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Impact of spatio-temporal simulations of rat damage on yield of rice (Oryza sativa L.) and implications for rodent pest management

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Rodents often damage crops throughout the growing season, from germination to harvest, thus making it difficult to understand the cumulative effects of rodent damage for crops such as rice that are able to partially compensate for damage. Compensation can make it difficult to understand the impact of variable rodent damage in terms of when the damage occurs, its severity and thus when, whether and how rodent pests should be controlled. The compensatory responses of rice to simulated rat damage carried out at different growth stages and at different spatial levels of severity showed that higher yield was recorded during the wet season in comparison to the dry season. However, yield loss was observed during all cropping stages for all levels of simulated damage for wet and dry season crops, with significant compensation noted at the transplanting [14 days after sowing (DAS)] and vegetative (45 DAS) stages. Only damage at the maturity (110 DAS) stage resulted in significant reductions in rice crop yield. Seasonal differences suggest water availability was an important factor that perhaps enhanced rice production. The ability of rice to compensate for early rodent damage could potentially reduce a farmer's perception of damage. However, failing to control rodents at these earlier crop growth stages could lead to increased rodent populations at the time of maturity when compensatory effects are limited.

Keywords: yield loss; rodents; crop damage; crop yield

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important cereal crops in the world and the second most important crop in Africa after maize (Wayne 2003). In Tanzania, rice is produced under typical monocultural systems (Nguyen & Labrada 2002) that can be subdivided into three agro-ecosystems: rainfed lowland (74%), rainfed upland (20%) and irrigated lowland (6%) (Balasubramanian et al. 2007). Rice consumed in Tanzania is produced from five regions, Mbeya, Shinyanga, Mwanza, Morogoro and Tabora, where the average production rate ranges from 1 to 1.5 t/ha mean yield (Anon 2009), 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 & Labrada 2002).

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 (Fiedler 1994). Outbreaks of this rodent species in rice cropping areas have been reported to cause severe crop damage and food shortages (Singleton et al. 2010a; Makundi & Massawe 2011). On average across Asia, 5%–10% of crop damage has been attributed to rodents (Singleton et al. 2004; Meerburg et al. 2008; Singleton et al. 2010b). In Nigeria, Rabiu and Rose (2004) reported that rodent damage of rice caused yield losses of 4.8% and 12.6% in 1990 and 1991, respectively. Rodent damage to rice, however, can be measured at several stages of crop growth. 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). The authors go on to report that at the ripening stage the measured value ought to be multiplied by approximately 6.5 to obtain cumulative damage to the rice crop or by 4.2 for an estimate of yield loss (Singleton et al. 2005). However, as rice plants are able to compensate for some degree of damage, particularly in early stages of growth, estimating rodent damage levels through yield loss is fraught with difficulty as the yield loss is dependent on both the timing and severity of rodent damage. Farmers may not fully observe the impact of early damage and potentially delay rodent management actions that inadvertently lead to more severe rodent damage at the time of harvest. Thus, the aim of this study was to investigate the impact of spatio-temporal variation in simulated rat damage on rice crop yield, with a view to providing farmers with better decision support information on rodent pest management actions and timing.

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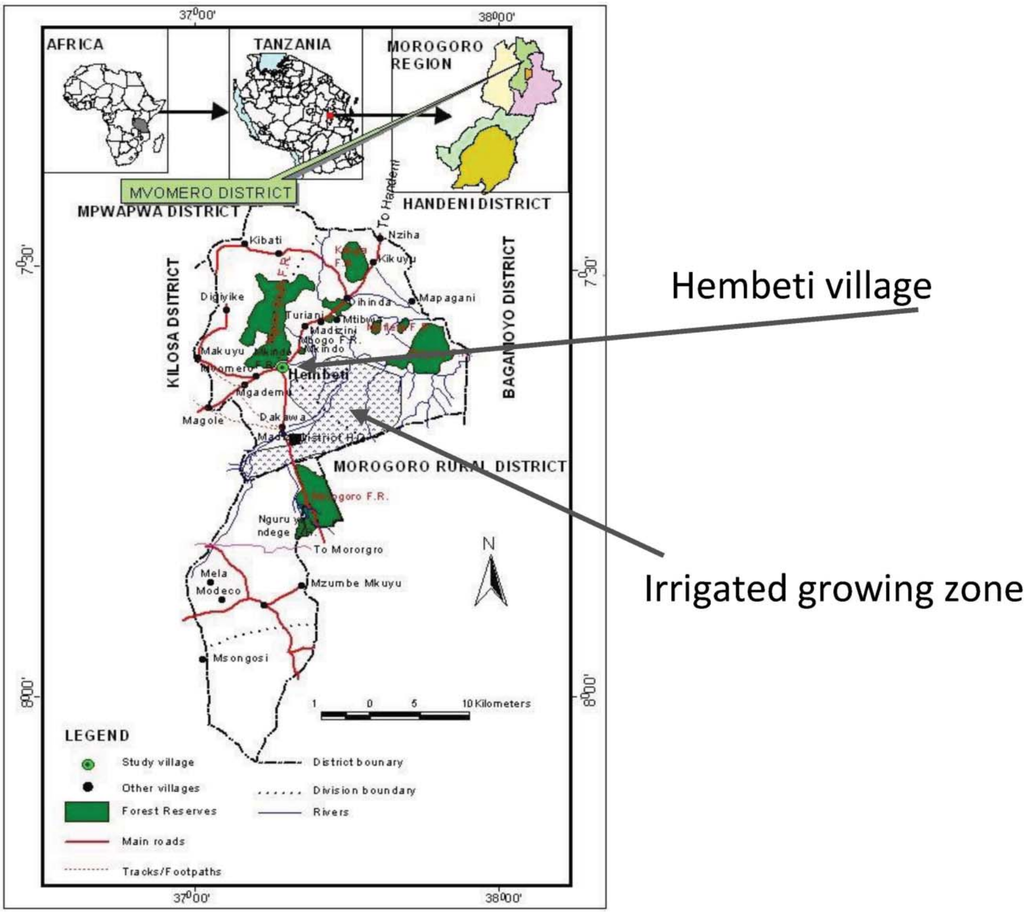

Figure 1. (Color online) Map showing the location of field studies. Wet and dry season crops are grown in the same area highlighted as the irrigated zone.

2. Materials and methods

2.1. *Study area*

Field trials were conducted in farmers' fields at Hembeti village (06°16′S, 37° 31′E) in Mvomero district, Morogoro region, Tanzania (Figure 1). The district has a typical tropical climate with bimodal rainfall. The long rainy season is from mid-February to May and the short rainy season is from November to December, with the remaining months mostly dry. The average annual rainfall ranges from 1500 to 2000 mm, and the mean temperature ranges from 15 to 29 °C. The altitude ranges from 380 to 520 m above sea level. Rice is the major crop in the area, and farmers produce two crops per year. The first crop is rainfed during the wet season from January to June and the second crop is planted in the dry season from July to December/January, which relies entirely on irrigation. Water for irrigation originates from surrounding mountains and flows through local canals to nearby farms. For wet and dry seasons, respectively, land preparation and rice transplanting are done in January and July, the rice booting stage is in April and October, the rice crop reaches physiological maturity in May and November, and farmers harvest in June and December. The SARO (TXD-306) rice variety was used, which is a standard variety grown by farmers in the area and has a high tillering ability with a range of 30−50 tillers per plant and a high yielding potential of 4−6.5 t/ha and takes 120 days to mature.

2.2. *Experimental design and layout*

The experiment was organized as a split−split plot in a randomized complete block design with three replicates. A field of 18 × 29 m with blocks of 13 × 8 m, and within each block, a plot of 2 × 2 m with paths of 0.5 m was used. Fourteen-day-old seedlings were transplanted using a 20 × 20 cm spacing interval with one seedling per hill. The main plot factor considered was season (wet and dry), with a sub-plot factor of growth stage (transplanting, vegetative, maturity) and a sub−sub plot factor of simulated rat damage level (0%, 10%, 20%, 25% and 50% of stems cut in a plot). Within each of the five damage level plots, three of the sub-plots were randomly assigned, one for each growth stage. Simulated rat damage was done at 14, 45 and 110 DAS at the three growth stages, i.e. transplanting [14 days after sowing (DAS)], vegetative (45 DAS) and maturity (110 DAS). Each stem was randomly chosen and cut using scissors from 3 to 5 cm above the ground surface at an oblique angle (45°) to mimic characteristic rat damage.

2.3. *Farm management practices in rice fields*

Farm management activities in the field trial followed local farming practices and crop calendar. Seeds of SARO (TXD-306) rice variety were raised in a nursery for two weeks and the seedlings were transplanted on a seedbed in mid-October 2012 and March 2013 for dry and wet seasons, respectively. Weed management was achieved by applying an herbicide (2,4-D Amine) at 32 DAS for the control of broad leaf weeds and by hand weeding at 40 DAS for uprooting weeds which did not respond to the herbicide. The study plots were fertilized with nitrogen in the form of urea applied twice at a rate of 80 kgN/ha, first during the early stage of tillering (16 DAS) and again during panicle initiation (80 DAS). In order to curtail possible rat damage during the experiment, the area was kept continuously baited with chronic rodenticide (Bromadiolone) in 50 cm lengths of bamboo (10 cm diameter) at each station with bait stations every 10 m, 2 g/station (bait in pelletized form). Bait was replaced every four days.

2.4. *Data collection*

The number of cut/uncut tillers and mean yield of grain per damage level plot were recorded. At harvest, the rice crop in each plot was cut, tied in bundles, air-dried for one day, hand threshed with sticks and then air-dried again for four days. Moisture content was measured with a grain moisture meter [Multi Grain Moisture Tester (MT-PRO), Sparex Ltd], and the crop from each plot replicate was weighed to the nearest 0.1 g and adjusted for variable moisture content using the following formula:

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

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

Yield was converted into tonnes per hectare based on each plot area of 4 m^2.

2.5. *Data processing and analysis*

Data were subjected to analysis of variance (ANOVA) using the split−split plot model, and the least significant difference (LSD) test procedure with parameters of season, growth stage, damage level and their interactions. Analysis was carried out using XLSTAT (version 2014.1.01, Addinsoft). The statistical model used in this analysis was as follows:

$$Y_{ijk} = \mu + R + S_j + (RS)_{ij} + G_k + (SG)_{jk} + L_l + (SL)_{jl} + (GL)_{kl} + (SGL)_{jkl} + (RSGL)_{ijkl},$$

where Y_{ijk} = yield, μ = general mean, R = ith replication effect, S_j = seasonal effect, $(RS)_{ij}$ = ijth main plot error, G_k = growth effect, $(SG)_{jk}$ = jkth interaction of season and rice growth stage, L_l = lth treatment level effect, $(SL)_{jl}$ = jlth interaction of season and removal plant level effect, $(GL)_{kl}$ = klth interaction of rice growth stage and removed plant level effect, $(SGL)_{jkl}$ = jklth interaction of season, rice growth stage and removed plant level effect and $(RSGL)_{ijkl}$ = experimental error.

The effect of each damage level (0, 10, 20, 25 and 50) was analysed following the statistical model

$$Y_{ijk} = \mu + R + L_j + (RL)_{ij},$$

where Y_{ijk} = yield, μ = general mean, R = ith replication effect, L_j = treatment level effect and $(RL)_{ij}$ = experimental error.

3. Results

A multifactor ANOVA with LSD incorporating the parameters of season, growth stage and damage level showed significant differences for each factor on mean yield (Table 1). The average yield for the wet season was 5.2 t/ha, which was significantly higher from the dry season yield of 3.1 t/ha (LSD = 0.157, $P < 0.05$). For the cutting treatments at the three growth stages, the mean yields at transplanting (4.5 t/ha) and vegetative (4.4 t/ha)

Table 1. Multifactor ANOVA on rice crop yield (t/ha) showing significant effects of season, growth stage and damage level on average yields. Significant interactive effects between growth stage and damage level suggest rice plant compensation has occurred.

Source	DF	Sum of squares	Mean squares	*F*	Pr > *F*
Model	29	148.296	5.114	37.055	<0.0001
Error	60	8.280	0.138		
Corrected total	89	156.576			
Season	1	104.114	104.114	754.448	<0.0001
Growth stage	2	15.386	7.693	55.746	<0.0001
Damage levels	4	21.292	5.323	38.572	<0.0001
Season*growth stage	2	0.763	0.381	2.764	0.071
Season*damage levels	4	1.055	0.264	1.911	0.120
Growth stage*damage levels	8	4.622	0.578	4.186	0.000
Season*growth stage*damage levels	8	1.065	0.133	0.965	0.472

Table 2. Effect on average rice crop yield (t/ha) through simulated rodent damage when different percentages of rice tillers have been cut at different crop growth stages in different seasons. Mean values followed by the same letter are not significantly different from each other (ANOVA with LSD, $P < 0.05$).

Interaction	Mean yield (t/ha)
Maturity*50	2.6a
Maturity*25	3.2b
Maturity*20	3.4b
Vegetative*50	3.5b
Maturity*10	3.9c
Transplanting*50	4.1c,d
Vegetative*25	4.2c,d
Transplanting*25	4.3c,d,e
Transplanting*20	4.6d,e
Transplanting*10	4.6d,e
Vegetative*20	4.7d,e
Vegetative*10	4.7d,e
Transplanting*0	4.9e
Maturity*0	4.8e
Vegetative*0	5.0e

stages were not significantly different from each other ($P > 0.05$); however, they were both significantly higher from the average yield at maturity (3.6 t/ha) (LSD = 0.192, $P < 0.05$). The average yields at each damage level were 4.9, 4.5, 4.2, 3.9 and 3.4 t/ha for damage levels of 0%, 10%, 20%, 25% and 50%, respectively. All values were significantly different from each other, except for 10% and 20% (LSD = 0.248, $P < 0.05$). Compensation in rice crop yield can be further observed through the significant interaction between growth stage and damage level (Table 1). No other interactive effects among parameters were noted. Observed differences by season, growth stage and damage level were statistically confirmed by LSD tests performed after the multifactor ANOVA (Table 2).

Percentage yield loss to rodents was calculated based on the difference between the yield in the untreated control plots, where 0% of rice stem tillers were cut and the loss observed when 10%–50% of the tillers were cut (Figure 2). From these data, the compensatory ability of rice to regrow new tillers (which were not counted in this study) is most apparent at the transplanting (14 DAS) stage in the wet season crop where all percent damage levels have approximately the same effect on yield loss. Percentage loss is observed to be overall higher in the dry season, at the maturity stage (110 DAS) and among the higher rates of damage, particularly 25% and 50%.

4. Discussion

Farmers may assume that all rat damage results in proportionate yield reductions (Mulungu et al., forthcoming). However, our results indicate that the impact of rice crop damage through the cutting of tillers on yields may be negligible, particularly if the damage occurs early in the growing season at the transplanting (14 DAS) through vegetative (45 DAS) stages of the crop. Our results indicate that tiller damage in these earlier stages is less important in the rainfed wet season crop than during the dry season, arguably due to water stress to the crop during the dry season, and this is supported by our data showing lower dry season yield. Unfortunately, our data indicate that late damage at the time of maturity (110 DAS) results in significant percentage yield loss, roughly approximate to the percentage of damage. Poché et al. (1981) and My Phung et al. (2010) argued this is due to the fact that at such a late stage the crop cannot produce more tillers to compensate for damage, since very little time is available for such compensatory growth. Similar findings were reported by Fulk and Akhtar (1981) who showed that rice grain yield may not be affected by loss of tillers at their early growth stages as the numbers of productive tillers are determined at the late tillering stage. Likewise, Buckle et al. (1979) reported that compensation capacity of rice damaged by rodents is higher at each growth stage than at maturity of the crop. Aplin et al. (2003) explained the term compensation of rice in terms of tiller regrowth and

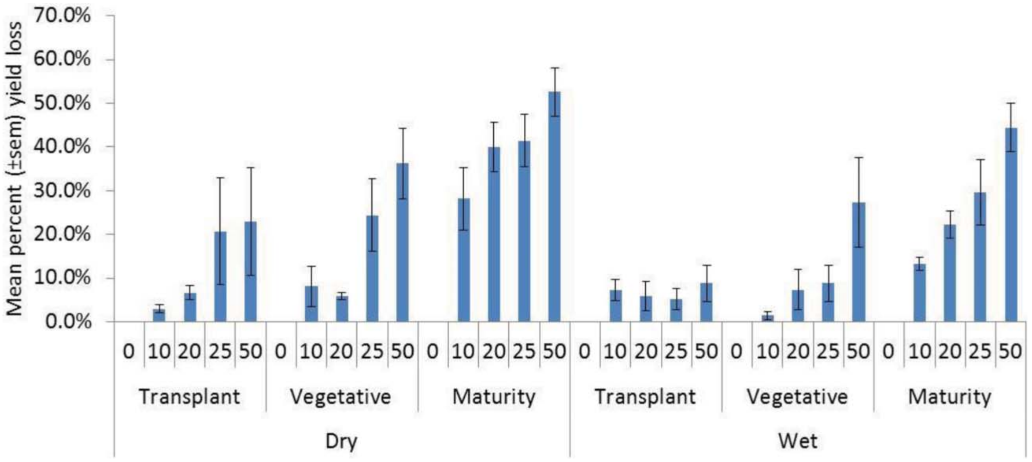

Figure 2. Yield loss observed due to simulated rodent damage by cutting rice tillers at different percentages of each crop area at three different growth stages over two cropping seasons.

panicle filling. Cut tillers that regrow before maximum tillering are likely to go through normal panicle initiation. However, a tiller that is cut after the plant has entered the panicle-initiation stage generally will not be able to produce a new panicle, but the plant may compensate for this loss by diverting its resources into the remaining panicles leading to panicles with larger or more numerous grains. Cuong et al. (2003) observed that the effect of rodent damage at different stages of rice growth was low when rodent damage occurred at the seedling stage (15−20 DAS) when the plant was able to compensate for the effect, but at tillering (35−40 DAS) and booting (55−60 DAS) stages, there was no compensation effect. The author further observed that the yield loss might be high and probably result in total yield loss when damage occurs at the reproductive phase, as there would not be sufficient time for compensation to occur.

The lower yield observed during the dry season is probably attributed to irregular irrigation and/or prolonged periods of water stress caused by insufficient water supply (Nguyen & Ferrero 2006). Similar results have been reported by Yue et al. (2006) who observed yield loss under drought stress and associated such loss with an increase of spikelet sterility and a reduction in panicle filling rate as well as grain weight. According to Sarvestani et al. (2008), water stress has negative impacts on rice growth and development, where the effects vary with phenological stages of the crop which are generally more severe from the flowering stage onwards.

Our results on the spatio-temporal effects of simulated rodent damage are the first report of such work in sub-Saharan Africa. As rice consumption is growing in Africa, understanding the potential impact of rodent pests on increased rice production across the continent can assist farmers' decision-making on limiting yield loss by rodents. Our research suggests that rodent damage early in the season may not result in significant yield losses. However, this may lead to inappropriate decision-making where rodent populations are left uncontrolled during early growth stages, allowing the rodent population to build and subsequently cause more damage at the time of harvest where rice plants are not able to compensate for such late damage. African farmers need to understand this complexity of rice plant compensation dynamics in order to interpret their observations correctly and decide when rodent populations should be managed to avert significant yield losses.

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