Chapter

Trap Barrier System (TBS) as a New Tool for Rodent Pest Management in Irrigated Rice in Africa

Loth S. Mulungu, Bernard M. Mchukya and Laurent L. Mnyone

Abstract

Rodent infestation poses a serious threat to smallholder farmers in both developed and developing countries where a large proportion of potential crop yield is lost. In Tanzania, the average annual yield loss of rice is estimated to be around 5–12%. Management of rodent pests in Africa relies mostly on the use of rodenticides which, however, are often applied only when damage has already occurred rather than routinely. Rodenticides used in this way are rarely economically and ecologically sustainable for managing rodents in irrigated rice. A "community-based Trap-Barrier-System (cTBS)" provides an alternative novel rodent control approach for controlling rodents in rice fields. This is basically a system where rodents are trapped in a rice field that is planted a short period earlier than the surrounding fields and therefore attracting rodents from a much wider area than the field itself. The system has proved very successful in irrigated rice fields in Tanzania, increasing rice yields in the intervention fields by 40.91%. A single cTBS can confer protection in up to 16 ha of irrigated rice field. Therefore, if scaled up and used widely, TBS has a great potential for managing rodent pests and improving yield in irrigated rice fields.

Keywords: trap barrier system, rodent pest, irrigated rice, management, community

1. Introduction

Rice (*Oryza sativa*) is among the three leading food crops of the world, with maize (corn) and wheat being the other two. All the three crops provide around 42% of the world's required caloric intake. In 2009, human consumption was responsible for 78% of the total usage of produced rice [1]. More than 3.5 billion of the world's population, which translates to at least half of the people living in the world, thinks of rice as their staple food.

According to IRRI [1], the top rice producing countries 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.

Rice is also one of the most important cereals grown and used as staple food in many African countries [2]. It is the second most important crop in Africa after maize [3]. Rice is produced under typical monoculture systems [4] that can be subdivided into three agro-ecosystems: rainfed lowland (74%), rainfed upland (20%) and irrigated lowland (6%), and the average production is 2.2 t/ha in Africa and 3.4 t/ha worldwide [4]. Farmers in Africa grow mainly local and traditional varieties, many of which have low yield potential. Most of the rice grown depends on rainfall and many irrigation schemes. 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 [5].

1.1 Impact of rodents to rice 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 [5, 6]. Rats can completely consume fields of growing rice and sometimes prevent planting where crops could otherwise be grown [7]. Rodent outbreaks in rice cropping areas have been reported to cause severe crop damage and food shortages [8] due to effects from sowing to physiological maturity of the crop.

In many countries, farmers consider rodents as an inevitable pest in their fields [9]. Thus, they consider chronic rodent damage as something beyond their control [10]. Rodent pest species cause numerous loses in different seasons and locations [11]. However, in some locations, for example, in Philippines, farmers tend to ignore rodent problems on standing rice when cut tillers are less than 5%. Significant reduction in yield is observed at 25% cut tillers when compared with rice field where rodent control is practiced [12]. 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, that is, at milky to soft dough stage.

Rodents, particularly rats, substantially cause damage to rice fields [12]. They eat rice seeds and seedlings (**Figure 1**), gnaw tillers (**Figure 2**), damage plants and feed

Figure 1.
Rice seedling in nursery damaged by rodent pest (Courtesy by Loth S. Mulungu).

Figure 2.
Rice tillers damaged by rodent pest (Courtesy by Loth S. Mulungu).

on grains [13, 14]. In Tanzania, it has been addressed as the major threat in rice crop production system. Farmers keep on controlling the pest to meet household food demands. Elsewhere, on average across Asia, 5–10% of crop damage has been attributed to rodents [9, 12].

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 [15, 16]. 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 necessitate repeated late replanting [17] and ultimately result in lower yield [11].

At vegetative stage while paddy is growing, rats cut rice tillers and use for building their nests [18] and eat [19]. Damage can be severe during the dry season and cuts are normally seen at the base [15, 16, 20]. At 45° which make different with other pest [21]. At maturity, rodents attack both milky and mature grains [15, 16, 21]. In Asia, an estimated rodent damage of 5–10% was recorded prior to rice harvest in 1999 [22]. In Tanzania, for example, rodents cause an estimated 10–12% pre-harvest loss of rice annually [23, 24].

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% [25]. In Vietnam, My Phung and Brown [26] 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 [27] 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 and 16% at the ripening stage. The rodents cause major impacts in agriculture in most parts of the world by attacking crops at any growth stage. However, according to Mulungu et al. [11], the impact of the 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 lowland irrigated rice [28]. In Indonesia, a loss of 10–20% for pre-harvest was observed each year [28].

2. Rodent management

2.1 Rodent management options

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 [29]. Studies on population characteristics of this species showed irregular population explosions and most of the outbreaks occurred during the dry season and last through the planting season of October–February [30].

In the past, most of the control measures used in then were localized [31]. 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 and non-lethal [31]. Many different methods for controlling rodent pests have been passed down through folklore or have been tested and proven effective in particular situations [32, 33].

2.1.1 Non-lethal or preventive measures

The non-lethal method involves habitat manipulation or cultural practices, exclusion/fencing and use of repellants. Environmental sanitation involving the removal of fallow patches in crop fields is another non-lethal practice used in many places [10]. Thick grass and bushes provide harborage and supplementary food resources to rodents. In Tanzania, the environmental sanitation has been done by farmers through slash and burning fields before sowing and harvesting as a way of displacing rodent population [10]. Deep plowing and regular weeding have been reported to suppress rodent population due to destruction of nests, removal of alternative source of food and harborages [34]. However, sanitation is not significantly effective as most farmers practice it on small plots that are interspersed with patches of fallow and permanent grassland [34].

According to Masol et al. [35], the behavioral defense of pest against contact especially for dietary poisoning influences their feeding and area repellent. For area repellent, Voznessenskaya et al. [36] reported the exposure to predator odor to cause disruption of the estrous cycle. Voznessenskaya et al. [37] reported reduced 26 reproductive outputs as the result of exposure to area repellent, specifically urine products derived from meat diets and urine from rats housed in a crowded condition. Mulungu et al. [33, 38] observed significant reduction in rodent activities following

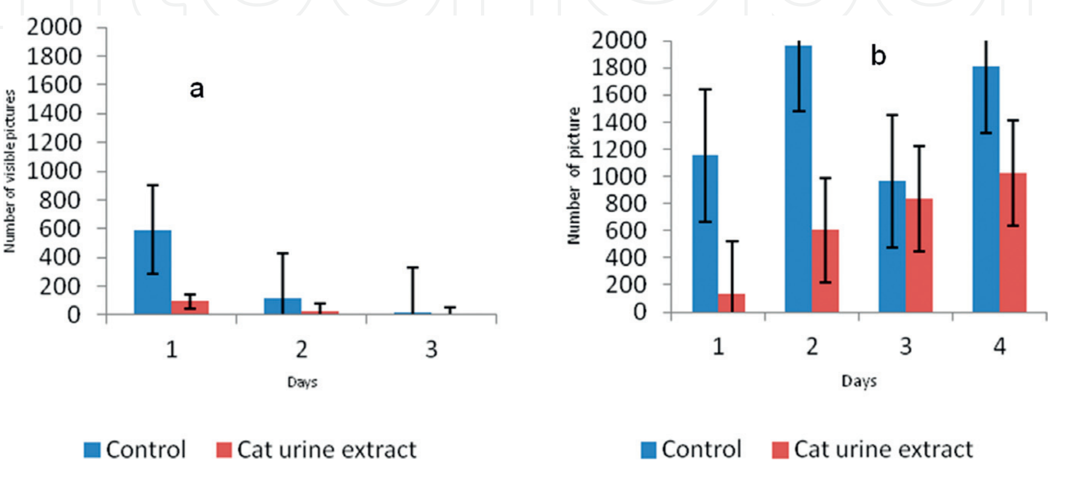

Figure 3.
Effectiveness of cat urine extract of (a) female cat urine extract and (b) male cat urine extract. Source: Mulungu et al. [33].

the application of cat urine. Female cat urine extract repelled significantly more rodents as compared to male cat urine extract (**Figure 3**). The author further reported that the repellent effect was observed from day 1 to 4, but not beyond (**Figure 4**).

In Tanzania, Ngowo et al. [32] evaluated two compounds, that is, thiram and cinnamamide treated in maize seeds as contact repellent, and reported that these two compounds excel over no treated maize seeds in both laboratory against *M. natalensis* and fields against rodent pest species. Mdangi [39] reported that castor oil (*Ricinus communis*) is therefore a promising rodent repellent for small scale maize farmers (**Figure 5**), which protect maize seeds during sowing time.

Another non-lethal method is exclusion or fencing, which is the technology that 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

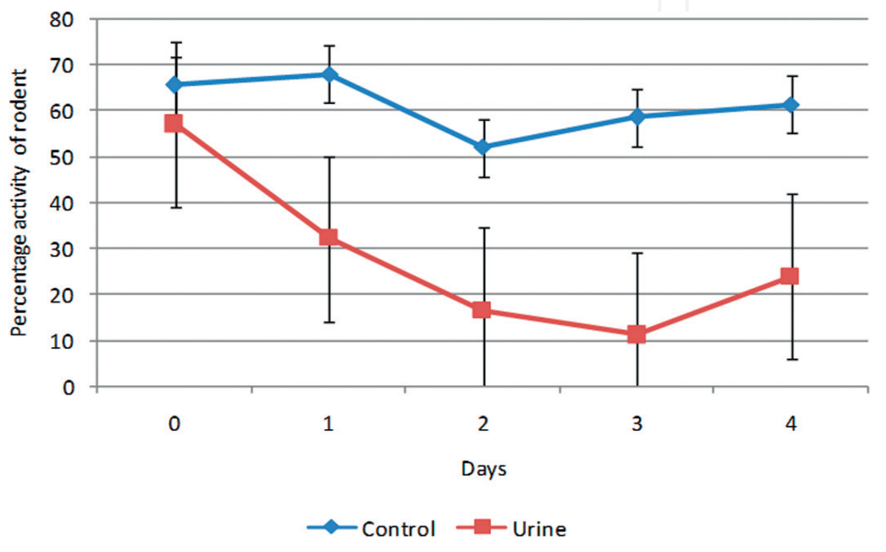

Figure 4.
Percentage rodent activities (±SD) on tracking tiles in rooms treated with either female or male cat urine extract. Source: Mulungu et al. [38].

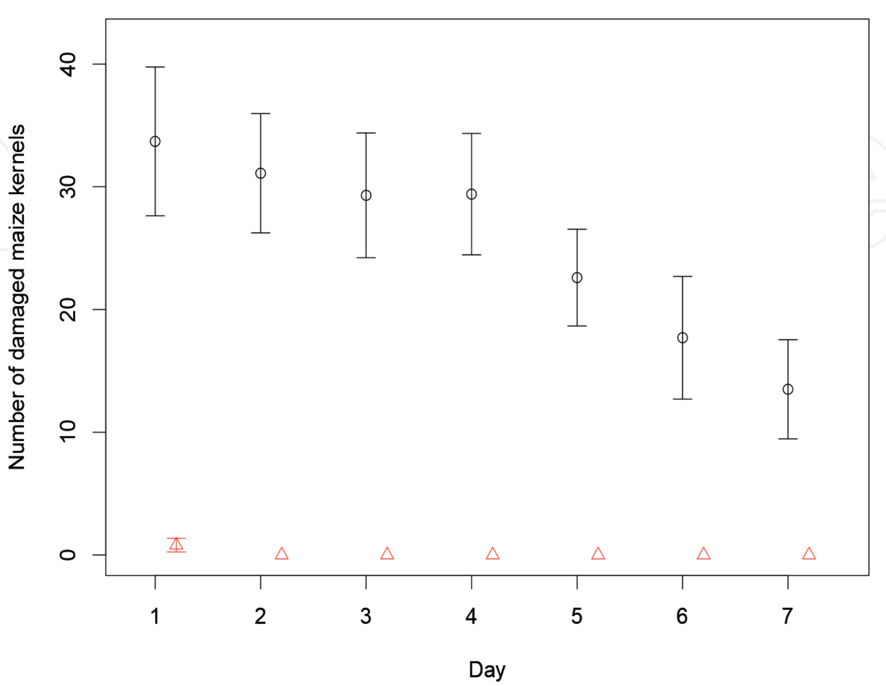

Figure 5.
Mean proportion of damaged treated maize against number of damaged maize seeds in the control group (black) and the treated group (red) at 150 g concentrations of castor oil. Source: Mdangi [39].

plots [40]. 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 [41].

2.1.2 Lethal approaches

The lethal rodent control methods are based on traditional, historical and conventional approaches (e.g. trapping, chemical, toxicants and biological control) [31, 42, 43]. The major methods of achieving satisfactory mortalities are physical killing by trapping and rodenticides [44, 45]. However, killing with rodenticides during rainfall and in irrigation schemes is compromised by water hence loss of effectiveness and increased chances of poisoning non-targeted organisms [45, 46].

Rodenticides and traps are known to provide immediate effects to the problem and are often considered to be the most practical, economical and effective methods of combating rodents. The biological method always requires a period of time before it becomes stable and provides substantial results [47].

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, has a high transmission rate and is target specific [48]. The role of natural predators in controlling rodent pests is an interesting, but frequently misunderstood, concept that is rarely effective in reducing pest populations to tolerable levels [49, 50]. 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 [51].

In Malaysia, the barn owl was reported to suppress rodents in rice fields resulting in significant lower crop damage [52]. 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 [53]. 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 [54]. Although this predator survives in some areas on a diet composed mainly of rats [55, 56], the introductions failed to achieve the desired result of reducing rat populations in sugarcane fields.

A variety of traps either commercially available or constructed in homes or villages are used to control rodents; the centuries-long search for "a better mousetrap" has not ended [57, 58]. 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 [10].

Although trapping is very labor 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 [59]. Trapping is also utilized where non-target animals are an important concern or where use of toxicants or other more effective methods is prohibited [59]. Trapping generally is not practical for managing large infestations or removing entire populations over extensive areas [60]. However, traps can be used effectively in limited areas or where substantial resources are available and more efficient techniques cannot be used or developed [60]. Farmers, however, try to minimize the crop damage and yield loss caused by rodents by adopting different rodent control methods including poisons (rodenticides), burrow digging to kill rodents, burying buckets full of water, use of live traps and kill traps [23].

Most subsistence farmers rely mostly on the use of rodenticides [61]. Both acute and chronic rodenticides have been used extensively during rodent outbreaks [62]. These chemicals carry significant economic costs and, if used inappropriately, can kill non-target animals (**Figure 6**) 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 [10]. Sometimes baiting using acute rodenticides especially zinc phosphate is only used during rodent outbreak [10].

However, rodents are able to multiply fast and re-colonize the farms after rodent control operation [63]. Rodenticides are generally an integral part of successful rodent pest management and, in some tropical habitats, are the only practical method available [64]. Unfortunately, farmers and extension personnel are often confused or uninformed as to how a particular product may be effectively used. In fact, it depends on (i) availability of the required rodenticides, farmers do not access of rodenticides in time when needed, and even if available, they are distributed while damage has already occurred. In some areas, farmers attempt to buy rodenticides from local vendors for control of rodent in their fields themselves. However, most of them report on inefficient control of rodent by the rodenticides they buy, and this is because some vendors sale fake rodenticides prepared from radio dry cell battery and its flour looks like zinc phosphate. Also, improper use of rodenticides and other chemicals for rodent control is a problem whereby farmers lower doses of rodenticides to cover their cultivated areas using few amounts. However, the dose supplied can result to resistance in some rodent species against the commonly and most frequently used chemicals. In some areas, farmers have improper use of chemicals recommended for human being; for example, indocid capsules have been alternatively used by farmers for the control of rodents in fields. (ii) Acceptability of bait formulations to rodents (often influenced by palatability under field conditions). In rodent pest management programs, poison baiting is the most widely used technique throughout the world [65, 66]. Although rodenticides can be incorporated either in bait, dust or water formulations [67], 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 on the rodent outbreak cases and request for control assistance after they observe some cases of crop damage in their fields. This results

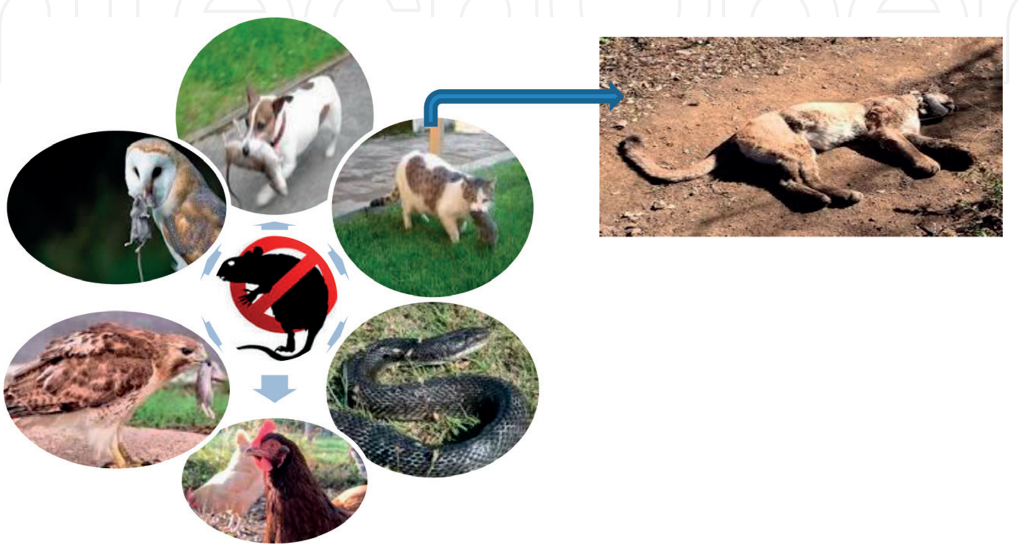

Figure 6.
Effect of acute poison to non-targeted animals. Source: Mdangi [39].

into delayed process in control as it takes time for the information to reach the responsible public rodent control centers. This is critical for alleviating damage [51, 68]. Another factor that limits the use of rodenticides is poverty; many small-scale farmers are poor, and therefore, in many cases, they cannot afford to buy sufficient rodenticides for their farms [23].

In addition, the use of rodenticides and other control methods provides only a short-term solution, and they are not effective in cases of high population as have been reported in irrigated rice systems where rodent breed throughout the year [68, 69]. In order, therefore, to minimize those problems, alternative measures must be sought and one of them being the use of trap barrier system (TBS). It has been reported that the application of TBS could increase yields by 10–25% [8] and is cost-effective in most seasons.

2.2 Philosophy on TBS for rodent management

Trap barrier system is a new environmentally friendly, physical rodent control method. It has been proved very successful in controlling rats in irrigated rice fields in Southeastern Asia.

2.2.1 Construction of TBS

An area of 10 m by 10 m or 20 m by 20 m, which is equal to size of one trap barrier, is constructed and measured by using tape measure, staked and marked with a piece of trees dug 50 cm into the ground and stands for 1.5 m above the ground. String and wire is used to maintain an erect barrier. Thereafter, polythene sheet with size of 45 m length and 1 m width is rolled around the staked pegs/piece of trees followed by covering the sheet with mud below the ground (about 5–10 cm), so that no rodent can penetrate the sheet. Therefore, a significant aspect of the trap barrier system (TBS) is that the crop protection occurs in ecologically acceptable manner, as the entire crop is wrapped in polyethylene sheets and held together with wooden bamboos, at sufficient height of about (90–95 cm) from above ground.

Live-multiple-capture cage traps (240 × 150 × 150 mm) are placed every 2.5 m (n = 8 per TBS) from each angle. The two multiple capture traps are installed along each side inside the sheet held tightly against the fence, facing the hole made on the polythene sheet, making a total of eight holes and eight traps per trap barrier. Trap barrier is repaired for any destruction if occurred (**Figure 7**).

2.2.2 Crop transplanting and animal trapping

The trap (lure crop) is transplanted inside the barrier immediately after trap barrier has been constructed in each season. The seedlings in the surrounding TBS are transplanted 3 weeks later (**Figure 8**). Moreover, every important agronomic practice is done. Trapping in the TBS starts after construction the barrier whereby two multi-capture traps. The multi-capture traps are cleared of rats and re-trap every morning for entire crop growth period.

2.2.3 Potential of TBS in rodent management in Tanzania

2.2.3.1 Rodent pest species captured

Two small mammal species were captured, which included *Mastomys natalensis*, which is a rodent pest species, and *Crocidura* spp., which is an insectivorous species. *Mastomys natalensis* contributed more than 97% of the total small mammals

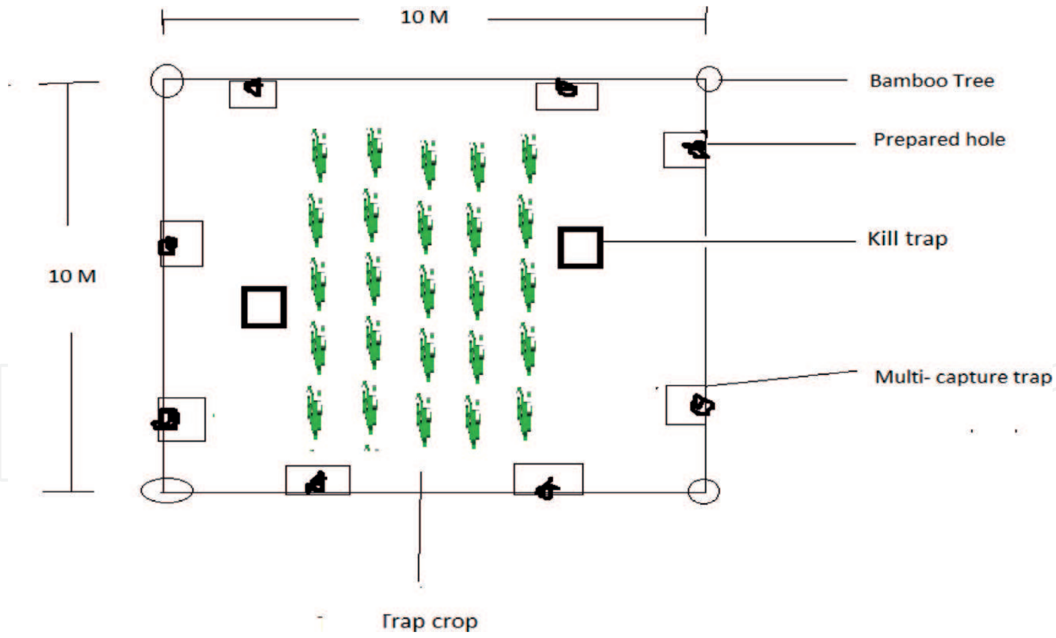

Figure 7.
A pictorial presentation of TBS structure. Source: Courtesy by Loth S. Mulungu.

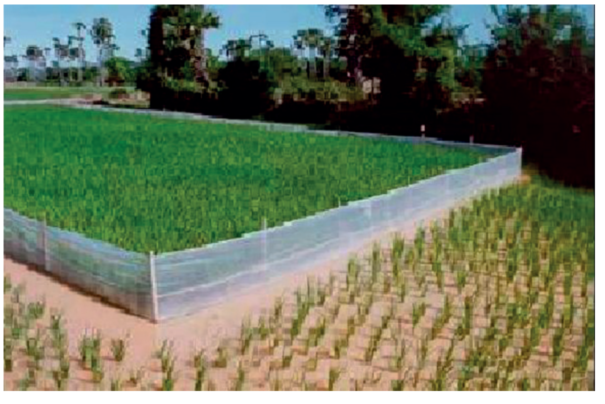

Figure 8.
Constructed TBS with rice inside planted 3 weeks before planting in surrounding. Courtesy by Grant Singleton.

captured in the study area for both dry and wet seasons. This observation of high abundance of *M. natalensis* is consistent with those reported by Vibe-petersen et al. [70] and Sluydts et al. [71] in maize farms, Makundi et al. [72] and Massawe et al. [73] in fallow fields and by Mulungu et al. [68] in irrigated rice fields. The presence of *M. natalensis* 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. [74], the species is a pioneer in colonizing disturbed habitats (e.g. by agriculture). Likewise, Odhiambo et al. [75] and Mulungu et al. [76] reported that the species feeds in almost all types of food in the environment but predominantly prefers seeds/grains. Leirs et al. [63] 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 [77].

2.2.3.2 Rodent population reduction

Studies have been conducted in Tanzania to assess the effectiveness of TBS on reduction of rodent pest species population [78]. Results showed no significant effect ($F_{1, 18} = 1.30$; $p = 0.32$) of the TBS on population abundance between dry and wet seasons if TBS has been used regardless the high population abundance of rodent observed on dry season than wet season. During dry season, higher catch ($F_{9, 20}$ = 9.604, $p \leq 0.0001$) was observed when the population is higher in October (16.0 animals) (**Table 1**). 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 [79, 80]. High population was observed at transplanting and booting stages in dry and wet seasons, respectively, although it is not significant with other crop growth stages. This is contrary with previous observations by Mulungu et al. [68] 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. [68] 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 July and January for dry and wet seasons, respectively. Generally, in this study, the rodent population decreases with an increase in crop growing stages.

2.2.3.3 Seasonal rodent population reduction

For the wet season, there was a significant interaction effect on monthly and *M. natalensis* population abundance ($F_{9, 20}$ = 9, $p \leq 0.0001$) with fields type practice applied. Highest number of rodent catch was observed in May (1.0 animal) than other months (**Table 2**). Lowest trap catches were observed in the control in the month of July (0 animals captured). The increase of crop damage corresponds with the increase of rodent population abundance.

The dry season (October) had high population abundance and high crop damage compared to wet season. This observation concurs with Meheretu et al. [81] 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. Both the wet and dry seasons are favorable for rat

Month*Management	Mean population	% Damage
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
DF	9	9
F	5.32	11.680
p	0.0001	<0.0001

Source: Mchukya [78].

Table 1.
Effect of interaction between months and population abundance on dry season.

Month*Management	Mean population	% Damage
May*Tbs	1.00 ± 0.0a	1.000 ± 0.0a
April*Control	0.67 ± 0.54ab	2.033 ± 1.66ab
June*Tbs	0.67 ± 0.54ab	0.700 ± 0.57ab
May*Control	0.67 ± 0.54ab	4.233 ± 1.94ab
April*Tbs	0.50 ± 0.35ab	3.400 ± 0.28ab
June*Control	0.33 ± 0.27b	0.733 ± 0.6b
March*Tbs	0.33 ± 0.27b	0.000 ± 0.0b
July*Control	0.00 ± 0.0b	0.000 ± 0.0b
July*Tbs	0.00 ± 0.0b	0.000 ± 0.0b
March*Control	0 ± 0b	0.967 ± 0.7b
DF	9	9
F	49.977	1.677
p	<0.0001	0.161

Source: Mchukya [78].

Table 2.
Effect of interaction between months and population abundance on wet season.

reproduction and crop damage. The presence of food, water and shelter in the area are factors that permit the survival of rat populations. In rice fields, the quantity and quality of the available harborage usually vary considerably from place to place and season to season. Sumangil [82] reported short-range seasonal movements among *R. argentiven*.

Quick [83] 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. [68] 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. As observed in wheat fields [84], rat activity increased in fields as the crops matured and the plots became dry.

The occurrence of rodent outbreaks in Tanzania is influenced by the rainfall pattern [85]. Rodents breed during the long rains and usually starts one month after the usual peak rainfall, lasting until dry season [85]. 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 6 months old before they begin to breed [85].

Fulk [86] 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 growth stages in both seasons. Average grain yield on the wet season and dry season was not different ($p > 0.05$). Wet season had relatively higher grain yield than the dry season. 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 [87].

According to Raes et al. [88], rice cultivated in the dry season experiences much of the moisture stress [89]. Other similar findings include that of Craufurd et al. [90], who reported that water stress has negative impacts on yield and effects vary with phenological stages, which are generally more severe from the flowering stage onwards. Yue et al. [91] 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 vegetative and booting stage at wet season. As damage ascended from zero to 50% stem tiller cut, yield losses followed the same trend. The 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.

It has been reported that percentage yield loss at these growth stages is roughly approximate to the percentage of damage [92, 93], 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 that rice plant compensation has occurred. Similar findings were reported by Fulk and Akhtar [94] 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. [95] reported that compensation capacity of rice damaged by rodents is higher at each growth stage than at maturity of the crop. Aplin et al. [77] explained the term compensation of rice in terms of tiller regrowth and panicle filling.

Cuong et al. [96, 97] 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. 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 condition in wet season, which limit rodent movement within the field while others migrate to domestic environment. These results agree well with those of Kim et al. [98] 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 plots with no TBS.

2.2.3.4 Radius covered by TBS in controlling rodent pests

Again, Mchukya [78] observed that distance measured (i.e., 0, 10, 20, 30, 50 m) from the TBS differs significantly ($F_{3,\ 38} = 4.61$; $p = 0.0076$) and indicating that up to 20 m, one structure of TBS manages rodent during dry season. However, at wet season, no effects ($F_{3,\ 38} = 0.94$; $p = 0.4293$) on rodent abundance between distance were tested. Across the season, there was significant difference between distance ($F_{3,\ 78} = 4.28$; $p = 0.0075$) where TBS reduces population up to 20 m.

During the dry season, low population and damage were maintained at late stages within a distance of ≤20 m and increased as the distance increased (≥ 20 m) away from the lure crop. On other side of wet season, population and damage were very low at early and late stages but high at vegetative and booting stages. Low population abundance and damage were maintained within a distance of ≤30 m but increased as the distance increased (≥30 m) away from the lure crop.

Across the season, low population and damage were maintained within a distance of 20 m (**Table 3**).

During the dry season, the effect of the TBS was much pronounced within 20 m distance of protection from the trap crop by considering the damage which was very high compared to wet season, although that low damage continue to reduce much more up to 30 m with the aid lure crop within the trap barrier. In this study, the distance covered by TBS was 0.5 acre, which is very small compared to singleton [22], whose TBS was effective within 200 m covering a total area of 15 ha.

The bunds surrounding small plots owned by farmers were acting as home range of rodents, which allow them for easiness of short movement in attacking rice that resulted to a minimum of 20 and 30 m distance of protection from the center of the trap crop in dry and wet seasons, respectively. Trap barrier system has proved very successful in irrigated rice fields in Southeastern Asia to control rats, a cost-beneficial and sustainable solution, and the yield of rice has increased with 10–25%. It is basically a system where rodents are trapped in a rice field that is planted a short period earlier than the surrounding fields and therefore attracting rodents from a much wider area [22].

2.2.3.5 Yield loss

There was no significant difference between treatments within and across the seasons, although the yield over time varied considerably between TBS and field without TBS and seasons. Highest value was observed in plots with TBS than fields without TBS plots in both seasons and across the season. However, there was relatively lower yield in dry season than the wet season due to higher rodent damage and water stress (**Table 4**).

Population abundance corresponds with the increase of crop damage. High population abundance and crop damage were much observed on dry season than wet season, although TBS saved 510 kg of harvested paddy. Assuming that 0.25 kg of rice when cooked can be consumed by one person, this means that a total of 2040

Distance (m)	Mean damage (%)		
	Dry season	Wet season	Across season
0	18.0b	5.0a	0.0667b
10	25.7b	9.9a	0.333ab
20	28.2ab	15.1a	0.5333ab
30	51.3a	25.3a	0.7333a
Source: Mchukya [78].			

Table 3.
Crop damage (%) at different distances within and across the seasons.

Treatment	Yield (t/ha)		
	Dry season	Wet season	Across season
Fields with TBS	3.83	5.69	4.76
Fields without TBS	3.323	4.33	3.83
Source: Mchukya [78].			

Table 4.
The yield of rice (t/ha) obtained from plots with TBS and those without TBS within the seasons.

people per meal in a given area or village could benefit from system. The cost-benefit ratios for the dry and wet seasons, respectively, indicate the strong potential of a TBS with trap crop for managing the rice field rat.

2.2.3.6 Economics on the use of trap barrier system

The benefits from all fields with TBS during wet and dry season were relatively high compared with that of the fields without TBS. Fields with TBS had higher undamaged tillers, which resulted in the increase of revenues that exceeded the cost of the plant protection regime, although it was noticed that the cost of plant protection using TBS was higher than fields without TBS. The yield from TBS and fields without TBS plots were 3.83 and 3.323 t/ha in the dry season (**Table 5**) and 5.69 and 4.33 t/ha in wet season (**Table 6**), respectively. Across the season (**Table 7**), the fields with TBS had higher mean yield (4.76 t/ha) compared to fields without TBS (3.83 t/ha). The benefit was obtained by taking the yield (t/ha) multiply by 900 Tsh/kg of harvested paddy. Therefore, the cost-benefit ratios for using a TBS were

Fields types	Yield (kg/ha)	Increased yield over control	Value of yield (Tsh)	Materials, labor, bait, rodenticides	Net benefit (NB)	Cost-benefit ratio (CBR)
With TBS	3830	507	456,300	215,000	241,300	**1:1.1**
Without TBS	3323					

Source: Mchukya [78].

Table 5.
Evaluation of the cost and benefit of control rodent pests with trap barrier system in dry season.

Fields types	Yield (kg/ha)	Increased yield over control	Value of yield (Tsh)	Materials, labor, bait, rodenticides	NB	CBR
With TBS	5690	1360	1,224,000	160,000	1,064,000	**1:6.7**
Without TBS	4330					

Source: Mchukya [78].

Table 6.
Evaluation of the cost and benefit of control rodent pests with trap barrier system in wet season.

Fields types	Yield (kg/ha)	Increased yield over control	Value of yield (Tsh)	Materials, labor, bait, rodenticides	NB	CBR
With TBS	4760	934	840,600	187,500	653,100	**1:3.5**
Without TBS	3826					

Source: Mchukya [78].

Table 7.
Evaluation of the cost and benefit of control rodent pests with trap barrier system across the seasons.

1:1.1 for the dry season, 1:6.7 for the wet season and 1:3.5 across the season. This is in contrast to the use of a TBS alone which, in Malaysia and the Philippines, requires crop losses of >30% before there is a positive benefit-cost ratio [99]. 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 yield losses [100]. Murakami [101] also reported a TBS to be effective against *R. qyntil-water* in paddies that had severe rat damage during the previous year.

The main factor providing the high benefit-cost ratio is the halo of protection provided to crops outside the TBS. Therefore, the selection of the project with the benefit-cost ratio or Profitability index (PI) method can also be done on the basis of ranking. The highest rank will be given to the project with the highest PI, followed by the others in the same order. According to Misuraca [102], the cost-benefit ratio exceeding one might be termed as the project worth undertaking as it become comparable to increasing returns to scale contributed by the project if a firm adopt it. The higher the cost-benefit ratio results in the higher net return [20]. The effect of a TBS plus trap crop on mean yield increased up to 20 m from the TBS and the associated cost-benefit ratios in this study.

2.3 Conclusion

Trap barrier system indicated its strong potential in lowering population abundance at a distance within 20 m away from the trap, which corresponding with low damage resulted to high yield. It is therefore recommended the small-scale farmers to use trap barrier system against pre-harvest rat losses to rice probably during dry season due to high rat densities. This will help them to save more, maximize their profit, and improve their living standard. Also, further study is needed to test this new technology in other irrigation schemes and other African countries and to determine the home range of rodent in order to provide valuable comparative data basis.

Author details

Loth S. Mulungu[1*], Bernard M. Mchukya[2] and Laurent L. Mnyone[1]

1 Pest Management Centre, Sokoine University of Agriculture, Morogoro, Tanzania

2 Rodent Control Centre, Ministry of Agriculture, Food Security and Cooperatives, Morogoro, Tanzania

*Address all correspondence to: lothmulungu@yahoo.co.uk

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