EVALUATION OF TRAP BARRIER SYSTEM FOR RODENT MANAGEMENT IN IRRIGATED RICE ECOSYSTEM IN MKINDO VILLAGE, TANZANIA

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A DISSERTATION SUBMITTED IN FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF CROP SCIENCE IN CROP PROTECTION OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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ABSTRACT

Rodents are one of the major factors limiting crop production in Central-eastern Tanzania. A study was conducted at Mkindo village from July, 2016 to July, 2017 to evaluate the effectiveness of trap barrier system (TBS) as rodent pest management tool in rice, which enclosed a crop planted 2 weeks earlier (trap-crop). The trap barrier of 10 m by 10 m was constructed using poles dug 50 cm into the ground and standing 1.5 m above the ground. A polythene sheet measuring 45 m in length and 1 m in width was rolled around the staked poles of wood. Two live-multiple-capture traps were placed at the base of the polythene on each side of the trap barrier. Damage to tillers and yield loss were assessed within the trap-crop and at 0, 10, 20 and 30 m on each side of the trap barrier. The effect of TBS on mean yield increased up to 20 m and 30 m in dry and wet season respectively from the trap crop. Two crops were monitored: dry season crop when rat densities were high and wet season crop when rat densities were low. Results show that there were no significant differences in rodent abundance between seasons and crop growth stage in farmers managed rice fields where *Mastomys natalensis* was the most abundant rodent pest species. Higher yield was recorded during the wet season compared to the dry season. The cost benefit ratios for using a TBS were 1:1.1 for the dry, 1:6.7 for the wet season. This showed potential of TBS in rodent management for reducing population abundance and crop damage in lowland rice in Tanzania. TBS surrounding crops provided cost-effective protection against pre-harvest rat- caused losses to rice in the dry season when rodent densities are highest. It is recommended that small scale farmers use TBS to reduce pre-harvest rat losses of rice in the dry season as opposite to wet season. This will help them to maximize their profits and improve their living standards. Further studies are needed to test this new technology in other irrigation schemes in Tanzania.

DECLARATION

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

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DEDICATION

I dedicate this work to my lovely mother ELESI KABWOGI for her heartfelt love, care and constant encouragement.

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LIST OF ABBREVIATIOS AND ACRONYMS

BCR	Benefit Cost Ratio
CBA	Cost Benefit Analysis
DAS	Days After Sowing
FAO	Food And Agriculture Organization
ha	Hectare
IPM	Integrated Pest Management
IRRI	International Rice Research Institute
M	Metre
m.a.s.l	Metre Above Sea Level
m^2	Metre Square
N	North
N	Sample Size
NR	Net Revenue
S	South
SD	Standard Deviation
Spp	Species
SUA	Sokoine University of Agriculture
t/ha	Tone Per Hectare
TBS	Trap Barrier System
TC	Total Cost
USA	United States of America

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Rice (*Oryza sativa L*) is among the three leading food crops in the world followed by maize (*Zea mays L*) and wheat (Wayne, 2003). 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). It is also the staple food across Asia where around half of the world's poorest people live and is becoming increasingly important in Africa and Latin America (IRRI, 2012). Rice provides not less than 42% of the world's required caloric intake where in 2009, human consumption was responsible for 78% of the total usage of produced rice (IRRI, 2009).

According to IRRI (2009), the top rice producing countries in millions of hectares include India (43.2), China (30.35), Indonesia (12.16), Bangladesh (12.00), Thailand (9.65), Vietnam (7.66), Burma (6.8), Philippines (4.5), Cambodia (2.9) and Pakistan (2.85). These countries are also among the top rice consumers of the world, and combine to account for around 90% of the world's rice consumption. More than 90% of the rice area in China is irrigated, with only relatively small areas being cultivated under rain fed conditions. China is the world's largest rice producer around 193 million metric tons (FAO, 2008), which accounts for as much as 35% of total world rice production.

In Africa, rice is one of the most important cereals grown in countries of Eastern and Central Africa (Alabi *et al.*, 2006). In Tanzania; rice is produced under typical monoculture systems (Nguyen, 2002) that can be subdivided into three agro-ecosystems:

rain fed lowland (74%), rain fed upland (20%) and irrigated lowland (6%). Rice in Tanzania is used almost entirely for human food (NBS, 2006) of about 30 per cent of rice is consumed at household level. Almost all the remainder is absorbed into the domestic market, with consumption highest in larger urban areas (FAO, 2005).

The leading paddy production regions in Tanzania include Mbeya (8.5%), Shinyanga (18.5%), Mwanza (13.6%), Morogoro (19.7%) and Tabora (10.2%) (National Sample Census of Agriculture, 2002 and 2003), where the average yield ranges from 1 to 1.5 t/ha which is significantly lower than that of Africa and that of the world (mean yield of 2.2 t/ha and 3.4 t/ha, respectively) (Nguyen, 2002). Most of the rice grown by small farmers depends on rainfall and many irrigation schemes need urgent rehabilitation. However, the yield and performance of wet land rice planted in different countries still exhibit wide variations due to the varying climate, land and soil, water supply, farming practices, socio-economic conditions and other biological agents such as rodents (Buckle, 1994).

In many countries, farmers consider rodents as an inevitable pest in their fields (Meerburg *et al.,* 2009). Massawe *et al*. (2006) reported that farmers in Tanzania have always considered rodent damage as inevitable. Thus they consider chronic rodent damage as something beyond their control. In Philippines, farmers tend to ignore rodent problems on standing rice when cut tillers are less than 5% (Hoque *et al*., 2008). The authors reported that farmers tend to seek help or apply control measures when rat damage is higher than 5% or when damage occurs at a critical stage of the crop. Rat damage to ripening rice crops in Asia, Africa, and Latin America can be an extremely serious agricultural problem, although economic losses are often difficult to estimate because of complex patterns of growth and recovery of plants related to the developmental stage when damage occurs (Fall, 1977, 1980; Buckle, 1994).

Rats can completely consume fields of growing rice and sometimes prevent planting where crops could otherwise be grown (Wood, 1994). In Africa, rodents are the most important agricultural pest. The severe crop damage they cause is a result of their omnivorous and opportunistic feeding behavior, extraordinary reproductive capabilities and a propensity for close association with human settlements. Multimammate rats thrive in the presence of cultivation and readily enter homes, damage stored foods and spread disease (Robbins *et al*., 1989). According to Mulungu *et al*. (2013), crop losses caused by rodents are largely attributed to *Mastomys natalensis*, the most economically important and widespread rodent pest across sub-Saharan Africa. Odhiambo *et al.* (2008) reported that *M. natalensis* is an opportunistic feeder consuming all types of food in different amounts reflecting the availability of food categories in its habitat. Outbreaks of this rodent species in rice cropping areas have been reported to cause severe crop damage and food shortages (Singleton *et al*., 2010) due to its effect from sowing to physiological maturity of the crop.

1.2 Justification

Subsistence farmers in Tanzania continue to lose rice crop from sowing to maturity as a result of rodent infestation resulting to food shortage (Mulungu *et al*., 2014). They do cause serious damage to crops (such as cereals, root crops, cotton and sugarcane) both before and after harvest. They also damage installations and are reservoirs or vectors for serious infectious diseases (Stenseth *et al*., 2003). Rodent damage to crops such as rice is a serious impediment in agriculture sector (Singleton *et al*., 1999a). It has been reported from West Java that cumulative damage to rice during the dry season was 54% at the primordial stage, 32% at the booting stage and 16% at the ripening stage (Singleton *et al*., 2005).

In Tanzania, rodents cause an estimated 10-25 pre-harvest loss of rice annually (Singleton *et al*., 2010). Farmers, however, try to minimise the crop damage and yield loss caused by rodents by adopting different rodent control methods including poisons (rodenticides), burrow digging to kill rodents, use of buckets, use of live traps, and kill traps (Mulungu *et al*., 2015). Most subsistence farmers rely mostly on the use of rodenticides (Makundi *et al.*, 1999). Both acute and chronic rodenticides have been used extensively during rodent outbreaks (Ngowo *et al*., 2005). These chemicals carry significant economic costs and, if used inappropriately, can kill non-target animals and have a negative effect on environment and human health. It can occur when the dead bodies of poisoned rats are eaten by other animals such as birds where the toxin enters the food chain causing death to a variety of other animals including human (Massawe *et al.*, 2006).

Sometimes baiting using acute rodenticides especially zinc phosphate is only used during rodent outbreak (Massawe *et al.,* 2006). However, rodents are able to multiply fast and re-colonise the farms after rodent control operation (Leirs *et al*., 1997). Rodenticides are generally an integral part of successful rodent pest management and, in some tropical habitats, are the only practical method available (Buckle, 1999). Unfortunately, farmers and extension personnel are often confused or uninformed as to how a particular product may be effectively used. Limitations in the use of rodenticides include: (i) some rodenticides are not available on farmer's locality. In some areas, farmers attempt to buy rodenticides from local vendors for control of rodents in their fields themselves. However, most of them report of inefficient control of rodents by the rodenticides they buy due to some vendors selling fake materials that are claimed to the rodenticides. Also improper use of rodenticides and other chemicals for rodent control is a problem because farmers lower doses of rodenticides and apply insufficient amounts. However, the dose supplied can result to resistance in some rodent species. (ii) Acceptability of bait formulations by rodents (often influenced by palatability under field conditions). In rodent pest management programs, poison baiting is the most widely used technique throughout the world (Gratz, 1973; Muktha, 1996). Although rodenticides can be incorporated either in bait, dust or water formulations (Pratt, 1983), they are generally included in food baits to achieve good control.

Much effort has been made to improve the palatability of rodent baits to ensure maximum ingestion by the target rodent pests and thereby improved efficacy. (iii) The timing of bait application: In some areas farmers report rodent outbreaks and request for control assistance after they observe crop damage in their fields. This result into delayed control as it takes time for information the responsible government agency. This is critical for alleviating damage (Makundi *et al.*, 1999; Mulungu, 2013). (iv) P+overty; many small scale farmers are poor and therefore cannot afford to buy rodenticides (Makundi *et al.*, 2010).

In addition, the use of rodenticides and other control methods provide only a short-term solution,they are not effective in cases of high populations as has been reported in irrigated rice systems where rodent breed throughout the year (Mulungu *et al*., 2013; Mulungu *et al.*, 2017). Therefore, to minimize those problems, alternative measures has been sought and one of them being the use of Trap Barrier System (TBS).

Trap Barrier System is a new environmentally-friendly, physical rodent control method in Africa. It has been proved proved very successful in irrigated rice fields in south eastern Asia to control rats, is a cost-beneficial and sustainable solution (Singleton, 1997). Rodents seem to cause little damage, but in fact they cause significant damage leading to widespread famine or major effects on livelihoods of small-scale farming families

(Singleton *et al.,* 2010). In Malaysia, rodents have caused yield losses of 5 %, while in Indonesia; 15 - 17% of the total planted area is estimated to be damaged annually (Singleton, 2003). In Tanzania loss by rodents has been estimated to be between 5 and 15 % (Makundi *et al.,* 1999), this amount is equivalent to 412.5 tonnes per year sufficiently to feed more than 2 million people for the entire year. Therefore, the use of Trap Barrier System could work with African rodent pest especially *M. natalensis* which is the major rodent pest species in sub-Saharan African countries including Tanzania (Mulungu *et al*., 2003).

1.3 Objectives

1.3.1 Overall objective

To investigate the effectiveness of Trap Barrier System (TBS) as rodent pest management tool in irrigated rice ecosystems.

1.3.2 Specific objectives

i. To evaluate the influence of Trap Barrier System on rodent population abundance.

ii. To determine the effective distance of Trap Barrier System for rodent management.

iii. To evaluate the cost benefit ratio on the use of Trap-Barrier System.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Ecology and Distribution of Multimammate rat (*Mastomys natalensis*)

Generally, rodents are the most successful and abundant mammals on earth, they are able to live in diverse climatic and geographic conditions where they thrive primarily on wild plants and crops, respectively (Fiedler, 1994). In East Africa more than 25 species of rodents have been recorded as agricultural pests (Massawe *et al*., 2006; Makundi *et al.*, 2007), whereby 12 species have been recognized as most notorious pests. The widely distributed rodent species reported in East Africa include house rat (*Rattus rattus L*.), Multimammate rats (*M. natalensis*), grass mouse and *Arvicanthis niloticus.* However, severe damage to rice crop in field is associated largely with *M. natalensis* thus the need for their management. The *M. natalensis* is a wide spread African murid rodent which belongs to the family muridae, the most common rodent in sub-Saharan Africa (Monadjem *et al*., 2015). It is the most abundant and most widely spread field rodent in Tanzania (Odhiambo, 2008).

Mastomys natalensis has the widest distribution of all African rodents (Colangelo *et al*., 2013), and are almost ubiquitously distributed across the African continent (Kennis *et al.*, 2008). *Mastomys natalensis* are characterised by high reproduction rate and dispersal that contribute to the success as a serious pest. The breeding season and growth of *M. natalensis* in Tanzania is much influenced by rainfall patterns which controls food availability in maize dominated cropping and farm-fallow mosaic landscape (Leirs *et al.*, 1997). However, in irrigated rice cropping system, breeding of *M. natalensis* occurs throughout the year due to the availability of food and water (Mulungu *et al.*, 2014).

2.2 Outbreaks of Rodent

Rodents have long been the scourge of smallholder farmers in many rice-growing regions in Asia and throughout the world. The most common rodent in sub-Saharan Africa is Multimammate rats. Stenseth *et al.* (2003) and Singleton *et al*. (2010) reported that, rodent outbreaks have been reported worldwide where cultivation of agricultural crops is conducted. According to Leirs (1995) outbreaks of *M. natalensis* can exceed 1000 animals per hectare, nevertheless damage and economic losses are significant even in years with low population densities. Tanzania experienced several irregular outbreaks in maize and rice fields in many regions such as Lindi, Morogoro, Dodoma, Singida and Tanga (Mwanjabe *et al*., 2002; Mulungu *et al*., 2012). The occurrence of rodent outbreaks in Tanzania is influenced by the rainfall pattern (Leirs, 1995). It is reported that, rodents breed during the long rains and usually starts one month after the usual peak rainfall, lasting until dry season (Leirs, 1995). Neonates grow slowly and normally do not mature before the next rainy period. Unless abundant rains appear before March and April the following year, they will be at least six months old before they begin to breed (Leirs, 1995). However, if the short rains are abundant, sub-adults mature and may breed as early as January. Neonates in such early breeding seasons grow fast and mature in their third month, starting to breed during the main breeding period. This additional generation allows the development of high densities later in the year (Leirs *et al*., 1996).

In 2004, there was an outbreak of *M. natalensis* populations in lowland irrigated rice in Mvomero distinct, Morogoro region. Outbreaks of this rodent species in rice cropping areas have been reported to cause severe crop damage and food shortages (Singleton *et al*., 2010; Makundi and Massawe, 2011).

2.3 Rodent Behaviour

Most rodents are herbivorous, feeding exclusively on plant material such as seeds, stems, leaves, flowers, and roots. Some are omnivorous and a few are predators. The field vole is a typical herbivorous rodent and feeds on grasses, herbs, root tubers, moss, and other vegetation, and gnaws on bark during the winter. It occasionally eats invertebrates such as insect larvae. Larger rodents tend to live in family units where parents and their offspring live together until the young disperse. Because of the high reproductive capacity of rodents; their populations can grow rapidly to utilize available habitat and food (Jacob, 2002). In stable environments rodents self-regulate their populations. Where by a population reaches the carrying capacity of an environment, reproduction declines and excess animals die (usually from disease, parasites, or predation) or immigrate to new areas. Yet rodents can survive in very adverse conditions even nuclear explosions by living in underground burrows (Jackson, 1972) and rebuilding their populations when conditions again become favourable. According to Fiedler and Fall (1994), habitat disruption or climatic changes that lead to increases in food and harbourage sometimes give rise to population outbreaks or irruptions of some rodent species. This results in extremely high populations that can inflict severe damage on crops.

Rodent population eruptions may result in damage that is highly visible and often spectacular, devastating crop fields over wide areas. In management strategies; movement, feeding and social behaviour are the most important aspects (Sridhara, 2006). Movement and the behaviour of rodents would quickly lead them into traps or results in their feeding on poison bait. It is reported that, different places undergoes periodic population eruption, forexample *Rattus argentiventer* in Southeast Asia, the Multimammate rats (*Mastomys natalensis*) in Africa, *Mus musculus* in Australia and Hawaii, the jirds, *Meriones hurrianae* and *Meriones shawi*, in South Asia and North

Africa, the Microtines (Voles and Lemmings) in Eurasia and North America, and cotton rats (*Sigmodon hispidus*) in southern USA and Central America (Wolff *et al*., 2007). Accordingly, rodents tend to avoid any strange object that is encountered in familiar surroundings. This behaviour is called *"neophobia"* or *"New object reaction"* (Kilonzo, 2006; Sridhara, 2006). Furthermore, rodents prefer locally available and nutritious tasty food (Kingdon, 1997; Sridhara, 2006). Therefore, knowledge on rodent behaviour helps deciding when to apply certain control measures. Observations show that rodent control in rice fields should be done before transplanting to reduce rodent population.

2.4 Economic Importance of Rodents

Few rodent species do very well in agricultural fields, but with nevertheless dismaying consequences. Rodents represent a major pest problem worldwide, both in the countryside and in the cities (Skonhoft *et al.,* 2006). They are currently considered to be one of the most impediments to an increased crop yield (Odhiambo, 2005). In sub Saharan Africa, the major rodent species causing severe damage to crops belong to the genus Mastomys (Massawe, 2003). Rodent pest consume and damage human foods in the field and stores. Through their gnawing and burrowing habit they destroy many articles (packaging, clothes and furniture). They are responsible for transmitting disease dangerous to man. Rat damage to ripening rice crops in Asia, Africa, and Latin America can be an extremely serious agricultural problem, although economic losses are often difficult to estimate. This is due to complex patterns of growth and recovery of plants related to the developmental stage when damage occurs (Fulk, 1981).

The amounts of food that are lost due to damage by rodents in crops are large and there is a pressing need for effective in- field rodent management (FAO, 1998). Rats can completely consume fields of growing rice and sometimes prevent planting where crops could otherwise be grown. For example, *Bandicota bengalensis* in southern Asia cuts mature rice in large patches and establishes extensive underground food caches. Similarly *Rattus tanezumi*, *M. natalensis* in Africa and *Rattus argentiventer* in the Philippines and other areas of Southeast Asia feed upon all stages of growing rice (Fulk, 1981), while *Sigmodon hispidus* in Central America avoids wet areas in rice fields and causes damage after water is removed when drying the crop before harvest. In addition, rodents are responsible for serious damage to crops before and after harvest, reservoir or vectors of zoonotic diseases as well as damaging some infrastructures (Begon, 2003; Stenseth *et al*., 2003).

However, besides their detrimental effects to the economy, rodents are also beneficial in some aspects such as in balancing the ecosystem through food chain, providing important protein supplement to the diet of people in many places in Asia, Africa and South America. They are useful in research and training (Singleton *et al*., 2010).

2.5 Rodent Damage to Crops

Rodents are primarily as consumers of grain that are the foodstuff for man. It has been estimated that rats and mice destroy up to one-third of grain crops under conditions of heavy infestation. Burrowing rodents may damage root crops. Rodents, particularly rats, substantially cause damage to rice fields (Singleton, 2010). They eat rice seeds and seedlings, gnaw tillers, damage plants, and feed on grains (Reissig *et al*., 1985; Brown and Singleton *et al*., 2001). In Tanzania, rats have been addressed as the major threat in rice crop production system. Farmers keep on controlling the pest to meet household food demands. Rodent damage to rice can be measured at several stages of crop growth. 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 consequently necessitates repeated late replanting (Mwanjabe, 1993; Makundi *et al*., 1999; Brown *et al*., 2006) and ultimately result in lower yield (Taylor, 1968; Myllymäki, 1987; Mulungu, 2003). At vegetative stage, rats cut rice tillers and use them for feeding (Reissing *et al*., 1985) and building their nests (Gergon *et al*., 2008). 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 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, MyPhung *et al*. (2010) 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. In West Java, monocultures of lowland irrigated rice, cumulative damage to rice during the dry season was 54% at the primordial stage, 32% at the booting stage, but only 16% at the ripening stage. Rodents have major impacts in agriculture in most parts of the world by attacking crops at any growth stage. However according to Mulungu *et al*. (2003) the impact of rodent damage on final yield depends on the country, season and crop type. For example, in Vietnam, rodent pests have been serious since 1995 and considered top three agricultural problems in pre harvest of low land irrigated rice (Brown *et al.*, 2003).

2.6 Rodent Pest Management

In tropical countries, rodents pose a continuous problem because of the climatic conditions, uninterrupted food supply and relatively open structures. Therefore the control of rodent pest should be approached as a management problem much more than a simple and single poisoning action. 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, 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). Many different methods for controlling rodent's pests have been passed down through folklore or have been tested and proven effective in particular situation (Lagwen, 2016)

Measures to control rodent pests are based on traditional, historical and conventional; they can be lethal methods (e.g. trapping, chemical, toxicants and biological control) and non-lethal (e.g. use of repellents, habitat manipulation and cultural practices, exclusion/fencing) (Sridhara, 2006; Mulungu *et al.,* 2010). The major methods of achieving satisfactory mortalities are physical killing by trapping as well as rodenticides (Makundi *et al.,* 2005; Sarker *et al.,* 2013). However, killing with rodenticides during rainfall and in irrigation schemes are destroyed by water hence loss its effectiveness and increase the chances of poisoning to non-target organisms (Thakur *et al.,* 2013).

2.6.1 The lethal or population reduction approach

Rodents are disinclined to gorge on an unknown food (perhaps reflecting an adaptation to their inability to vomit), preferring to sample, wait and observe whether it makes them or other rats sick. This phenomenon of poison shyness is the rationale for poison that kills only that kill only after multiple doses. Besides being directly toxic to the mammals that ingest them, including dogs, cat and humans, many rodenticides present a secondary poisoning risk to animals that hunt o scavenge the dead corpses of rats. It 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 methods always requires a period of time before they become stable and provides substantial results (Bale *et al.*, 2008).

2.6.1.1 Biological control

Pathogens and predatory animals are the main agents used for the biological control of rodents. The pathogens that have been used are of the genus Salmonella; none is rodent-specific and all can cause severe infection in man and domestic animals. The introduction of predators to control pests is an ecologically and conceptually appealing approach for reducing rodent pest populations. Introducing biological agents to control rodents is a promising area for research, but many challenges remain to find a candidate which is sufficiently pathogenic to achieve the desired level of control, has a high transmission rate, and is target specific (Singleton *et al*., 1990).

The introduction of predators to control pests is an ecologically and conceptually appealing approach for reducing rodent pest populations. Introducing biological agents to control rodents is a promising area for research, but many challenges remain to find a candidate which is sufficiently pathogenic to achieve the desired level of control, has a high transmission rate, and is target specific (Singleton *et al*., 1980). The role of natural predators in controlling rodent pests is an interesting, but frequently misunderstood, concept that rarely is effective in reducing pest populations to tolerable levels (Howard, 1967; Nelson, 2002).

The introduction of barn owls, for example, to Hawaii for rodent control in the 1960s was ineffective. Some studies on barn owl in lowland Southern England revealed that barn owls can adapt and establish to various living conditions in which rodent population exist (Tobin, 1990). In Malaysia, the barn owl was reported to suppress rodents in rice fields resulting into significant lower crop damage (Hafidzi *et al*., 2003). Successful introduction of exotic vertebrate predators into new areas for pest control purposes has never been demonstrated and, in some cases, has resulted in unanticipated, calamitous ecological effects (Taylor, 1984). During the late 1800s, the small Indian mongoose (*Herpestes javanicus*) was introduced into both the West Indies and Hawaii to control rat populations in sugarcane fields (Cox, 1999). Although this predator survives in some areas on a diet composed mainly of rats (Baldwin *et al*., 1952, Kami, 1964), the introductions failed to achieve the desired result of reducing rat populations in sugarcane fields. Often, predators aren’t able to keep rodent numbers below levels that are acceptable to most people. Further, pet food can serve as an attractant and provide a continuous food supply to rats and mice in suburban environments.

2.6.1.2 Trapping

Trapping is the safest and most effective method for controlling rats in and around homes, garages, and other structures. Trapping is less costly than poison bait but more labour intensive. Trapping of rodents around the houses help to reduce rodent population, although depends on the type of traps used. Traps for catching mice are different from those for catching rats. Trapping is widely used by specialists for surveillance and monitoring of rodent infestations and is, perhaps, the most selective technique to remove individual rodents from problem situations (Massawe *et al*., 2006). Although trapping is very labour intensive and requires skill to be used effectively, its relatively low cost compared to other approaches often makes it a primary method of choice for rodent control. Trapping is also utilized where non-target animals are an important concern or where use of toxicants or other more effective methods are prohibited (Fall *et al*., 1998). Trapping generally is not practical for managing large infestations or removing entire populations over extensive areas (Gosling *et al.*, 1989). However, traps can be used effectively in limited areas or where substantial resources are available and more efficient techniques cannot be used or developed (Gosling *et al*., 1989).

2.6.1.3 Rodenticides

Rodenticides are a heterogeneous group of compounds that exhibit markedly different toxicities to humans and rodents. Some rodenticides are lethal after one exposure while others require more than one. Toxicants frequently are the most practical and cost effective tools for reducing rodent populations over large areas (Dunlevy, 2000). Rodenticides require minimal manpower to apply and, when properly formulated and applied, have the potential to provide quick results with minimal impact on the environment and non-target animals (Caughley *et al*., 1998). Farmers in Tanzania, use rodenticides (zinc phosphate as an acute and bromadioline as chronic) as part of rodent management practices (Lagwen, 2016). However, most of rodenticides used are registered as a restricted product which needs to be used only by trained personnel to handle the chemical. Although rodenticides remain the most frequently used tools, they have a number of negative impacts to environment and development of bait toxiphobia caused by acute rodenticides (Mulungu *et al.*, 2003).

The use of rodenticides is rarely economically and ecologically sustainable because they are often applied only when damage has already occurred (Mulungu *et al*., 2003; Sokonhoft *et al.*, 2006). Therefore, there is an urgent need to think on alternative rodent control measures which reduce risks to environment and other beneficial organisms. The failure of many rodenticide baiting programs results not from bait shyness or resistance to toxicants, but because of improper application of bait (Mulungu, 2003). Rodenticide baiting programs used by some Hawaiian macadamia growers were ineffective because rats spent most of their time in the orchard canopy and rarely consumed baits that were broadcasted on the orchard floor (Tobin *et al*., 1997).

2.6.2 The non-lethal or preventive measures

The most obvious way to deal with a pest that is causing damage is to remove the pest, which usually means killing it. This direct approach may not be either the most effective or the most economical in practice though. For this reasons, the population may be regulated if the preventive measures are considered. The non-lethal or preventive measure involves habitat manipulation or cultural practices, exclusion/fencing and use of repellants. These methods prevent and reduce immigration of rodents; forcing rodents to emigrate; reduction of pest birth rate; and increase pest mortality (Smith *et al.,* 2015).

2.6.2.1 Environmental sanitation

Sanitation is fundamental to rat control and must be continuous. If sanitation measures aren’t properly maintained, the benefits of other measures will be lost and rats will quickly return either in the field or house. Environmental sanitation approach involves the removal of fallow patches in crop fields (Massawe *et al.*, 2006). Thick grass and bushes provide harbourage and supplementary food resources to rodents. In Tanzania, the practices for environmental sanitation has been done by farmers through slash and burning fields before sowing and harvesting as a way of displacing rodent population (Massawe *et al.,* 2006). Environmental sanitation approach involves the removal of fallow patches in crop fields (Massawe *et al.,* 2006). Thick grass and bushes provide harbourage and supplementary food resources to rodents. In Tanzania, the practices for environmental sanitation has been done by farmers through slash and burning fields before sowing and harvesting as a way of displacing rodent population (Massawe *et al.*, 2006). Deep ploughing and regular weeding has been reported to suppress rodent population due to destruction of nests, removal of alternative source of food and harbourages (Masawe e*t al.,* 2003). However, sanitation is not significantly effective as most farmer's practices on which small plots are interspersed with patches of fallow and permanent grassland (Masawe *et al.,* 2003).

2.6.2.2 Use of repellents

Repellants may also be used to deter rodent populations. Both natural and chemical-based repellants are commercially available and vary in effectiveness. According to Masol *et al.* (1994), the behavioral defense of pest against dietary poisoning and on semi chemical influences their feeding. Voznessenskaya *et al*. (1992) reported the exposure to predator odour to cause disruption of the oestrous cycle. Voznessenskaya *et al*. (2003) reported reduced 26 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. Mulungu *et al*. (2016) and Mulungu *et al*. (2017) observed a significant difference in rodent activities which however, depended on the sex of the cat that donated the urine base. Female cat urine extract repelled significantly more rodents as compared to male cat urine extract. The author further reported that the repellent effect was observed from day 1 to 4; but not beyond. 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, Lagwen. (2016) 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.

2.6.2.3 Exclusion/fencing

This technique involves assessing the conditions for attraction and preventing infestation by eliminating their entry access, closing gaps and small holes, sealing common entrance points, assessing hard-to reach high places (roofs, eaves, attics) and crawl space to close openings for easy access. It is mostly practiced in smaller areas or in valuable crops like seedbeds and research plots (Fielder *et al*., 1994). 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 *et al*., 2007).

2.7 Integrated Pest Management

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. A successful rodent control strategy typically includes environmental sanitation, trapping, population control if necessary etc. Establishment of action thresholds before taking any pest control action, action threshold should be set a point at which pest populations or environmental conditions indicate that pest control action must be taken. Sighting single pest does not always mean control is needed. The level at which pests will either become an economic threat is critical to guide future pest control decisions.

2.7.1 Monitoring and identifying pests

People don't know often see rats, but signs of their presence are easy to detect. In California, the most troublesome rats are two introduced species, the roof rat and the Norway rat. It's important to know which species of rat is present in order to choose effective control strategies. 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.

2.7.2 Prevention

As a first line of pest control, IPM programs work to manage the crop, lawn, or indoor space to prevent pests from becoming a threat. Integrated pest management 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. The best way to prevent a rodent infestation and contact with rodents is to remove the food sources, water and items that provide shelter for rodents.

2.7.3 Population control

Rodents thrive on the rich food supply provided by the agricultural production system. When food, water and shelter are available, rodent population can increase quickly. While the most permanent form of control is to limit food, water, shelter and access to buildings, direct population control often is necessary. The application of rodent control is often poorly timed or inadequate, so that populations recover quickly, or else control is performed in response to high rodent numbers, after the damage has been done (Carlson *et al*., 1993) .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. 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.

2.8 Trap Barrier System (TBS)

Rodent is one of important pests attacking rice both in vegetative and generative phases. Impact of rodents on variety of agricultural crops has been detrimental throughout the world. Damage appears to augment with their sufficiently large population influx among the cultivations and indoor situations. Farmers commonly rely on chemical and physical methods to control rodents, which are applied spontaneously and eventually less effective and are hazardous to the environment and human health (Palis *et al*., 2007; Singleton *et al*., 2010). 2.9 Cost Benefit Ratio (CBR). A promising method of rodent control is the use of a physical barrier with live-multiple capture traps inserted intermittently at the base. The TBS for rodent control in rice fields is an ecologically based rodent management strategy that aims to manage a low rat population in a sustainable and environmentally sound manner (Singleton *et al.*, 1999). This TBS was developed in Malaysia to control populations of *Argentiventer* spp in rice crops

(Singleton, 1999). The TBS works on the principle that after rats makes contact with the barrier; they take the line of least resistance by following it along until they come to the opening of a trap which they then enter.

Singleton *et al.* (1998; 1999), reported that effectiveness of TBS for rodent management and without exerting any impacts on the sustainability of agricultural systems. Integration with the trap barrier system strongly emphasizes on not only reducing the rodent damage, but also on socioeconomic benefits in the cultivations of Indonesia, Philippines, Thailand, Vietnam and the delta of Mekong river in China (Brown *et al*., 2006; Davis *et al*., 2004; Singleton *et al*., 1998; 2003; Tuan *et al*., 2003). Although diversity among rodents' damage patterns may be a predicament to reduce their continued damage profiles in wake of favorable ecological conditions in Punjab, but the implications of ecologically based TBS constitutes the perfect basis for their management without altering the productivity of the agro-ecosystems.

The benefit-cost ratios for the dry and wet seasons, respectively, indicate the strong potential of a TBS with trap-crop for managing the rice field rat (Singleton *et al.*, 1990). This is in contrast to the use of a TBS alone in Malaysia and the Philippines, requires crop losses of > 30% before there is a positive benefit-cost ratio (Singleton, 1994). There has been only one report in Southeast Asia of high benefit-cost ratios for a TBS alone: ratios of 19: l and 28: l in Malaysia in a region where 56% of rice farms had suffered complete yields losses (Lam, 1993). Integration with the Trap Barrier System strongly emphasizes on not only reducing the rodent damage, but also on socioeconomic benefits in the cultivations of Indonesia, Philippines, Thailand, Vietnam and the delta of Mekong river in China (Brown *et al*., 2006; Davis *et al*., 2004; Singleton *et al.*, 1998; 2003; Tuan *et al*., 2003). Although diversity among rodents' damage patterns may be a predicament to reduce their continued damage profiles in wake of favorable ecological conditions in Punjab, but the implications of ecologically based trap barrier system constitutes the perfect basis for their management without altering the productivity of the agro-ecosystems.

In Vietnam, rice production is prone to damage by rodent pests. In 1997, rodents were classified by the Ministry of Agriculture and Rural Development of Vietnam as one of the three most important problems that the agricultural sector faced (Singleton *et al*., 2003). In a recent consultation with rice farmers in 2017, rodents were mentioned as one of the most common pests (Palis *et al*., 2007). Implications of trap barrier system throughout the sub habitats, reduced the rodent populations' abundance, to the ecologically acceptable limitations Present studies proved to be effective point indicators for effectiveness of the TBS to decrease house mouse (*Mus musculus* Linn) infestations on maize on all growth stages, but with elevated intensity for the flowering stage, resulting in maximum capture in Faisalabad and Jhang Pakistan (Kanwal, 2016).

The TBS approach first found favors with farmers who had acute rat problems or were trying to reclaim abandoned rice fields in Malaysia. Under such circumstances, as many as 6872 rats were caught in one night and 44,101 rats in 9 weeks (Lam *et al*., 1990). These are extreme cases where the subsequent reduction in rat damage to crops, more than compensate for the monetary outlay for the TBS. Cost benefit ratio is an indicator of the relative economic performance of the treatments (Aziz *et al*., 2012). It is the ratio of the benefits of a project or proposal, expressed in monetary terms, relative to its costs, also expressed in monetary terms (Weisbrod *et al*., 1969). A ratio above one indicates that the investment will be profitable while a ratio below one means that it will not (Boardman, 2006).

2.9 Evaluation of Costs and Benefits

The final step when creating a cost benefit analysis is to weigh the costs and benefits to determine if the proposed action is worthwhile. Through comparing the total costs and total benefits values, if the total costs are much greater than the total benefits, one can conclude that the project is not a worthwhile investment of company time and resources (Aziz *et al*., 2012).

(a) If total costs and total benefits are roughly equal to one another, it is best to reevaluate the costs and benefits identified and revise the cost benefit analysis. Often times, items are missed or incorrectly quantified, which are common errors in a cost benefit analysis ((Boardman, 2006).

(b) If the total benefits are much greater than the total costs, one can conclude that the proposed action is potentially a worthwhile investment and should be further evaluated as a realistic opportunity (Boardman, 2006).

For example Brown *et al.* (2006) reported that the average yield of rice in two sites, one without a TBS was 2.7 t/ha, compared to 4.2 t/ha on the TBS sites which provided a benefit-cost ratio of 20: 1. Author further reported that in the wet season, each TBS provided an average 16% increase in yield (20 t/ha) within 5 m of the fence and 9.75% increase (0.5 t/ha) from 50 to 200 m from the fence.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location

The study area is located in Mkindo village in Hembeti Ward, Mvomero District; Morogoro Region in Tanzania (Figure 1). The study area is characterized by an average annual temperature of 24.4˚C, with a minimum of 15.1˚C in July and a maximum of 32.1˚C in February. The mean relative humidity is 67.5%. Geographically, the Mkindo Irrigation Scheme lies between latitude 6˚16' and 6˚18' South and longitude 37˚32' and 37˚36' East The altitude ranges from 345 meters to slightly above 365 m a.s.l. The study area is characterized by an average annual temperature of 24.4˚C, with a minimum of 15.1˚C in July and a maximum of 32.1˚C in February. The mean relative humidity is 67.5%. The area has bimodal rainfall regime with short rains from October to December and long rains from March to May. The average total rainfall per year is between 1200 mm to 1500 mm. The lowland irrigated rice crops reaches physiological maturity in July and January when farmers also harvest the crop for the wet and the dry cropping seasons, respectively. Similarly, farmers transplant the crop in August and February while the remaining months, the crop is at a vegetative stage.

3.2 Experimental Design

The study was conducted as a factorial experiment with two factors. Factor (A) was seasons represented by four levels which were months; July to November 2016 (dry season) and February, June 2017 (wet season). Factor (B) had two management methods with two levels which were (i) control (non- trap barrier system) and (ii) trap barrier system (TBS). The treatments combination was replicated three times under field conditions. The levels in factor B were randomly assigned at an interval of 240 m apart as described by Mulungu *et al*. (2016).

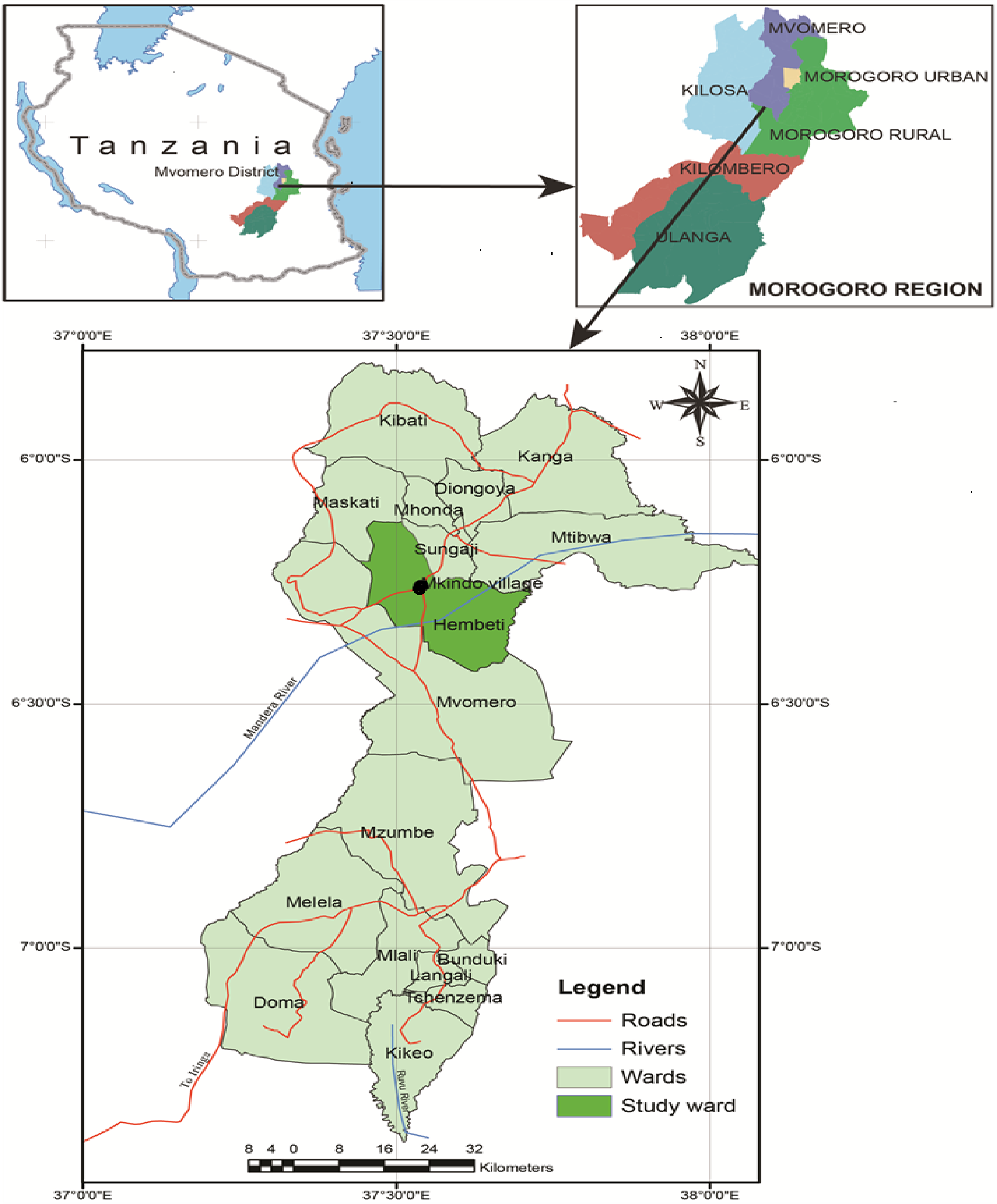

Figure 1: Map showing location of the study area: Wet and dry season crops are cultivated in the same area highlighted as the irrigated zone.

Source: Reuben *et al*., (2016)

3.3 Construction of TBS

An area of 10 m by 10 m (at the centre of a 0.5 ha plot) which is equal to size of one trap barrier was measured using staked and marked with wood poles dug 50 cm into the ground and standing 1.5 m above the ground. String and wire were used to maintain an erect barrier. Thereafter, polythene sheet of 45 m length and 1 m width was rolled around the staked poles followed by covering the sheet with mud below the ground so that no rodents coved penetrate the sheet. Live-multiple-capture cage traps (240 x 150 x 150 mm) were placed every 2.5 m (n = 8 per trap barrier) from each angle, whereby the two multiple capture traps were installed along each side inside the sheet held tightly against the fence, facing the hole made on the polythene sheet. Three Trap Barrier Systems were constructed as a replication for comparison with three plots without TBS (controls) replicates (Plate 1). Interval from one trap barrier to another was 300 m apart. Trap barriers were repaired for any damage that occurred.

Plate 1: Trap barrier system construction

Source: Singleton *et al*. (1999b)

3.4 Crop Transplanting

The crop was transplanted inside the barrier immediately after Trap barrier was constructed in each season. The seedlings in the surrounding TBS were transplanted three weeks later. Moreover, every important agronomic practice was done to both TBS and non TBS plots. Trapping in the TBS started soon after construction of the barrier whereby two multi-capture traps were installed on each side of the prepared holes and continued up to crop maturity stage. The multi-capture traps were cleared of rats and re-trapping was done every morning for the entire crop growth period. Trapping for population monitoring was also conducted surroundings of the TBS and non TBS (Control).

3.5 Rodent trapping

A total of eight trapping lines were set in each plot with TBS and non-TBS at a distance of 10 m from each other (Appendix 1). Each line had 8 trapping stations named A to H. A single trap (Sherman trap, Plate 2) was placed at each trapping station making a total of 64 traps. Traps were baited with peanut butter mixed with maize flour and placed late evening and were inspected early in the morning at 6.00 am. In each field rodent population were determined by trapping at different crop stages; during transplanting (two weeks from sowing), vegetative (development of seminal roots and up to five leaves), booting (development panicle) and maturity stage (hard and yellow colored grains, golden yellowing of leaves). A number of two trap nights with 384 traps were set and making total trap nights of 768 in each crop stage of crop growth. The animals caught were counted thereafter drowned in water for five minutes.

The number of rats captured and species obtained were then compared between fields (TBS and non TBS). Percentages contributions of each species were calculated as:

$$Z = \left(\frac{n}{N}\right) x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, Z = % of individual species, n = number of species, and N = total number of rodents captured.

Plate 2: Sherman trap used for capturing rodents during monitoring

Source: Singleton *et al*. (1999b)

3.6 Data Collection

3.6.1 Animal trapping

The data collected during the study were number of rodents captured and species composition per hectare. Therefore, the population abundance of rodents estimates were analyezed based on absolute numbers counted per month.

3.6.2 Crop loss assessment

Assessment of crop damage was conducted at the base of a hill in each season. The two fields (TBS and non TBS) were assessed where by the quadrat of 1m by 1m was used randomly for sampling systematically within the trap-crop (0 m) and 10, 20 and 30 m from the trap-crop. The numbers of damaged and undamaged tillers per quadrant were recorded during transplanting, vegetative, booting and maturity stage on each season. Tillers found inside the quadrants were recorded.

3.6.3 Damage estimation

The number of cut and uncut tillers inside the quadrat were counted and computed as follows:

$$D = \left(\frac{E}{M}\right) x\ 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where, D = % number of tiller cut, E = number of tiller cut, and M = total number of tillers (Cuong *et al.*, 2003).

3.6.4 Yield estimation

A quadrat of 1m by 1m was used randomly for sampling systematically within the trap-crop (0 m) and 10, 20 and 30 m from the trap-crop during maturity stage on each season. Samples of grain from each field were placed in moisture meter to determine moisture content in order to standardize yield for comparison. Thus the following formula was used:

$$\boldsymbol{Y = \left[\frac{100 - k}{(100 - 12)}\right] x\ j} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where, Y = adjusted weight of the sample at 14% moisture content, k = percentage moisture content of the sample as determined by moisture meter, and j = initial weight of the yield in each field (Cuong *et al.*, 2003).

3.6.5 Cost benefit analysis

The data collected were yield (kg/ha) from TBS and non TBS plots separately, cost of farm operation (labor) and the cost of materials for TBS installation (plastic sheets, wooden poles, string, staples, traps, and traps).

3.7 Statistical Analysis

The number of rodents and species collected were analysed using statistical model of factorial design at 0.05 using statistical software XLSTAT (version 2011.2.06). The statistical model used in this analysis was as follows:

$$Y_{ijk} = \mu + R_i + S_j + T_k + (SJ)_{jk} + \varepsilon_{ijk}$$

Where:

Yijk = response

μ = general mean

R_i = replication with i^{th} effect

S_j = Seasonal/month j^{th} effect

T_k = treatment k^{th} effect

ε_{ijk} = Experimental error due ijk^{th}

3.8 Cost Benefit Analysis

The yield obtained in both treatments (i.e. Trap barrier system and non-trap barrier system) were converted into kilogram per hectare and yield was converted into monetary value and deducting operational costs. Cost benefit Ratio was calculated as:

CBR = YNR/ TC ……………………………………………………………………….… (4)

Whereby,

YNR = TR- TC…………………………………………………………………..…... (5)

TR= Y x P………………………………………………………………………………. (6)

Where, CBR = Cost benefit Ratio, YNR= yield net revenue, TC =Total cost, TR= Total revenue, Y= Yield (kg/ha), P= Price of paddy (Kubo, 2004). The benefit was obtained by taking the yield (t/ha) multiply by 900 Tshs/kg of harvested paddy (Table 8).

CHAPTER FOUR

4.0 RESULTS

4.1 Species Composition in Study Area

During this study, two small mammal species were captured namely; *M. natalensis* and *Crocidura* sp. *Mastomys natalensis* contributed more than 97% of the total number of small mammals captured in the study area in both dry and wet seasons (Table 1).

Table 1: Species composition of small mammals in the study area across seasons

Species	Dry Season		Wet season	
	Number of animals	Percentage contribution	Number of animals	Percentage contribution
Mastomys natalensis	106	99.1	35	97.2
Crocidura spp	1	0.9	1	2.8
Total	107	100	36	100

4.2 Population Abundance of *M. natalensis*

4.2.1 Effect of TBS on rodent seasonal population abundance at different rice growth stages

The effect of TBS on rodent population abundances was highly significant different ($p = 0.0001$) between the two studied seasons (Dry vs. wet seasons). A higher population of rodents was observed during the dry season (46 animals/ha) than wet season (28 animals/ha) as indicated in Table 2.

Table 2: Population abundance at different growth stages of rice during the study period

Growth stage	Animals/ha	
	Dry season	Wet season
Transplanting	46	9

Vegetative phase	12	13
Booting	34	28
Harvest maturity	7	13

4.2.2 Effects of TBS on monthly Rodent population abundance

Results showed that, during the dry season there were highly significant differences (p = 0.000) in population abundance and crop damage (p = 0.002). However, during the wet season there were highly of significant differences (p = 0.006) for population abundance and non-significant differences (p = 0.421) for damage (Table 3).

Table 3: Monthly Rodent population size and crop damage during the dry and wet seasons

Dry Season			Wet Season		
Month	Animals/ha	% Damage	Month	Animals/ha	% Damage
September	16	8.22	March	9	0.48
October	47	28.50	April	17	1.15
November	31	20.33	May	28	5.38
December	7	10.38	June	2	0.72
January	0	3. 82	July	0	0
MEAN	20	14.25		11	1.55
$LSD_{0.05}$	3.89	9.03		0.38	1.30
Rep	0.0001	0.0023		0.0055	0.4209

$LSD_{0.05}$= least significant difference at P≤0.05, Rep = Replication effects

4.2.3 Interaction of TBS between month and population abundance and percentage damage

Results showed that during the dry and wet seasons, there was highly significant interaction effect (p = 0.0001) between month and population abundance (Table 4). However, in October a higher population abundance (16 animals/ha) occurred in TBS with low damage (27.23%) compared to the non TBS (10 animals/ha and 29.77**%** damage). Lowest populations (0 animal/ha) and damage (0%) were observed in July in TBS and control (Table 4).

Table 4: Mean effect of interaction between months and population abundance and percent rice damage in both dry and wet seasons.

Month*Management	Animals/ha	% Damage
a: Dry season		
Oct*Tbs	16.0 ± 4.1a	27.2331 ± 1.42a
Oct*Control	10.31 ± 1.7a	29.7671 ± 1.96a
Nov*Tbs	2.7 ± 1.2b	20.2000 ± 0.78ab
Nov*Control	2.31 ±1.2b	21.2672 ± 2.11ab
Dec*Tbs	2.01±1.4b	10.3330 ± 0.79bc
Sept*Control	1.71 ± 1.0b	9.53 ± 7.78bc
Sept*Tbs	1.00 ± 0b	1.0000 ± 0c
Dec*Control	0.00 ± 0b	10.4334 ± 4.88bc
Jan*Control	0.00 ± 0b	3.7003 ± 3.02c
Jan*Tbs	0.00 ± 0b	3.0672 ± 2.5c
Mean	4±1b	14±2.52c
F	9.604	11.680
Rep	<0.0001	< 0.0001
b: Wet season		
May*Tbs	1.00 ± 0.0a	1.000±0.0abc
April*Control	0.67 ± 0.54ab	2.033 ± 1.66abc
June*Tbs	0.67 ± 0.54ab	0.700 ± 0.57bc
May*Control	0.67 ± 0.54ab	4.233 ± 1.94a
April*Tbs	0.50 ± 0.35ab	3.400 ± 0.28ab
June*Control	0.33 ± 0.27b	0.733 ± 0.6bc
March*Tbs	0.33 ± 0.27b	0.000 ± 0.0c
July*Control	0.00 ± 0.0b	0.000 ± 0.0c
July*Tbs	0.00 ± 0.0b	0.000 ± 0.0c
March*Control	0 ± 0b	0.967 ± 0.7abc
Mean	0b	1.31±0.58c
F	4.206	25.163
Rep	< 0.0001	0.161

Means with the same letter(s) in the same column are not significantly different at $p \leq 0.05$

4.3 Crop Losses

4.3.1 Rodent crop damage by distance

During the dry season there was a very high significant difference in terms of rodent abundance between monthly (p = 0.0001), non-interactive effect between month and distance (p = 0.73). Rodent abundance was higher in October (Table 3) compared to other months while the TBS reduced rodent population abundance up to 20 m from the structure. However, during wet season, there was no significant difference in rodent abundance between distances (p = 0.43), non-interactive effect between month and distance (p = 0.068). However, a significant effect was observed between month (p = 0.001) where the populations were higher during transplanting stage (Table 2). Similarly, TBS had a high significant effect (p = 0.008) in reducing rodent pest population up to 20 m away from the trap crop, with non-interactive effect months and distance (p = 0.256) was observed.

Crop damage corresponded with an increase of rodent population abundance. During the dry season high population abundance corresponded with high crop damage (Table 3). During the wet season, rodent populations and crop damage were low at early and late stages but high at booting stage (Table 5). Low population abundance and damage were maintained within a distance of ≤ 30 m but increased as the distance increased (≥ 30 m) away from the trap crop (Table 5).

Table 6: Crop damage (%) at different distances from trap barrier during dry and wet seasons

	Mean damage (%)	
Distance (m)	Dry season	Wet Season
0	18.00	5.00
10	25.70	9.90
20	28.20	15.10
30	51.30	25.30
MEAN	30.15	13.82
CV (%)	55.71	41.77
$LSD_{0.05}$	5.71	2.52
Rep	0.0023	0.42

LSD0.05 = least significant difference at P≤0.05, CV (%) = coefficient of variation,

Re = Replication effects

4.3.2 Rodent Population abundance at different crop growth stage

Results showed that during the dry season, there was highly significant interaction effect (p = 0.000) in population abundance and crop damage (Table 6), non-interactive effect between month and distance (p = 0.467) was observed. However, during wet season, there was significant interaction effect (p = 0. 001) in population abundance and crop damage while non-interactive effect between month and distance (p = 0.343) was noticed. During dry season, rodent population abundance (53 animals/ha) and crop damage (32.33%) were higher in transplanting stage as compared to other stages. Rodent population abundance and damage decreased with crop growth stages. However, during wet season, rodent population abundance (27 animals/ha) and crop damage (2.30%) were higher in booting stage as compared to other crop growth stages (Table 6).

Table 7: Interaction between rodent population abundance at different growth stage

Growth Stage	Dry season		Wet season	
	Animals/ha	Mean Damage (%)	Animals/ha	Mean Damage (%)
Transplanting	53	32.33	16	0.50
Vegetative phase	18	8.22	11	0.17
Booting	34	20.30	27	2.3
Harvest Maturity	12	3.38	0	0
MEAN	30	16.06	14	0.74
CV (%)	65.97	35.46	35.46	114.00
$LSD_{0.05}$	3.89	1.30	1.30	4.71
Rep	0.0001	0.0023	0. 0.005	0.4206

LSD0.05 = least significant difference at P≤0.05, CV (%) = coefficient of variation, Re = Replication effects

4.3.3 Yield

Results show that there were no significant differences in yield between TBS and non TBS plots during the dry season (p = 0.161) and wet season (p = 0.518) although the yield overtime varied considerable between types of management and seasons. The highest value was observed in TBS than non TBS plots in both seasons. However, yield was relatively lower during the dry season compared to the wet season (Table 7).

Table 8: Effects of TBS on rodent pest species and rice yield (t/ha) during dry and wet seasons

Treatment	Yield (t/ha)	
	Dry season	Wet season
TBS	3.8	5.7
Control	3.3	4.3
MEAN	3.6	5.0
CV (%)	24.4	18.7
$LSD_{0.05}$	0.7	3.3
Rep	0.2	0.5

LSD0.05 = least significant difference at P≤0.05, CV (%) = coefficient of variation,

Re = Replication effects

4.4 Cost Benefit Analysis

4.4.1 Dry season

The benefit from all TBS plots in both seasons was very high compared to the control plots. Plots with TBS had higher undamaged tillers which resulted in higher revenues that exceeded the total cost.The cost of plant protection using TBS was higher than plots without TBS for the two seasons still the yield obtained was high compared to plots without TBS plots. The yield from TBS and Non TBS plots were 3830 kg/ha and 3323 kg/h in the dry season (Table 8).

Table 9: Cost and benefit of managing rodent pests with Trap Barrier System in dry season*

Treatments	Yield (kg/ha)	Increased yield over control	Value of yield (Tsh) *	Materials, Labour, Bait, (Tshs)	Net benefit (NB)	Cost Benefit Ratio (CBR)
TBS	3830	507	456300	215000	241300	1:1.1
Control	3323					

*Cost of rice: 900 Shs/kg

4.4.2 Wet season

During the wet season, the yield from TBS and Non TBS plots were 5690 kg/ha and 4330 kg/ha in the dry season. The benefit obtained is shown in Table 9.

Table 10: Cost and benefit of managing rodent pests with Trap Barrier System in wet season*

Treatments	Yield (kg/ha)	Increased yield over control	Value of yield (Tsh)*	Materials, Labour, Bait, (Tshs)	NB	CBR
TBS	5690	1360	1224000	160000	1064000	1:6.7
Control	4330					

*Cost of rice: 900 Shs/kg

CHAPTER FIVE

5.0 DISCUSION

The current observations which show high abundance of *M. natalensis* in the study area is consistent with those reported by Vibe-petersen *et al*. (2006) and Sluydts *et al*. (2009) on maize farms, Makundi *et al*. (2009) and Massawe *et al*. (2011) in fallow fields. This genus has been recorded in high population densities in disturbed landscape in agricultural fields throughout sub-Saharan Africa (Leirs, 1995; Leirs *et al.*, 1996). In irrigated rice fields in Tanzania, its population density fluctuates markedly between months with the highest population peak reported during the dry season (Mulungu *et al*., 2013). The pest is sexually active throughout the year, although it reaches the highest level when the rice crop is at the maturity stage (Mulungu *et al*., 2013). This suggests that breeding is highly influenced by the rice production systems, which is different from maize-dominated mosaic habitats. In a maize-dominated habitat, the occurrence of rodent outbreaks is reportedly influenced by rainfall pattern (Linn, 1991; Leirs, 1995).

In irrigated rice agro ecosystems, water and food are not limiting factors. Breeding occurs over a longer period and population size is generally higher, with a much weaker link with rainfall (although breeding is still most prominent in the rainy seasons). More juvenile rats are recorded in August and September, indicating that the main breeding seasons is during the rainfall season (Mulungu *et al*., 2013). Therefore, the rodents are indirectly influenced by rainfall, though the quantity and quality of their food, which is dependent on the phenology of the rice crops and surrounding vegetation. In irrigated rice fields, vegetative plant materials (leaves, stems and seeds) are the most abundant components of the diet of *M. natalensis*, while other food types (invertebrates, fruits) are consumed only in low quantities (Mulungu *et al*., 2014). Agricultural cropping patterns in Tanzania typically consist of a relatively small-scale matrix of agricultural fields and fallow land (Odhiambo *et al.*, 2005).

In this study, a high population was observed at transplanting and booting stages in dry and wet seasons respectively. This is contrary with previous observations by Mulungu *et al.* (2013) who reported that a high population 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. According to Mulungu *et al*. (2013) farmers start land preparations and transplanting in July and January for dry and wet seasons, respectively whereas in the current study planting and land preparation started in September and February for dry and wet seasons, respectively. Generally, in this study the rodent population decreases with an increase in crop growing stages.

The present observations concur with Meheretu *et al*. (2014) 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. Both the wet and dry seasons are favorable for rodent reproduction and crop damage. Availability of food, water and shelter in an area are factors that favor the survival of rodent populations. In rice fields, the quantity and quality of the available harborage usually varies considerably from place to place and season to season. 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 occurrence of rodent outbreaks in Tanzania is influenced by the rainfall pattern (Leirs, 1995). Rodents breed during the long rains and usually starts one month after the usual peak rainfall, lasting until dry season (Leirs, 1995). Neonates grow slowly and normally do not mature before the next rainy period. Unless abundant rains appear before March and April the following year, they will be at least six months old before they begin to breed (Leirs, 1995). 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 vegetative and booting, rodent damage was lowest at maturity in both seasons. The lower yield observed during the dry season is probably attributed to rodent damage, irregular irrigation and/or prolonged periods of water stress caused by insufficient water supply (Nguyen, 2004; McHugh, 2002).

According to Raes *et al.* (2007), rice cultivated in the dry season experiences more moisture stress (Sumarno, 2010). Other similar findings include that of Craufurd *et al*. (2013), who reported water stress to have negative impacts on yield. The effect varies with phonological stages but is more severe from the flowering stage onwards. Yue *et al.* (2006) reported that 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. Damage at dry season resulted into lower yield losses compared to wet season. At early growth stage such as transplanting, yield loss was observed to be higher compared to later growth stages in dry season and booting stage at wet season. As damage ascended from zero to 50% stem tiller cut, yield losses followed the same trend.

It has been reported that percentage yield loss at vegetative and booting growth stages is roughly approximate to the percentage of damage (Singleton *et al.*, 2003; Poche *et al.*, 1981) which is attributed by the fact that at late stages the crop cannot produce more tillers to compensate for damage since very little time is available for such compensatory growth. 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 (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. 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.

Cuong *et al*. (2003) 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. The 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 to availability of moisture/flood conditions in the wet season which limits rodent movement within the field. 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, rodent damage recorded in the dry season was higher than that of the wet season especially in plots with no TBS.

Crop damage increased with an increase in rodent population abundance for both dry and wet seasons. During the dry season, the effect of the TBS was much pronounced within a distance of 20 m. However, this was different from wet season whereby rodent population abundance and crop damage were low within30 m from the trap barrier. This agrees with the previous studies where TBS proved successful in irrigated rice fields in South East

Asia to control rats. According to Singleton *et al.* (1999), TBS was effective within 300 m typically covered a total area of 10-15 ha. In South East Asia, TBS was used as a cost benefit and sustainable solution, for rodent damage management. It reduced damage from 10 to 5%, resulting into more available rice for human consumption (Meerburg *et al.*, 2009).

In this study, high population abundance and crop damage much were observed during the dry season than wet season although TBS saved 507 kg/ha of harvested paddy in dry and 1360 kg/ha in wet season. Assuming that 0.5 kg of rice when cooked can be consumed by two people, the saved 507 kg could be consumed by 2028 people in a given area or village. For the 1360 kg saved by TBS in wet season, a total of 5,440 people could benefit from the system in a single meal. The cost-benefit ratios from this study indicate the strong potential of a TBS with trap-crop for managing *M. natalensis.* The cost-benefit ratios for the dry and wet seasons, respectively, indicated the strong potential of a TBS for managing the rice field rat. TBS throughout reduced the rodent populations' infestations on all growth stages. The main factor providing the high cost-benefit-ratio was the halo of protection provided to crops outside the Trap Barrier. TBS saved 53.57% and 56.73% of the yield obtained in both dry and wet seasons respectively.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMANDATION

6.1 Conclusion

Mastomys natalensis ranks first as an important rodent pest of lowland irrigated rice in the study area. It was dominant specie attacking the rice in both seasons; however the population size and crop damage was higher in dry season than wet season. The number of rodent population was more significant in TBS, but the percentage of rice damage was lower. The yield of rice in the second season (wet) was higher than that in the first season (dry). TBS indicated the effectiveness in lowering *M. natalensis* infestations on rice on early growth stages especially during the dry season where population size was high. Not only the TBS lower crop damage, but is an environmentally safe ecologically based rodent management measure and safe control program. The installing of this technique can be affordable by the small scale farmers through sharing of cost depending on the size of the specific area.

6.2 Recommendations

i. From this study, it is recommended that farmers should apply the TBS in order to optimize their yield and benefit.

ii. It is further recommended that in order to optimize economic benefits of the TBS in rice production in the study area, farmers should opt to use the TBS during the wet season.

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APPPENDICES

Appendix 1: Experimental layout of the study

Appendix 2: Image of damaged rice tillers by rodent

Appendix 3: Bunds in rice field acting as pathway to farmers and rodents hiding habitats