < 0.001$) and positive partial correlation ($r = 0.91$) was observed between grain yield and thousand grain weight followed by number of filled grain per panicle, number of panicle per plant, number of panicle per m^2 and percentage grain fill (Table 14). There were no significant ($P < 0.05$) partial correlation ($r = 0.00$) observed between grain yield and number of spikelet per panicle (Table 14).

The 1000 grain weight was highly significant ($P < 0.001$) and positively partially correlated with number of panicle per plant ($r = 0.63$), number of spikelet per panicle per panicle ($r = 0.58$), number of filled grain and percentage grain fill ($r = 0.47$) (Table

14).There were no significant (P < 0.05) partial correlation (r = 0.50) between1000 grain weight and number of panicle per metre square (Table 14).

Percentage grain fill produced significant (P < 0.001) and positive partial correlation with number of panicle per plant (r = 0.49), number of panicle per metre square (r = 0.39) and number of filled grain per panicle (r = 0.58) (Table 14). It was only number of spikelet per panicle that showed significant (P < 0.001) negative partial correlation (r = -0.55) with percentage grain filling (Table 14).

Number of filled grain per panicle had significant (P < 0.001) positive partial correlation with only number of spikelet per panicle (r = 0.35) (Table 14). Conversely, no significant (P > 0.05) positive partial correlation between number of filled grain per panicle, and number of panicle per plant (r = 0.21) and number of panicle per metre square (r = 0.08) were recorded (Table 14).

Number of spikelet per panicle displayed highly significant (P < 0.001) negative partial correlation with number of panicle per plant (-0.35) and number of panicle per metre square (-0.36) (Table 14).

Number of panicle per m^2 displayed highly significant (P < 0.001) positive partial correlation with number of panicle per plant (0.71) (Table 14).

Table 14: Partial correlation coefficients among yield and yield components

Character	Np/pl	Np/m^2	Nsp/p	Nfg/p	%gf	1000gw (g/plot)	Gy (t/ha)
Np/pl	-						
Np/m^2	0.71***						
Nsp/p	-0.35***	-0.36***					
Nfg/p	0.21^{ns}	0.08^{ns}	0.35***				
%gf	0.49***	0.39***	-0.55***	0.58***			
1000gw (g/plot)	0.63***	0.50***	0.05^{ns}	0.58***	0.47***		
Gy (t/ha)	0.68***	0.67***	0.00^{ns}	0.72***	0.64***	0.91***	-

*** = Highly significant ($P < 0.001$), ^{ns} = Not significant ($P < 0.05$), Np/m^2 = Number of panicles per metre square, Np/pl = Number of panicles per plant, Nsp/p = Number of spikelets per panicle, Nfg/p = Number of filled grains per panicle, %gf = Percentage grain fill, 1000gw = 1000 grain weight, grain yield (t/ha)

CHAPTER FIVE

5.0 DISCUSSION

The current observation of high abundance of *M. natalansis* in the study area is consistent with those reported by Vibe-petersen *et al*. (2006) and Sluydts *et al*. (2009) in maize farms, Makundi *et al*. (2009) and Massawe *et al*. (2011) in fallow fields and by Sheyo (2010) and Mulungu *et al*. (2013) in irrigated rice fields.The presence of *M. natalensis* (Appendix 2) in such high population abundances in this area is probably associated with availability of food, habitat and/or reproduction potential of the species. According to Makundi *et al*. (2007), the species is a pioneer in colonizing disturbed habitats (e.g. by agriculture). Likewise, Odhiambo *et al*. (2005) and Mulungu *et al*. (2011) reported that the species feeds in almost all types of food in the environment but predominantly prefers seeds/grains. Leirs *et al*. (1997) incriminated *M. natalensis* to be an opportunistic rodent species and named it characteristically to conform with *r*-selected strategy when conditions are favorable.

Rodent populations usually fluctuate from time to time (Aplin *et al*., 2003). It has been reported that the fluctuations can be accelerated by factors like food availability and/or other environmental factors such as water flooding or vegetation cover (Douangboupha *et al*., 2009; Mulungu *et al*., 2015b). In this study, however, high population was observed at transplanting although it was not statistically significant with other crop growth stages. This is contrary with previous observations by Mulungu *et al*. (2013) who reported that high population was recorded during the dry season at transplanting and vegetative crop growth stages. The discrepancy of these two observations in the same area may be due to a change of planting calendar. Mulungu *et al*. (2013) reported that farmers start land preparation and transplanting in July and January for dry and wet seasons, respectively

whereas in the current study planting and land preparation starts in September and February for dry and wet seasons, respectively. The second reason is that in the current study, difference in crop growth stages (i.e. transplanting in dry season and maturity in wet season) were very close (only one month difference) and may have account for no rodent population differences.

Generally, in this study the rodent population decreases with an increase in crop growing stages. The present observation concurs with Meheretu *et al*. (2014) in wheat crop who reported that when wheat was at maturity stage, rodent abundance was low. One could expect an increase of population as the crop grows due to availability of shelter and cover. Quick (1990) reported that an increase in rice damage towards maturity was associated with an increase in crop cover (i.e. rice tillers) and food (i.e. rice grain). The same was observed by Mulungu *et al*. (2013) who reported that rodent population abundance increases with an increase of rice growth stages. Frequent rains and irrigation, which flooded rat burrows, may have effectively kept rodent activities low or forced some rodents to migrate to domestic environment as *M. natalensis* is semi-domestic species and in the current study trapping was not carried in houses. As observed in wheat fields (Poche *et al.,* 1979), rat activity increased in fields as the crops matured and the plots became dry. Fulk (1977) reported similar influxes of rodents into rice fields in Pakistan. As the rice ripened and water was drained from the plots, rodent numbers increased rapidly.

Despite high numbers of rodent individuals recorded at transplanting, rodent damage was highest at maturity growth stages in both seasons. This can be attributed to the fact that rodents prefer grain/seeds as their main diet (Meheretu *et al*., 2014; Mulungu *et al*., 2014) regardless its number. In this study, it was observed that an average crop damage recorded at maturity crop growth stage in dry season could be associated with few or no food alternatives thus rodents concentrate on rice. It has been reported that higher population

abundance of rodents in maize crop cause higher damage to crop (Mulungu *et al.*, 2003). Similar results in the same study area were reported by Sixbert (2013) who observed rodent damage at wet and dry seasons to be 6% and 11%, respectively.

It has been reported that, the relationship between yield and yield components can be described as a product of number of panicles/m^2, number of spikelets/panicle, percentage filled grain and weight of 1000 grains (De Datta, 1981). In this study, average grain yield on the wet season and dry season were significantly different (P < 0.001). Wet season had significantly (P < 0.001) higher grain yield than the dry season. The lower yield observed during the dry season is probably attributed to irregular irrigation and/or prolonged periods of water stress caused by insufficient water supply. Similar observation was reported by Nguyen and Ferrero (2004) and McHugh (2002). According to Raes *et al.* (2007), rice cultivated in the dry season experiences much of the moisture stress (Sumarno and Sutisna, 2010) and higher pest and disease incidences than in the wet season. Other similar findings include that of Craufurd *et al.* (2013), who reported water stress to have negative impacts on yield and effects vary with phenological stages where generally is more severe from the flowering stage onwards. Yue *et al.* (2006) reported yield loss under drought stress could be associated with an increase of spikelet sterility and a reduction in panicle filling rate as well as grain weight.

Results of this study also indicate that rice crop damage through the cutting of tillers may have negligible impact on yield, particularly if the damage occurs early in the growing season at the transplanting stage of the crop. Tiller damage in this stage is less important due to its compensation. The current study shows that vegetative and late damage at the time of maturity results in significant percentage yield loss. It has been reported that percentage yield loss at these growth stages is roughly approximate to the percentage of damage (Singleton *et al.*, 2003a; Poche *et al.*, 1981) which is attributed by the fact that at a

late stages the crop cannot produce more tillers to compensate for damage since very little time is available for such compensatory growth. This has also been observed on the effect of damage levels of zero and 10% rodent damage. These two damage levels are not statistically different but differ with other higher damage levels (i.e. 20 - 50%) indicating that rice can compensate at lower levels. Compensation in rice crop yield can be further observed through the significant interaction between growth stage and damage level. The significant interactive effects between growth stage and damage level suggest rice plant compensation has occurred.

Similar findings were reported by Fulk and Akhtar (1981) who showed that rice grain yield may not be affected by loss of tillers at their early growth stages as the numbers of productive tillers are determined at the late tillering stage. Likewise, Buckle et $al.$ (1979) reported that compensation capacity of rice damaged by rodents is higher at each growth stage than at maturity of the crop. Aplin et al. (2003) explained the term compensation of rice in terms of tiller re-growth and panicle filling. Cut tillers that re-grow before maximum tillering likely go through normal panicle initiation. However, a tiller that is cut after the plant has entered the panicle-initiation stage will generally not be able to produce a new panicle, but the plant may compensate for this loss by diverting its resources into the remaining panicles leading to panicles with larger or more numerous grains. Similarly, Cuong et al. (2003) observed that the effect of rodent damage at different stages of rice growth was low when rodent damage occurred at the seedling stage (15 – 20 DAS) when the plant was able to compensate for the effect; but at tillering (35 – 40 DAS) and booting (55 – 60 DAS) stages there was no compensation effect. The author further observed that the yield loss might be high and probably result in total yield loss when damage occurs at the reproductive phase as there would not be sufficient time for compensation to occur.

Difference in grain yield in crop plants could be attributed to the effect of weather, pest pressure (damage) and field management. In this study, average number of panicles per plant in the wet season was observed to be higher than that of the dry season. This perhaps may be due availability of moisture in wet season than in dry season. These results agree well with those of Kim *et al*. (2009) who reported that drought exposure during the earlier stages of reproductive growth affects panicle formation negatively. Also, rice rodent damage recorded in the dry season was higher than that of the wet season. Average number of panicles per plant was also higher at transplanting than other crop growth stages. Similar results were supported by Kariali *et al*. (2012) who observed that late formed tillers on higher culm nodes senesce earlier than that of an older tiller and contributes less in grain number and yield. In addition, according to Yoshida (1981), tillers produced at early growth stages normally produce panicles while those developed on later stages may or may not. Further results show that the average numbers of panicles per plant between damage levels were observed to be different. The control and 10% damage plots had higher number of panicles per plant than other damage levels. These results agrees with Mobasser *et al*. (2009) who reported decrease in tiller numbers and increase panicle number as plant density increases.

The average number of spikelet per panicle was higher during dry than wet season. These results agree well with those reported by Yoshida and Parao (1972) who observed higher number of spikelet per panicle in dry season. These findings were expected to contribute positively in the final grain yield in the dry season but according to Yoshida (1981), unfavorable weather conditions during ripening may hamper continued growth of some spikelets resulting in unfilled spikelet hence decrease in yield. This was the case for the current study where yield during the dry season was lower than that of the wet season. However, higher number of spikelets per panicles was observed at transplanting stage indicating that early damage leaves the plant with enough time to translocate some of its

resources thereby resulting into formation of more seed formation. Similarly, Sarwar (2015) reported that, wheat can compensate well for damage at early growth stages. Higher numbers of spikelets per panicle were observed in zero rodent damage level and decrease with an increasing rodent damage level tiller cut indicating that removal of tillers affects plant leaves and therefore chlorophyll and ultimately the ability of the plant to process and store its food.

The number of panicles per m^2 was higher during wet than in dry season. This observation agrees with Zubaer (2007) who reported decrease in number of panicles per area as attributed by water stress which actually restricts translocation of assimilates into grains. Similarly, number of panicles per area was higher at transplanting than other crop growth stages indicating that the plant had enough time to re-grow new tillers which developed into panicles after damage occurred.

Average number of panicles between rodent damage levels was observed to be higher in 10% than other higher rodent damage levels indicating that as more tillers are damaged, the plant remains with few tillers which develop into productive tillers (i.e. panicles).

The average number of filled grains per panicle for wet season was higher than that the dry season. The differences in grain filling over season observed in this study may be accounted by moisture availability. Similar findings were reported by Vries *et al*. (2010) where rice planted in the wet season out-yielded those planted in the dry season. Similarly, average number of filled grains per panicle between growth stages was higher at transplanting than at vegetative and maturity stages. This could be attributed by time difference when damage was imposed. Early damage leaves the plant with enough time to compensate thereby more filled grains. The simulated rodent damage levels from the control had higher number of filled grains per panicle than others. This also could be

accounted by absence of damage imposed giving tillers enough time to develop into panicles.

The average percentage grain filling for wet season was higher than that of the dry season. The result concurs with Machunde (2013) who reported that decrease in grain filling was a result of moisture stress. According to Yoshida (1981), water shortage during plant growth stages may cause shortage of assimilates supply due to inhibition of photosynthesis process. Similarly, the average percentage grain filling was higher at transplanting than other crop growth stages indicating that damage at early crop growth stage have minimum effect on grain filling and ultimately grain yield.

Furthermore, percentage grains filling between simulated rodent damage levels was higher in control plots than other rodent damage levels of tiller cut plots. This could be associated with available number of productive tillers where in control plots, no tiller damage was done leaving all control plots rice plants with all their tillers thereby increasing more grains.

A 1000 grain weight for wet season was higher than of the dry season. The result agrees with those of Devasinghe et al. (2013) who reported 1000 grain weight of rice in the wet season to be 5% higher than in dry season. In addition, Ober and Setter (1990) reported that water stress imposed during grain filling, especially at the early stage, usually results in a reduction in grain weight. Also, 1000 grain weight was higher in plots were damage was imposed at transplanting than on the other growth stages indicating that plants damaged at transplanting had enough time to translocate more assimilated than other stages. At 10% damage level, 1000 grain weight was higher than zero and other higher damage levels (damage 10%) indicating that damage of tillers at 10% gave the remaining tillers extra resources to develop into panicles and high assimilates.

The partial correlation relationships observed in the current study for the number of panicles per plant, number of panicles m^{-2}, number of filled grains per panicle, percentage grain fill and1000 grain weight were highly and positive correlated with grain yield. Similar findings were reported by Chakraborty *et al.* (2010) for number of panicle per plant, Ogunbayo *et al.* (2014) for number of panicle m^{-2}, Sürek and Befier (2003) and Ogunbayo *et al.* (2014) for number of filled grain per panicle, Sürek and Befier (2003), Gunasekaran *et al.* (2010) and Bagheri *et al.* (2011) for percentage grain fill and Sürek and Befier (2003) and Ogunbayo *et al.* (2014) for 1000 grain weight. These finding are in agreement with Ram (1992), Mehetre *et al.* (1995), Samonte *et al.* (1998), Sürek and Befier (2003) who reported that grain yield was influenced by 1000 grain weight. All these components which showed positive partial correlation with yield could therefore be used as an indicator for yield variation for estimation even when we need to control rodent crop damage. Any damage or stress which affects one or more of these factors will affect grain yield. It is therefore possible to develop thresholds based on the named yield components for effective and sound rodent pest species management/strategy option.

In this study there was great relation between crop yield loss and stem tillers cut (damage). Damage at wet season resulted into lower yield losses compared to dry season. At early growth stage such as transplanting, yield loss was observed to be lower compared to later growth stages. As damage ascended from zero to 50 % stem tiller cut, yield losses followed the same trend; except for 10% stem tillers cut at early growth stages were there was compensation.

These results on the spatio-temporal effects of simulated rodent damage are the first report of such work in sub-Saharan Africa. As rice consumption is growing in Africa, understanding the potential impact of rodent pests on increased rice production across the continent can assist farmers' decision making on limiting yield loss by rodents. These

observations suggest that rodent damage early in the season may not result in significant yield losses. However, this may lead to inappropriate decision making where rodent populations are left uncontrolled during early growth stages, allowing the rodent population to build and subsequently cause more damage at the time of harvest where rice plants are not able to compensate for such late damage. African farmers need to understand this complexity of rice plant compensation dynamics in order to interpret their observations correctly and decide when rodent populations should be managed so as to avert significant yield losses.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Mastomys natalensis ranks first as an important rodent pest of rice in the study area. Their population was higher in dry as compared to wet season and decreases as the crop grows from transplanting, vegetative to maturity stage. Similarly, rodent damage was higher in dry season as compared to wet season and mostly occurred at vegetative and maturity rice growth stages. The ability of rice to compensate for early rodent damage could potentially reduce a farmer's perception of damage. However, failing to control rodents at early crop growth stages could lead to increased rodent populations at the time of maturity when compensatory effects are limited although all levels tested in this study were significant different with no and 10% rat damage levels. In addition, most of the yield components measured during wet season over performed compared with dry season reflecting the importance of water in rice yield and at the same time in reducing rodents pest pressure on rice. In the study area, majority of farm fields are planted in the wet season.

6.2 Recommendations

Based on this study, rice damage at less than 10% stem tillers cut early in the season (when rice is at transplanting or vegetative growth stages) did not result into significant yield loss. However, this may lead to inappropriate decision-making where rodent populations are left uncontrolled during early growth stages, allowing the rodent population to build and subsequently cause more damage at the time of harvest where rice plants are not able to compensate for such late damage. Farmers need to understand this complexity of rice compensation dynamics in order to interpret their observations correctly and decide when rodent populations should be managed to avert significant yield losses.

REFERENCES

Ali, M., Mian, M.A.K., Rasul, M. G., Aziz Miah, M. A., Alam, M.Z. and Hossain, M.A. (2012).Genetic diversity in local aromatic rice (*Oryza sativa* L.) genotypes.*Bangladesh Journal of Plant Breeding and Genetics*, 25: 33 - 40.

Anjum, F.M., Pasha, I., Bugti, M.A and Butt, M.S (2007).Mineral composition of different rice varieties and their milling fractions.*Pakistan Journal of Agricultural Sciences*. 2: 322 - 336.

Aplin, K.P., Brown P.R., Jacob, J., Krebs, C.J and Singleton, G.R. (2003).*Field methods for rodent studies in Asia and Indo-Pacific*.Australian Centre for International Agricultural Research Monograph 100.Canberra, Australia. 223pp.

Bagheri, N, Babaeian-jelodar, N. and Pasha, A. (2011).Path coefficient analysis for yield and yield components in diverse rice (*Oryza sativa* L.) genotypes.*Biharean biologist* 5: 32 - 35.

Bale, J.S., van Lenteren, J.C. and Bigler, F. (2008). Biological control and sustainable food production. *Journal of Philosophical Transactions of the royal society* 363: 761 - 776.

Banwo, O.O. (2006). Management of major insect pest of rice. In: *Management of Selected crop pest of Tanzania. (edited by Makundi, R.H*). Pest Management Centre, Sokoine University of Agriculture, Morogoro, Tanzania. Tanzania Publishing House Limited, Dar es Salaam. 66 - 79pp.

Barnett, A and Dutton, J. (1995).*Expedition field techniques: Small mammals (excluding bats)*. Royal geographic society with IBG, 1 Kensington Gore, London. 131pp.

Bill and Melinda Gates Foundation (2012).Developing the rice industry in Africa: Tanzania assessment July, 2012. [http://www.inter-reseaux.org/IMG/pdf/20120803_Tanzania_rice_value_chain_analysis_external_.pdf] site visited on 4/1/2014.

Bomford, M. (1990). Food and reproduction of wild house mice: Diet and breeding seasons in various habitats on irrigated cereal farm in New South Wales. *Australian Wildlife Research* 14: 183 - 196.

Boonsong, P., Hongnark, S., Suasa-ard, K., Khoprasert, Y., Promkerd, P., Hamarit, G., Nookarn, P. and Jäkel, T. (1999).Rodent management in Thailand. In: *Ecologically-based management of rodent pests*. (eds Singleton, G.R., Hinds, L., Leirs, H. and Zhang, Z.). ACIAR, Australia. 494pp.

Borah, R.K and Baglari, D. (2014).Evaluation of traps against *Bandicota bengalensis* in rice field at the Upper Brahmaputra Valley Zone of Assam.*Crop Research* 48: 72 - 75.

Brown, P.R. and Singleton, G.R. (2000).*Impacts of house mice on crops in Australia – Cost and Damage.Human Conflicts with Wildlife: Economic Considerations Paper 6*.University of Nebraska, Lincoln. 48 - 58pp.

Brown, P.R., Huth, N.I., Banks, P.B and Singleton, G.R (2006).Relationship between abundance of rodents and damage to agricultural crops.*Journal of agriculture, ecosystem and Environment* 120: 405 - 415.

Buckle, A.P. (1999). Rodenticide-Their Role in Rodent Pest Management in Tropical Agriculture. In: *Ecologically-Based Management of Rodent Pests, Singleton, G.R., L.A. Hinds, H. Leirs and Z. Zhang (Eds.)*. Australian Centre for International Agricultural Research, Canberra, Australia. 163 - 177pp.

Buckle, A.P., Yong, Y.C and Rowe, F.P. (1979). Yield response of the rice variety (Improved Mashuri) to simulated rat damage. *Malaysian Agricultural Journal* 52: 135 - 144.

Chakraborty, S., Das, P.K., Guha, B., Sarmah, K.K. and Barman, B.B (2010). Quantitative genetic analysis for yield and yield component of boro rice (*Oryza sativa* L.). *Notulae Scientia Biologicae* 2: 117 - 120.

Chambers, L.K., Lawson, M. and Hinds, L.A. (1999).Biological control of rodents - the case for fertility control using immunocontraception. In: *Ecologically-based management of rodent pests. (eds Singleton, G.R., Hinds, L., Leirs, H. and Zhang, Z.)*, Australian Centre for International Agricultural Research, Australia. 215 - 242pp.

Chang, T. T. (1976). The Origin, Evolution, Cultivation, Dissemination, and Diversification of Asian and African Rices.*Euphytica* 25: 425 - 441.

Cheaney, R.L. and Jennings P.R. (1975).*Field problems of rice in Latin America*.Centro Internacional de Agricultura Tropical (CIAT), Apartado Aéreo No. 6713 Cali, Colombia.104pp.

Christopher, M.J., Balasubramanyam, M. and Purushotham, K.R. (1984). Rodent problem in poultry farms of Tirupati, Andha Pradesh. *Poultry guide* 1: 47 - 50.

Coşkun, A.S., Atalay, C., Dağlı, C., Doğan, N. and Kürşad, H. (2012).A Case Study Suicide Attempt Using Zinc Phosphide. [http://www.jcam.com.tr/files/KATD-744.pdf] site visited on 17/6/2012.

Coulson, A. and Diyamett, B. (2012).*Improving the Contribution of Agricultural Research to Economic Growth: Policy Implications of a Scoping Study in Tanzania*.International Growth Centre, London, UK. 46pp.

Craufurd, P.Q., Vadez, V., Jagadish, S.V.K., Prasad, P.V.V and Allaha, Z. (2013). Crop science experiments designed to inform crop modeling. *Agricultural and Forest Meteorology* 170: 8 - 18.

Cuong, L, Q., Chien, H.V., Han, L.V., Duc, V.H. and Singleton, G.R. (2003) Relationship between rodent damage and yield loss in rice in the Mekong delta. In: *Rats, Mice and People: Rodent biology and Management*. (*Edited by Singleton, G.R., Hinds, L.A., Krebs, C.J. and Spratt, D.M.)*Australia Centre for International Agriculture Research, Canberra, Australia.297 - 300pp.

Day, T. and MacGibbon, R. (2007).*Multiple-Species exclusion fencing and technology for mainland sites*. Proof Fencing Ltd, Cambridge University, New Zealand. 418 - 433pp.

De Datta, S.K. (1981). *Principles and practice of rice production*.A Wiley Inter-science publication. Canada. 618 pp.

Deng, W., Wang, G.Y. and Zhao, S.D. (2011). Anti-fertility effects of crude ethanol extracts of *TripterygiumHypoglaucum* (Levl.) Hutch in male Mongolian gerbils (*Meriones Unguiculatus*).*Journal of Applied Animal Research* 39: 44 - 48.

Devasinghe, D.A.U.D., Premaratne, K.P. and Sangakkara, U.R. (2013).Impact of rice straw mulch on growth, yield components and yield of direct seeded lowland rice (Oryza sativa L.).*Journal of Tropical Agricultural Research* 24: 325 - 33.

Dhar, P. and Singla, N. (2013).Effect of triptolide on reproductive output of male *Bandicota bengalensis. International Journal of Advanced Research* 1: 705 - 716.

Dhar, P. and Singla, N. (2014).Effect of triptolide on reproduction of female lesser bandicot rat, *Bandicota Bengalensis. Journal of Drug and Chemical Toxicology* DOI: 10.3109/01480545.2014.884111

Douangboupha, B., Brown, P.R., Khamphoukeo, K., Aplin, K.P. and Singleton, G.R (2009).Population dynamics of rodent pest species in upland farming systems of LAO PDR.*Kasetsart Journal of Natural Science* 43: 125 - 131.

East and Central Africa Rice Research Network (ECARRN) (2006). *Priority Setting for Eastern and Central Africa Rice Research Network*, ASARECA-ECARRN. 79pp.

Fall, M.W. (1977).Rodents in tropical rice. In: Singleton, G.R. (2003). *Impacts of rodents on rice production in Asia*.International Rice Research Institute Discussion Paper Series No. 45, Los Banos, Philippines, 14p.

FAO (2000).*FAO rice Information*, Vol. 2. Rome.Italy. 201pp.

FAO (2002).*Annual report*. [http://www.fao.org] site visited on 12/6/2012.

FAO (2004). Biotechnology: meeting the needs of the poor? [http://www.fao.org/newsroom/en/focus/2004/41655/index.html] site visited on 12/9/2013.

FAO (2005).*Rice is Life*: *International year and its implication*. Rome, Italy. 133pp.

FAO (2010).*Good Agricultural Practices (GAP) on horticultural production for extension staff in Tanzania*. Rome, Italy. 175pp.

FAO (2010).*Training manual on Good Agricultural Practices (GAP) on horticultural production for extension staff in Tanzania.*Working paper series 13. 187pp.

FAOSTAT (2013). Top ten rice producing countries of the world in 2012. [http://faostat.fao.org/site/339/default.aspx] site visited on 21/09/2013.

Fayenuwo, J.O., Olakojo, S., Akande, M., Amusa, N.A. and Olujimi, O.A. (2007). Comparative evaluation of vertebrate pest damage on some newly quality protein maize (QPM) varieties in southern-western Nigeria.*African Journal of Agricultural Research* 2: 592 - 595.

Feore S.M., Bennett, M., Chantrey, J., Jones, T., Baxby, D. and Begon, M. (1997).*The effect of cowpox virus infection on fecundity in bank voles and wood*

mice.Proceeding of the Royal Society of London Biological Science. 264: 1457 - 1461.

Fiedler, L.A. (1988). Rodent pest problems and management in Eastern Africa.*FAO Plant Protection Bulletin* 36: 125 - 134.

Fiedler, L.A. (1994). *Rodent pest management in Eastern Africa*. Plant Protection and Production Paper No. 23. 83pp.

Fielder, L.A and Fall, M.W. (1994). *Rodent Control in Practice: Tropical Field Crops*. Denver Wildlife Research Centre, Colorado, U.S.A. 313 - 338pp.

Fishel, F., Bailey, W., Boyd, M., Johnson, B., O'Day, M., Sweets, L. and Wiebold, B. (2001).*Integrated Pest Management: Introduction to crop scouting*. University of Missouri Extension, Columbia. 22pp.

Fitzwater, W.D. and Prakash, I. (1989).*Handbook of Vertebrate Pest Control*.Indian Council of Agricultural Research, New Delhi. 103pp.

Fulk, G. (1977). Food hoarding of *Bandicota bengalensis* in a rice field.*Mammalia* 41: 59 - 61.

Fulk, G.W. and Akhtar, M.T. (1981).An investigation of rodent damage and yield reduction in rice.*Journal of Tropical Pest Management* 27: 116 - 120.

Gacheri, C. (2012). *Integrated Pest Management (IPM) in Kenya*. Dudutech, Kenya. 2pp.

Gergon, B.E; Catudan, B.M. and Desamero, N.V. (2008). Ecology based rat management system in Banaue and Hungduan rice terraces. In: *Philippines Rats: Ecology*

and Management. (*Edited by Singleton, G.R., Joshi, R.C. and Sebastian, L.S.*). Philippine Rice Research Institute, Luzon. 85 - 100pp.

Gunasekaran, M., Nadarajan, N. and Netaji, S.V.S.R.K. (2010).Character association and path analysis in Inter-Racial Hybrids in rice.*Electronic Journal of Plant Breeding* 1: 956 – 96

Hafidzi, M.N and Mohd NA, M.I. (1999). Prey selection by barn owls in rice fields in Malaysia. In: *Rats, Mice and People: Rodent biology and Management.* (*Edited by Singleton, G.R., Hinds, L.A., Krebs, C.J. and Spratt, D.M.).*Australia Centre for International Agriculture Research, Canberra, 220 - 223pp.

Haifa (2014).Nutritional recommendation for rice (*Oryza sativum* L.). [http://www.haifa-group.com/knowledge_center/crop_guides/rice/] site visited on 24/02/2016.

Inchaurraga, L. (1973). Prevencion del ataque de ratas en arroz de riego con laminas de zinc. *Bol.* CIARCO, 3: 166 - 169. In: Fielder, L.A and Fall, M.W. (1994). *Rodent Control in Practice: Tropical Field Crops.* Denver Wildlife Research Centre, Colorado, U.S.A. 313 - 338.

Jaèkel, T., Khoprasert, Y., Endepols, S., Archer-Baumann, C., Suasa-ard, K., Promkerd, P., Kliemt, D., Boonsong, P and Hongnark, S. (1999).Biological control of rodents using *Sarcocystis singaporensis.International Journal of Parasitology* 29: 1321 - 1330.

Jaèkel, T., Khoprasert, Y., Promkerd, P. and Hongnark, S. (2005). An experimental field study to assess the effectiveness of bait containing the parasitic protozoan

Sarcocystis singaporensis for protecting rice crops against rodent damage. *Crop protection* 25: 773 - 780.

Jaèkel, T., Khoprasert, Y., Sorger, I., Kliemt, D., Seehabutr, V., Suasa-ard, K., Hongnark, S., 1997. Sarcosporidiasis in rodents from Thailand.*Journal of Wildlife Diseases* 33: 860 - 867.

Kadigi, R.M.J. (2003). Rice production economics at the local and National level: A case study of Usangu plains in Tanzania.7pp.

Kanyeka, Z,L., Msomba S,W., Kihupi, A.N. and Penza, M.S.F. (1994). Rice ecosystems in Tanzania: characterisation and classification. *Researchand Training Newsletter*, 9:13 - 15. In: Bucheyaki, T.L, Shennkalwa, E, Kadadi, D and Lobulu, J (2011). Assessment of Rice Production Constraints and Farmers Preferences in Nzega and Igunga Districts.*Journal of Advances in Developmental Research* 2: 30 - 37.

Kariali, E., Sarangi, S., Panigrahi, R., Panda, B.B., Mohapatra, P.K. (2012). Variation in senescence pattern rice tillers and its effect on panicle biomass growth and grain yield. *American Journal of plant science* 3: 1047 - 1057.

Kayeke, J., Rodenburg, J., Mwalyego, F. and Mghogho, R. (2010).*Incidence and severity of the facultative parasitic weed Rhamphicarpa fistulosa in lowland rainfed rice in southern Tanzania*. Second Africa Rice Congress, Bamako, Mali, 22 - 26 March 2010.

Kim, H. E., Park, H. S. and Kim, K. J. (2009). Methyl jasmonate triggers loss of grain yield under drought stress. *Plant Signal Behavior* 4: 348 - 349.

Kingdon, J. (1997). *The kingdom field guide to African mammals*. Harcourt Brace and Company, New York. 364pp.

Kishore, N. and Rao, S. (2010). Rodent infestation on Rice crop. In: *Kumar, N., Kumar, V., Singh, C. and Shukla, V. (2013). Studies on association between rodents infestation in different stage of rice cultivation. International Journal of Agriculture Science and Research (IJASR)* 3: 117 - 126.

Leirs, H. (1995). *Population ecology of Mastomys natalensis*(Smith 1834).*Implication for rodent control in East Africa*. Agricultural Edition, Belgian Administration for Development Cooperation, Brussels. 268pp.

Leirs, H. (2003). Management of rodents in crops: Pied Piper and his orchestra. In: *Rats, Mice and People: Rodent biology and Management.* (*Edited by Singleton, G.R., Hinds, L.A., Krebs, C.J. and Spratt, D.M.)*.Australia Centre for International Agriculture Research, Canberra, 183 - 190pp.

Leirs, H., Stenseth, N., Nichols, J.D., Hines, J.E., Verhagen, R. and Verheyen, W. (1997). Stochastic seasonality and non-linear dependent factors regulate population size in an African rodent. *Nature*389: 176 - 180.

Ling-Ling, L. (1997). Effectiveness of live traps and snap traps in trapping small mammals in Kinmen.*Acta Zoologica Taiwanica* 8: 79 - 85.

Loven, J. and Williams, R. (2010).*Animal damage management: Controlling rodents in commercial poultry facilities*. Department of Entomology, Purdue University. 15pp.

Lurz, R. (1913). An epidemic of plague on Kilimanjaro in 1912.In: *The role of rodents and small carnivores in plague endemicity in Tanzania*. (Edited by Kilonzo, B.S., Mhina, J., Sabuni, C. and Mgole, G.), *Belgian Journal of Zoology* 135: 119 - 125.

Lwezaura, D., Madulu, R., Ndunguru, A., Paul, C. and Chalamila, B. (2011).*Baseline survey report*.Regional Rice Centre of Excellence. 38pp.

Machunde, Z.A. (2013). Variation and interrelationships among yield and yield components in lowland rice genotypes (Oryza sativa L.) in Mwanza region. MSc. Thesis, Department of Crop Science and Production, SUA, Morogoro. 84pp.

MacNiven, E., de Catanzaro, D. and Younglai, E.V. (1992). Chronic stress increases oestrogen and other steroid around intrauterine implantation in inseminated rats. *Physiology and behavior* 52: 159-162.

Makundi, R.H., Massawe, A.P. and Loth, L.S. (2007).Reproduction and population dynamics of *Mastomys natalensis* Smith, 1834 in an agricultural landscape in the Western Usambara Mountains, Tanzania.*Integrative Zoology* 2: 233 - 238.

Makundi, R.H., Massawe, A.W., Mulungu, L.S. and Katakweba, A. (2009). Species diversity and population dynamics of rodents in a farm-fallow field mosaic system in central Tanzania. *African Journal of Ecology* 48: 313 - 320.

Makundi, R.H., Mbise, T.J and Kilonzo, B.S. (1991).Observations on the role of rodents in crop losses in Tanzania and control strategies.*Beitrage Tropical Landwirsch Veterinary Medicine*29: 465 - 474.

Makundi, R.H., Oguge, N.O. and Mwanjabe, P.S. (1999).Rodent Pest Management in East Africa – an Ecological Approach. In: *Ecologically Based Rodent Management (Edited by Singleton, G.R., Hinds, L.A., Leirs, H. and Zhang, Z.),* Australian Centre for International Agricultural Research. Canberra, Melbourne, Australia. 460 - 476pp.

Marsh, D., Black, D. and Pauly, W. (2013). Integrated Pest Management.Land and water resource department, Parks division. [http://pdf.countyofdane.com/lwrd/parks/IPMP_November_2011.pdf] site visited on 25/1/2014.

Masol, J.R., Epple, G. and Nolte, D.L. (1994).*Semiochemicals and improvement in rodent control*.U.S. Department of Agriculture, Animal and Plant Health Inspection service. Philadelphia, U.S.A. 327 - 345pp.

Massawe, A.W. (2003). Effect of cropping systems and land management practices on rodent population characteristics.PhD Thesis, Sokoine University of Agriculture, Morogoro, Tanzania, 3 - 20pp.

Massawe, W.A., Mulungu, L.S., Makundi, R.H., Dlamini, N., Eiseb, S.J., Kirsten, F., Mahlaba, T., Malebane, P., Maltitz, E.V., Monadjem, A., Taylor, P., Tutjavi,

V. and Belmain, S.R. (2011).Spatial and Temporal Population Dynamics of Rodents in Three Geographically Different Regions in Africa: Implication for Ecologically-Based Rodent Management. *African Journal of Zoology* 46: 393 - 405.

McHugh, O.V (2002). Growing more rice with less water: adaptive water management schemes utilized in the system of rice intensification (SRI). Thesis presented to the Faculty of Graduate School of Cornell University in Partial Fulfillment of the requirement for the degree of Master of Science, Cornell University, Madagascar. 113pp.

Meerburg, B.G., Singleton, G.R. and Leirs, H. (2009). The Year of Rat ends – time to fight hunger! Society of Chemical Industry.Published online in Willey Interscience.*Pest Management Science* 65: 351 - 352.

Meheretu, Y., Sluydts, V., Welegerima, K., Bauer, H., Teferi, M., Yirga, G., Mulungu, L.S., Haile, M., Nyssen, J., Deckers, J., Makundi, R. and Leirs, H. (2014). Rodent abundance, stone bund density and its effects on crop damage in the Tigray highlands, Ethiopia. *Journal of Crop Protection* 55: 61 - 67.

Mehetre, S. S., Mahajan, C.R., Patil, P. A., Lad, S.K., Dhumal, P. M. (1995). Variability, Heritability, Correlation, Path Analysis, and Genetic Divergence Studies in Upland Rice.*Journal of Iran* 19: 8 - 9.

Mghase, J., Shiwachi, H., Nakasone, K. and Takahashi, H. (2010). Agronomic and socioeconomic constraints to high yield of upland rice in Tanzania. *African Journal of Agricultural Research* 5: 150 - 158.

Miller, R.W., Stuart, A.M., Joshi, R.C., Banks, P.B. and Singleton, G.R. (2008).Biology and management of rodent communities in complex agroecosystems-rice terraces. In: *Philippines Rats: Ecology and Management. (Edited by Singleton, G.R., Joshi, R.C. and Sebastian, L.S.)*, Philippines Rice Research Institute, Luzon. 25 - 36pp.

Ministry of Agriculture of Kenya (MAK) (2008).National Rice Development Strategy (NRDS) (2008 - 2018). [http://www.jica.go.jp/english/our_work/thematic_issues/agricultural/pdf/keny a_en.pdf] site visited on 3/1/2014.

Ministry of Agriculture, Food Security and cooperatives (MAFS). (2011). *Regional Rice Centre of Excellence: Inventory of rice technologies. Extension service section*. Dar es salaam, Tanzania. 34pp.

Ministry of Agriculture, Food Security and cooperatives (MAFS).(2009). *National rice development strategy*.Final Draft. Tanzania. 1- 32pp.

Minot, N. (2010). *Stable food prices in Tanzania*. Markets, Trade and Institution division, International Food Policy Research, Washington, DC. 15pp.

Mobasser, H.R., Yadi, R., Azizi, M., Ghanbari, A.M. and Samdaliri, M. (2009). Effect of density on morphological characteristics related lodging on yield and yield components in varieties rice (Oryza sativa L.) in Iran. *American-Eurasian Journal of Agriculture and Environmental Science*. 5: 745 - 754.

Montgomery, D.C. (2004). *Design and analysis of experiments*.5th edition.John Wiley and Sons, Inc. New York. 684pp.

Msangi, A.S. (1968). Observations on the endemicity of plague in Tanzania. In: *The role of rodents and small carnivores in plague endemicity in Tanzania*. (Edited by Kilonzo, B., Mhina, J., Sabuni, C. and Mgole, G.), *Belgian Journal of Zoology*. 135: 119 - 125.

Mulungu, L.S. (2003). Assessment of Maize (*Zea mayz L.*).Damage and Yield loss due to Rodents in Field.Thesis for Award of PhD Degree at Sokoine University of Agriculture, Morogoro, Tanzania. 178pp.

Mulungu, L.S., Borremans, B., Ngowo, V., Mdangi, M.E., Katakweba, A.S., Tesha, P., Mrosso, F.P., Mchomvu, M. and Kilonzo, B.S. (2015). Comparative study of the movement of *Mastomys natalensis* in irrigated rice and fallow fields in eastern Tanzania. *African Journal of Ecology* 1: 1 - 7.

Mulungu, L.S., Makundi, R.H and Leirs, H (2003a). Robustness of techniques for estimating rat damage and yield loss in maize fields. In: *Rats, Mice and People: Rodent biology and Management*. (*Edited by Singleton, G.R., Hinds, L., Krebs, C.J. and Spratt, D.M.*), Australia Centre for International Agriculture Research, Canberra. 224 - 228pp.

Mulungu, L.S., Makundi, R.H and Massawe, A.W. (2006).Characteristics of rodent damage to major crops in Tanzania and crop loss assessment technique. In: *Management of Selected Crop Pest in Tanzania (Edited by Makundi, R.H.)*, Tanzania Publishing House, Dar es Salaam. 476: 248 - 267.

Mulungu, L.S., Massawe, A.P., Kennis, J., Crauwels, D., Eiseb, S., Mahlaba, T., Monadjem, A., Makundi, R.H., Katakweba, A.S. and Belmain, S.R. (2011).Differences in diet between two rodent species, *Mastomys natalensis* and *Gerbilliscus vicinus* in fallow land habitats in central Tanzania.*African Journal of Zoology* 46: 387 - 392.

Mulungu, L.S., Mdangi, N.M., Katakweba, A.S., Tesha, P., Mrosso F.P., Mchomvu, M., Sheyo, P.M. and Kilonzo, B.S. (2013). Population dynamics and breeding patterns of Multimammate mouse, *Mastomys natalensis* (Smith 1934) in irrigated rice fields in Eastern Tanzania. *Pest Management Science*. 69: 371 - 377.

Mulungu, L.S., Mlyashimbi, E.C.M., Ngowo, V., Mdangi, M., Katakweba, A.S., Tesha, P., Mrosso, F.P., Mchomvu, M., Kilonzo, B.S. and Belmain, S.R. (2014). Food preferences of the Multi-mammate mouse, *Mastomys natalensis* (Smith 1834) in irrigated rice field in eastern Tanzania. *International Journal of Pest Management* 1: 1- 8.

Mulungu, L.S., Ngowo, V.D., Makundi, R.H., Massawe, A.W. and Leirs, H. (2010).Winning the Fight against Rodent Pests: Recent Developments in Tanzania.*Journal of Biological Sciences* 10: 333 - 340.

Mulungu, L.S., Sixbert, V., Ngowo, V., Mdangi, M., Katakweba, A.S., Tesha, P., Mrosso, F.P., Mchomvu, M., Kilonzo, B.S. and Belmain, S.R. (2015b). Spatio – temporal patterns in the distribution of the multimmate mouse, *Mastomys natalensis* in rice crop and fallow land habitats in Tanzania. *Mammalia* 79: 177 - 184.

Mulungu, L.S; Makundi, R.H; Leirs, H; Massawe, A.W; Vibe-Petersen, S. and Stenseth, N.C. (2003b). The rodent density-damage function in maize fields at an early growth stage. In: *Rats, Mice and People: Rodent biology and Management*. (*Edited by Singleton, G.R., Hinds, L.A., Krebs, C.J. and Spratt, D.M.*), Australia Centre for International Agriculture Research, Canberra. 301 - 303pp.

Murakami, O., Priyono, J. and Triastiani, H. (1990).Population management of the ricefield rat inIndonesia. In: *Rodents and rice, report and proceedings of an expert panel meeting on rice rodent control. (Edited by Quick, G.R.*), Manila, Philippines, International Rice Research Institute.49 - 54pp**.**

Mwanjabe, P.S. (1993).The role of weeds on population dynamics of *Mastomys natalensis* in Chunya (Lake Rukwa) valley. In: *Economic importance and control of rodent pests in Tanzania* (*Edited by Machang'u, R.S.*), Workshop proceedings, 6th - 8th July, 1992. Sokoine University of Agriculture, Morogoro, Tanzania. 229 - 232pp.

Mwanjabe, P.S. and Leirs, H. (1997). An early warning system for IPM based rodent control in smallholder farming systems in Tanzania, *Belgian Journal of Zoology* 127:49-58.

Mwanjabe, P.S. and Sirima, F.B. (1993). Large scale rodent control in Tanzania: Present status. In: *Economic importance and control of rodent pest in Tanzania*. (*Edited by Machang'u, R.S.),* Workshop proceedings July 6 - 8, 1992, Sokoine University of Agriculture, Morogoro, Tanzania.134 - 142pp.

Mwanjabe, P.S., Sirima, F.B and Lusingu, J. (2002).Crop losses due to outbreaks of *Mastomys natalensis* (Smith, 1834) Muridae, Rodentia, in the Lindi region of Tanzania.*International Biodeterioration and Biodegradation Journal* 49: 133 - 137.

My Phung, N.T. and Brown, P.R. (2011). Pattern and dynamics of rodent damage to lowland irrigated rice crops in An Giang, Vietnam. (Abstract). *International Journal of Pest Management* 57: 67 - 79. [http://www.ingentaconnect.com] site visited on12/9/2013.

Myllymäki, A. (1987). Control of rodent problems by use of rodenticides: rationale and constraints. In: *Control of mammal pests. (Edited by Richards, C.G.J. and Ku, T.Y.*), Taylor and Francis, London. New York, Philadelphia. 83 - 111pp.

Nagel, R. (2010). Living with Phytic Acid: Preparing Grains, Nuts, Seeds and Beans for Maximum Nutrition. The Weston A. Price foundation. [http://www.westonaprice.org/food-features/living-with-phytic-acid] site visited on 3/1/2014.

Nagorsen, D.W and Peterson, L.R (1980).*Mammal collector's manual. A guide for collecting, documenting and preparing mammals specimens for scientific research*.Life Sciences Miscellaneous Publications.Royal Ontario Museum, Toronto.79pp.

National Agricultural Research Institute (NARI) (2001). *Morphology and Growth of Rice Plant*.NARI Bubia, LAE, Morobe province. 15pp.

Neal, B.R. (1984) Relationship between feeding habits, climate and reproduction of small mammals in Meru National Park. *African Journal of Ecology* 22: 195 - 205.

Neelanarayanan, P. (1997). A field evaluation on predatory pressure of barn owl (*Tyto alba stertens* Hartert, 1929) on rodent pests.PhD thesis.Mayiladuthurai, Bharatidasan University. 92pp.

Newsome, A.E. (1990). The control of vertebrate pests by vertebrate predators.*Trends Ecological Evolution* 5:187 - 191.

Ngowo, V., Mulungu, L.S., Makundi, R.H., Massawe, A.W., Machang'u, R.S. and Leirs, H. (2005). Spatial pattern and distribution of rodent damage in maize fields in Tanzania.*Belgian Journal of Zoology* 135: 183 - 185.

Ngowo, V.D. (2003). Rodent outbreaks by districts (1988/89 – 2001/02).*Paper presented at the National Inter-sectoral and stakeholders workshop on plague control and prevention, Lushoto July 2003.*

Nguyen, V.N. and Ferrero, A. (2004).*The sustainable development of rice-based production systems in Europe.*International Relations Council (IRC) Newsletter. 54: 115 - 124.

Ngwediagi, P., Maeda, E., Kimomwe, H., Kamara, R; Massawe, S., Akonaay, H.B. and Mapunda, L.N.D. (2009).*Tanzania report on the state of plant genetic resources for food and agriculture*. Dar es salaam, Tanzania. 87pp.

Nuss, E.T and Tanumihardjo, S.A (2010).*Maize: A paramount staple crop in the context of global nutrition*. A comprehensive reviews in food science and food safety. 9: 417 - 436.

Nyambo, B. (2009). *Integrated pest management* plan (IPMP). Agricultural Sector Development Program (ASDP), Dar es salaam, Tanzania. 115pp.

Ober, E. S. and Setter, T. L. (1990). Timing of kernel development in water-stressed maize: water potentials and abscisic acid concentrations. *Annals of Botany* 66: 665 - 672.

Odhiambo, R.O., Makundi, R.H., Leirs, H. andVerhagen, R. (2005). Dietary selection in *Mastomysnatalensis* (Rodentia: Muridae) in the maize agro-ecosystemsof central and southwestern Tanzania. *Mammalia* 72: 169 - 177.

O'Donoghue, P.J., Watts, C.H.S. and Dixon, B.R. (1987). Ultrastructure of *Sarcocystis spp*. (Protozoa: Apicomplexa) in rodents from North Sulawesi and West Java, Indonesia. *Journal of Wildlife Disease* 23: 225 - 232.

Ogunbayo, S.A., Sie, M., Ojo, D.K., Sanni, K.A., Akinwale, M.G., Toulou, B., Shitu, A., Idehen, E.O., Popoola, A.R., Daniel, I.O. and Gregorio, G.B. (2014). Genetic variation and heritability of yield and related traits in promising rice genotypes (*Oryza sativa* L.) *Journal of Plant breeding and Crop Science* 6: 153 - 159.

Oosthuizen, M.K. and Bennett, N.C. (2009). Seasonal Variation in Gonadal Steroids of Males and Females in the Cape Mole-Rat (*Georychus capensis*): The Potential for Opportunistic Breeding. *African Journal of Zoology* 44: 117 - 122.

Pest control newsletter (2009). The use of traps in rodent control. Pest control advisory section. Issue No. 13. 2pp.

Pierce,R., Randol, H. and McNamara, J. (2012). *Integrated pest management plan for the outdoor environment*. Portland State University, USA. 15pp.

Plantwise (2014). Knowledge Bank, Tanzania.[http://www.plantwise.org/ Knowledge Bank/Datasheet.aspx] site visited on 11/1/2014.

Poche, R. M., Mian, M. Y., Haque, M. E., Miah, D., Mannan, A. (I)., Mannan, A. (II). and Sultana, P. (1979). *Rodent damage to wheat in Bangladesh*.Special Report No. 1. Bangladesh Agricultural Research Institute, Vertebrate Pest Division. 19pp.

Poche, R.M., Haque, M.E., Mian, M.Y., Sultana, P. and Karim, M.A. (1981).Rice yield reduction by simulated rat damage in Bangladesh.*Journal of Tropical Pest Management* 27: 242 - 246.

Poche, R.M., Main, M., Haque, M.E and Sultana, P. (1982).Rodent damage and burrowing characteristics in Bangladesh wheat fields.*Journal of Wildlife Management* 46: 139 - 147.

Quick, G.R. (Ed) (1990).*Report and proceedings of an expert meeting on rice rodent control*, Los Banos, Philippines, September 10 - 14, 1990.

Raes, D., Kafiriti, E.M., Wellens, J., Deckers, J., Maertens, A., Mugigo, S., Dondeyne, S. and Descheemaeker, K. (2007). Can soil bunds increase the production of rain-fed lowland rice in south eastern Tanzania? *Agricultural Water management* 89: 229 - 235.

Ram, T. (1992). Character association and path coefficient analysis in rice hybrids and their parents.*Journal of the andaman science association* 8: 26-29.

Rao, A.M.K.M. (2002). Rodent problems in India and strategies for their management. In: *Rats, Mice and People: Rodent biology and Management. (Edited by Singleton, G.R., Hinds, L.A., Krebs, C.J. and Spratt, D.M.*), Australia Centre for International Agriculture Research, Canberra, 203 - 212pp.

Reissig, W.H., Heinrich, E.A., Lit singer, J.A., Moody, K., Fiedler, L., Mew, T.W. and Barrio, A.T. (1985).*Illustrated Guide to Integrated Pest Management in Rice Tropical Asia*. International Rice Research Institute (IRRI), Philippines. 411pp.

Rhodes, L. and Moldave, K. (2002).*Contraception and fertility control in animals*. Alliance for Contraception in cats and dogs. Old Cornelius Pass Rd, Portland, U.S.A. 117pp.

Rural Livelihood Development Company (RLDC) (2009). Improving rice profitability through increased productivity and better marketing focusing on Tanzania's central corridor.[http://www.rldc.co.tz/docs/ RLDC%202009%20Annual%20Report.pdf] site visited on 13/5/2012.

Safianu, R. and Robert, R.K. (2004). Crop damage and yield loss caused by two species of rodent in irrigated fields in northern Nigeria. *International Journal of Pest Management* 50: 323 - 326.

Sahni, K. and Prabha, C. (2012).Comparative efficiency of Zinc phosphide and Bromodioline against rats in houses.*Journal of life science* 4: 67 - 68.

Saikia S. and Borah R. K. (2015).Efficacy of rodenticides baiting in rice field of upper Brahmaputra valley zone of Assam.*Indian Journal of Entomology* 76: 321 - 324.

Samonte, S. O. P. B., Wilson, L. T., Mcclung, A. M. (1998). Path Analyses of yield and yield-related traits of fifteen diverse rice genotypes. *Crop Science* 38: 1130 - 1136.

Sarkar, D., Datta, V. and Chattopadhyay, K.S. (2013).*Assessment of pre and post-harvest losses in rice and wheat in West Bengal* (Study No.172).Agro-economic research centre, Visva-Bharati, Santiniketan, India. 65pp.

Sarwar, M. (2015). Pattern of Damage by Rodent (Rodentia: Muridae) Pests in Wheat in Conjunction with Their comparative Densities throughout Growth Phase of Crop. *International Journal of Scientific Research in Environmental Sciences* 3: 159 - 166. [http://www.ijsrpub.com/ijsres] site visited on 26/12/2015.

Sebastian, L.S (2006). Management of Field Rats. Philippine Rice Research Institute (Phil Rice). *Rice Technology Bulletin* 55: 1 - 16.

Shao, Y; Fan, X; Liu, H; Xiao, J; Ross, S. and Brisco, B. (2001).Rice monitoring and production estimation using Multi-temporal RADARSAT.*Remote Sensing of Environment* 76: 310 - 325.

Sharma, P.K. and Rao, A.M.K.M. (1989).Effect of bund dimensions on rodent infestation in rice. International Rice Research Institute (IRRI), Newsletter, 14, 40pp.

Shayo, N.B., Mamiro, P., Nyaruhucha, C.N.M, and Mamboleo, T. (2006). Physio-chemical and grain cooking characteristics of selected rice cultivars grown in Morogoro.*Journal of Science* 32: 1 - 35.

Sheikher, C. and Jain, S.D. (1997). Rodents in cauliflower and cabbage: population, damage and control. *International Journal of Pest Manage* 43: 63 - 69.

Sheyo, P.M. (2010). Rodent population characteristics in rice producing areas of Mvomero district. Dissertation submitted for partial fulfillment of the requirement for the Degree of Masters of science in Crop Science of Sokoine University of Agriculture, Morogoro, Tanzania. 97pp.

Singleton, G.R (1999).Bringing science to bear on rodent control in agriculture – implications for food security in Southern Asia.*Development Bulletin*.49: 33 - 35pp.

Singleton, G.R. (1994).*The prospects and associated challenges for the biological control of rodents*.Proceedings of the Sixteenth Vertebrate Pest Conference.Paper 54. 301 - 307pp.

Singleton, G.R. (2003).Impacts of rodents on rice production in Asia. International Rice Research Institute. Discussion Paper Series No. 45, Los Banos, Philippines, 30pp.

Singleton, G.R. (2010a). CGIAR SP-IPM: Rodents – gnawing away at crops, stored grain and our health. *Technical Innovation Brief,* No. 1, January 2010. [http://www.spipm.cgiar.org/c/document_library/get_file] site visited on 7/1/2014.

Singleton, G.R. and Petch, D.A. (1994).*A Review of Biology and Management of Rodent Pest in Southern Asia*. Canberra, Australia Centre for International Agricultural Research, Canberra, Technical Report No. 30. 65pp.

Singleton, G.R. and Redhead, T.D. (1990).Structure and biology of house mouse populations that plague irregularly; an evolutionary perspective.*Biological Journal of the Linnean Society* 41: 285 - 300.

Singleton, G.R., Belmain, S.R. and Brown, P.R. (2010b).Rodents outbreaks: an age old issue with a modern appraisal. In: *Rodent outbreaks: ecology and impacts. (Edited by Singleton G.R., Belmain, S.R., Brown, P.R. and Hardy, B.)*, International Rice Research Institute, Los Banos, Philippines. 1 - 9pp.

Singleton, G.R., Hinds, L.A., Leirs, H. and Zhang, Z. (Eds) (1999).*Ecologically-based management of rodent pests*.Australian Centre for International Agricultural Research. Canberra. 494pp.

Singleton, G.R., Smythe, L., Smith, G., Spratt, D.M., Aplin, K. and Smith, A.L. (2003). Rodent diseases in Southern Asia and Australia: inventory of recent surveys. In: *Rats, Mice and People: Rodent biology and Management. (Edited by Singleton, G.R., Hinds, L.A., Krebs, C.J. and Spratt, D.M.)*.Australia Centre for International Agriculture Research, Canberra, 25 - 30pp.

Singleton, G.R., Sudarmaji, Jacob, J. and Krebs, C.J. (2005).Integrated management to reduce rodent damage in lowland rice crops in Indonesia.*Journal of Agriculture, Ecosystems and Environment* 107: 75 - 82.

Sixbert, V. (2013).Population dynamics and breeding patterns of rodent pest species and crop loss assessment in irrigated rice in Mvomero district.Dissertation submitted for partial fulfillment of the requirement for the Degree of Masters of science in Crop Science of Sokoine University of Agriculture, Morogoro, Tanzania. 72pp.

Sluydts, V., Davis, S., Mercelis, S. and Leirs, H. (2009). Comparison of multimammate mouse (*Mastomys natalensis*) demography in monoculture and mosaic agricultural habit: Implication for pest management. *Journal of Crop Protection* 28: 647 - 654.

Smith, A. (1834). An epitome of African zoology, or a concise description of the objects of the animal kingdom inhibiting Africa, its inlands and seas. 1. Mammalia. *South Africa Quarterly Journal* 2: 145 - 160.

Smith, R.H and Greaves, J.H. (1986).*Resistance to anticoagulant rodenticides: the problem and its management*. University of reading and Ministry of Agriculture, Fisheries and Food, Tolworth laboratory, Surbiton, UK. 302 – 315 pp.[http://spiru.cgahr.ksu.edu/proj/iwcspp/pdf2/4/302.pdf] site visited on 21/9/2013.

Srilakshmi, B. (2005). *Food Science* (3rd Ed).New Age International (P) Ltd, New Delhi. 401pp.

Stenseth, N.C., Leirs, H., Skonhoft, A., Davis, S.A., Pech, R. P., Andreassen, H.P., Singleton, G.R., Lima, M., Machangu, R.M., Makundi, R.H., Zhang, Z., Brown, P.R., Shi, D. and Wan, X. (2003). Mice, rats, and people: the bio-economics of agricultural rodent pests. *Frontiers in Ecology and the Environment* 1: 367 - 375.

Sudarmaji., Rochman., Singleton, G.R., Jacob, J. and Rahmini. (2003). The efficacy of a trap-barrier system for protecting rice nurseries from rats in West Java, Indonesia. In: *Ecologically-Based Management of Rodent Pests.* (*Edited by Singleton, G.R., Hinds, L.A., Leirs, H. and Zhang, Z.*), Australian Centre for International Agricultural Research, Canberra, Australia. 306 - 308pp.

Sultan, P and Jaeger, M.M. (1992).*Control strategies to reduce pre-harvest rat damage in Bangladesh*. Proceedings of the Fifteenth vertebrate pest conference.University of Caliphonia. Davis. 261 - 267pp.

Sumarno and Sutisna, E. (2010).Identification of rice (Oryza sativa l.) varieties suitable for dry season and wet season planting.*Indonesian Journal of Agricultural Science* 11: 24 - 31.

Sürek, H. and Befier N. (2003).Correlation and path coefficient analysis for some yield-related traits in rice (*Oryza sativa* L.) under thrace conditions. *Turk Journal of Agriculture* 27: 77 - 83.

Sutherland, W. J. (1996). *Ecological census techniques*: a handbook. Cambridge University Press, Cambridge, UK.

Taherzadeh, A. and Hojjat, S.S. (2013).Study of Post-harvest losses of Wheat in North Eastern Iran.*International Research Journal of Applied and Basic Science*. 4: 1502 - 1505.

Taylor, D. (1968). An outbreak of rats in agricultural areas of Kenya in 1962.*Journal of East African Agriculture*. 34: 66 - 77.

Taylor, P.J., Downs, S., Monadjem, A., Eiseb, S.J., Mulungu, L.S., Massawe, A.W., Mahlaba, T.A., Kirsten, F., Maltitz, V.E., Malebane, P., Makundi, R.H., Lamb, J. and Belmain, S.R. (2012). Experimental treatment-control studies of ecologically based rodent management in Africa: balancing conservation and pest management. *Wildlife Research*. 39: 51 - 61.

Telford, S.R. (1989). *Population biology of the Multimammate rat*, *Praomys* (*Mastomys*) *natalensis* at Morogoro, Tanzania, 1981-1985.Bulletin of Florida State Museum Biological Science. 34: 249 - 288.

The Regional Agriculture and Fisheries Information Division (2008).*Management of field rats*.Department of Agriculture, Regional Field Unit No. IV-B (MIMAROPA). 8pp.

The world factbook. (2013). The work of a nation: The center of intelligence. [https://www.cia.gov/library/publications/the-world-factbook/geos/tz.html] site visited on 4/6/2013.

United Nations Environment Program (UNEP). (2014). *Convention on migratory species: review of the ecological effects on migratory birds*. 18th Meeting of the scientific council, 1 -3 April. 2014. 81pp.

Van Elsen, K. and E. van de Fliert (1990).*Development of a Community based Programme on Integrated Rodent Management in Rice in Indonesia.* Proceedings of the Expert Panel Meeting on Rice Rodent Control, IRRI, Los Baños, Philippines. 33pp.

Vantassel, D. and Ferraro, S. (2005). Controlling House Mice. [http://www.enviroproppm.com/resources/pdfs/Mice.pdf] site visited on 6/6/2014.

Vibe-Petersen, S., Leirs, H. and Bruyn, L.D. (2006).Effects of predation and dispersal on *Mastomys natalensis* population dynamics in Tanzanian maize fields.*Journal of Animal Ecology* 75: 213 - 220.

Voznessenskaya, V.V., Naidenko, S.V., Feoktistova, N.Yu., Krivomazov, G.J., Miller L.A. and Clark, L. (2003). Predator odors as reproductive inhibitors for Norway rats. USDA National Wildlife Research Centre − Staff Publications, paper 251. [http://digitalcommons.unl.edu/icwdm_usdanwrc] site visited on 11/07/2016.

Voznessenskaya, V.V., Wysocki, C.J. and Zinkevich, E.P. (1992). Regulation of the rat oestrous cycle by predator odors: role of the vomeronasal organ. In: *Chemical signals in vertebrates. (Edited by Doty, R.L. and Muller-Schwarze, D.)*, New York, Plenum Press. 281 - 284pp.

Vries, M.E., Rodenburg, J., Bado, B.V., Sow, A., Leffelaar, P.A and Giller, K.E. (2010).Rice production with less irrigation water is possible in a Sahelian environment. *Field Crop research* 116: 154 - 164.

Walker, P.T. (1987). Empirical models for predicting yield loss caused by type of the insect: the Stem Borers. In: *Crop Loss and Pest Management. (Edited by Teng, P.S)*.America Psychopathological Society, USA. 133 - 138pp.

Weihong, J.I., Veitch, C.R. and Craig, J.L. (1999). An evaluation of the efficiency of rodent trapping methods: The effect of trap arrangement, cover type, and bait. *New Zealand Journal of Ecology* 23: 45 - 51.

Whitaker, R. and Dattatri, S. (1986). The role of reptiles in controlling food pests. In: *How does rodent behavior impact on population dynamics?* (Krebs, C.J.), Australian Centre for International Agricultural Research, Australia. 115 - 123pp.

White, J.G., Wilson, J. and Horskins, K. (2003). Habitat manipulation and rodent damage control: reducing rodent damage in Australia macadamia orchards. In: *Rats, Mice and People: Rodent Biology and Management. (Edited by Singleton, G.R., Hinds, L.A., Krebs, C.J and Spratt, D.M.)*.Symposium, 4. 213 - 216pp.

Wiese, M.V. (1982). *Crop Management by Comprehensive Appraisal of Yield Determining Variables*.Annual Review of Phytopathology. Vol. 20: 419-432.

Witmer, G.W., Moulton, R.S and Swartz, J.L. (2012).*Rodent burrow systems in North America: Problem posed and potential solution*. Proceeding of the 25th Vertebrate Pest Conference.(Edited by Timm, R.M). University of California, Davis. 208 - 212pp.

Wood, B.J. (1985). Biological control of vertebrates: a review and assessment of prospects for Malaysia. *Journal of Plant Protection* 2: 67 - 97.

Worldwide rice production. (2011). Rice Production ChartsBin.[http://chartsbin.com/view/1009] site visited on 4/1/2014.

Yoshida, S. (1981).*Fundamentals of rice crop science*. IRRI. Manila, Philippines. 279pp.

Yoshida, S. and Parao, F.T (1972). Performance of improved rice varieties in the tropics with its special reference to tillering capacity *Experimental Agriculture* 8: 203 - 212.

Yue, B., Xue, W., Xiong, L., Yu, X., Luo, L., Cui, K., Jin, D., Xing, Y. and Zhang, Q. (2006). Genetic basis of drought resistance at reproductive stage in rice: separation of drought tolerance from drought avoidance. *Genetics* 172: 1213 - 1228.

Zaman V. (1976).Host range of *Sarcocystis orientalis*. In: *Biological control of rodents using Sarcocystis singaporensis (Edited by Jakel, T., Khoprasert, Y.,*

Endepols, S., Archer-Baumanna, C., Suasa-ard, K., Promkerd, P., Kliemt, D., Boonsong, P. and Hongnark, S.), *Parasitology* 29: 1321 - 1330.

Zhang, Z., Xu, L., Guo, C., Wang, Y. and Guo, Y. (2010).Effect of ENSO-driven precipitation on population irruptions of Yangtze vole Microtus fortis calamorum in the Dongting Lake region of China.*Integrative Zoology* 5: 176 - 185.

Zubaer, M.A., Chowdhury, A.K.M.M.B., Islam, M.Z., Ahmed, T. and Hasan, M.A (2007). Effects of water stress on growth and yield attributes of Aman rice Genotypes. *International Journal of Sustainable Crop Production* 2: 25 - 30.

APPENDICES

Appendix 1: Simulated experiment, cut at maturity stage (a) 10% cut (b) 20% cut (c) 25% cut and (d) 50% cut
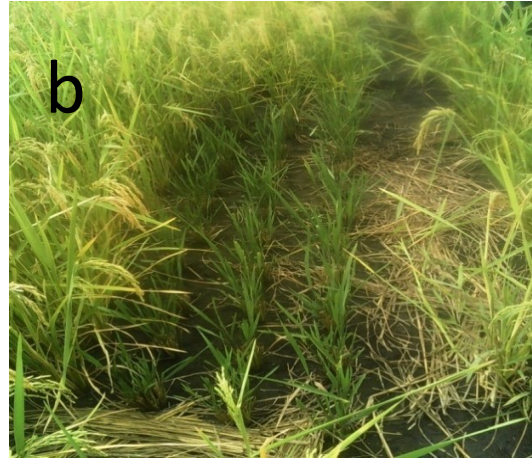
Appendix 2: Some of rodent pest captured(both *M.natalensis*) in the study area