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

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15

16 **Abstract**

17 Rodents often damage crops throughout the growing season, from germination to
18 harvest, thus making it difficult to understand the cumulative effects of rodent damage
19 for crops such as rice that are able to partially compensate for damage. Compensation
20 can make it difficult to understand the impact of variable rodent damage in terms of
21 when the damage occurs, its severity and thus when, whether and how rodent pests
22 should be controlled. The compensatory responses of rice to simulated rat damage
23 carried out at different growth stages and at different spatial levels of severity showed
24 that higher yield was recorded during the wet season in comparison to the dry season.
25 However, yield loss was observed during all cropping stages for all levels of simulated
26 damage for wet and dry season crops, with significant compensation noted at the
27 transplanting (14 DAS) and vegetative (45 DAS) stages. Only damage at the maturity
28 (110 DAS) stage resulted in significant reductions in rice crop yield. Seasonal differences
29 suggest water availability was an important factor that perhaps enhanced rice
30 production. The ability of rice to compensate for early rodent damage could potentially
31 reduce a farmer's perception of damage. However, failing to control rodents at these
32 earlier crop growth stages could lead to increased rodent populations at the time of
33 maturity when compensatory effects are limited.

34 **Keywords:** yield loss, rodents, crop damage, crop yield

35

36 **1. Introduction**

37 Rice (*Oryza sativa* L.) is one of the most important cereal crops in the world and the
38 second most important crop in Africa after maize (Wayne 2003). In Tanzania, rice is
39 produced under typical monocultural systems (Nguyen and Labrada 2002) that can be
40 subdivided into three agro-ecosystems, rainfed lowland (74%), rainfed upland (20%)
41 and irrigated lowland (6%) (Balasubramanian et al. 2007). Rice consumed in Tanzania is
42 produced from five regions, Mbeya, Shinyanga, Mwanza, Morogoro and Tabora where
43 the average production rate ranges from 1 – 1.5 t/ha mean yield (Anon 2009), which is
44 significantly lower than that of Africa and that of the world (mean yield of 2.2 t/ha and
45 3.4 t/ha, respectively) (Nguyen and Labrada 2002).

46 According to Mulungu et al. (2013), crop losses caused by rodents are largely
47 attributed to *Mastomys natalensis*, the most economically important and wide-spread
48 rodent pest across sub-Saharan Africa (Fiedler 1994). Outbreaks of this rodent species in
49 rice cropping areas have been reported to cause severe crop damage and food
50 shortages (Makundi & Massawe 2011; Singleton et al. 2010a). On average across Asia,
51 5-10% crop damage has been attributed to rodents (Meerburg et al. 2008; Singleton et
52 al. 2010b; 2004). In Nigeria, Rabiou and Rose (2004) reported that rodent damage of rice
53 caused yield losses of 4.8% and 12.6% in 1990 and 1991, respectively. Rodent damage
54 to rice, however, can be measured at several stages of crop growth. It has been
55 reported from West Java that cumulative damage to rice during the dry season was
56 54% at the primordial stage, 32% at the booting stage and 16% at the ripening stage
57 (Singleton et al. 2005). The authors go on to report that at the ripening stage the

58 measured value ought to be multiplied by approximately 6.5 to obtain cumulative
59 damage to the rice crop or by 4.2 for an estimate of yield loss (Singleton et al. 2005).
60 However, as rice plants are able to compensate for some degree of damage,
61 particularly in early stages of growth, estimating rodent damage levels through yield
62 loss is fraught with difficulty as the yield loss is dependent on both the timing and
63 severity of rodent damage. Farmers may not fully observe the impact of early damage
64 and potentially delay rodent management actions that inadvertently lead to more
65 severe rodent damage at the time of harvest. Thus the aim of this study was to
66 investigate the impact of spatio-temporal variation in simulated rat damage on rice
67 crop yield, with a view to providing farmers with better decision support information
68 on rodent pest management actions and timing.

69

70 **2 MATERIALS AND METHODS**

71 ***2.1 Study area***

72 Field trials were conducted in farmers' fields at Hembeti village (06°16'S, 37° 31'E) in
73 Mvomero district, Morogoro region, Tanzania (Fig. 1). The district has a typical tropical
74 climate with bimodal rainfall. The long rainy season is from mid-February to May and
75 the short rainy season is from November to December, with the remaining months
76 mostly dry. The average annual rainfall ranges from 1,500–2,000 mm, and the mean
77 temperature ranges from 15 to 29°C. The altitude ranges from 380 - 520 meters above
78 sea level. Rice is the major crop in the area, and farmers produce two crops per year.
79 The first crop is rain-fed during the wet season from January to June and the second

80 crop is planted in the dry season from July to December/January, which relies entirely
81 on irrigation. Water for irrigation originates from surrounding mountains and flows
82 through local canals to nearby farms. For wet and dry seasons, respectively, land
83 preparation and rice transplanting are done in January and July, the rice booting stage
84 is in April and October, the rice crop reaches physiological maturity in May and
85 November, and farmers harvest in June and December. The SARO (TXD-306) rice
86 variety was used, which is a standard variety grown by farmers in the area and has a
87 high tillering ability with a range of 30 to 50 tillers per plant and a high yielding
88 potential of 4-6.5 t/ha and takes 120 days to mature.

89

90 ***2.2 Experimental design and layout***

91 The experiment was organized as a split-split plot in a randomized complete block
92 design with three replicates. A field of 18 x 29 m with blocks of 13 x 8 m, and within
93 each block, a plot of 2 x 2 m with paths of 0.5 m was used. Fourteen day-old seedlings
94 were transplanted using a 20 x 20 cm spacing interval with one seedling per hill. The
95 main plot factor considered was season (wet and dry), with a sub-plot factor of growth
96 stage (transplanting, vegetative, maturity) and a sub-sub plot factor of simulated rat
97 damage level (0, 10, 20, 25, and 50% of stems cut in a plot). Within each of the five
98 damage level plots, three of the sub-plots were randomly assigned, one for each
99 growth stage. Simulated rat damage was done at 14, 45 and 110 days after sowing at
100 the three growth stages, i.e. transplanting (14 DAS), vegetative (45 DAS) and maturity

101 (110 DAS). Each stem was randomly chosen and cut using scissors from 3 to 5 cm
102 above the ground surface at an oblique angle (45°) to mimic characteristic rat damage.

103

104 ***2.3 Farm management practices in rice fields***

105 Farm management activities in the field trial followed local farming practices and crop
106 calendar. Seeds of SARO (TXD-306) rice variety were raised in a nursery for two weeks
107 and the seedlings were transplanted on a seedbed in mid-October, 2012 and March,
108 2013 for dry and wet seasons, respectively. Weed management was achieved by
109 applying an herbicide (2, 4-D Amine) at 32 days after sowing (DAS) for the control of
110 broad leaf weeds and by hand weeding at 40 DAS for uprooting weeds which did not
111 respond to the herbicide. The study plots were fertilized with nitrogen in the form of
112 urea applied twice at a rate of 80 kgN/ha, first during the early stage of tillering (16
113 DAS) and again during panicle initiation (80 DAS). In order to curtail possible rat
114 damage during the experiment, the area was kept continuously baited with chronic
115 rodenticide (Bromadiolone) in 50 cm lengths of bamboo (10 cm diameter) at each
116 station with bait stations every 10 m, 2 g/station (bait in pelletized form). Bait was
117 replaced every four days.

118

119 ***2.4 Data collection***

120 The number of cut/uncut tillers and mean yield of grain per damage level plot were
121 recorded. At harvest, the rice crop in each plot was cut, tied in bundles, air-dried for
122 one day, hand threshed with sticks and then air-dried again for 4 days. Moisture

123 content was measured with a grain moisture meter (Multi Grain Moisture Tester (MT-
 124 PRO), Sparex Ltd), and the crop from each plot replicate was weighed to the nearest
 125 0.1 g and adjusted for variable moisture content using the following formula:

126

$$127 \quad Y = [(100-k)/(100-12.5)] \times j$$

128

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

131 Yield was converted into tonnes per hectare based on each plot area of 4 m².

132

133 ***2.5 Data processing and analysis***

134 Data were subjected to analysis of variance (ANOVA) using the split-split plot model,
 135 and the Least Significant Difference (LSD) test procedure with parameters of season,
 136 growth stage, damage level and their interactions. Analysis was carried out using
 137 XLSTAT (version 2014.1.01, Addinsoft). The statistical model used in this analysis was as
 138 follows:

139

$$140 \quad Y_{ijk} = \mu + R + S_j + (RS)_{ij} + G_k + (SG)_{jk} + L_l + (SL)_{jl} + (GL)_{kl} + (SGL)_{jkl} + (RSGL)_{ijkl}$$

141

142 where: Y_{ijk} = Yield, μ = general mean, R = ith replication effect, S_j = seasonal effect, (RS)
 143 = ijth main plot error, G_k = Growth effect, (SG) = jkth interaction of season and rice
 144 growth stage, L_l = lth treatment level effect, (SL) = jlth interaction of season and removal

145 plant level effect, $(GL)_{kl}$ = kl^{th} interaction of rice growth stage and removed plant level
146 effect, $(SGL) = jkl^{\text{th}}$ interaction of season, rice growth stage and removed plant level
147 effect, and $(RSGL)_{ijk}$ = Experimental error.

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

150

$$151 \quad Y_{ijk} = \mu + R + L_j + (RL)_{ij}$$

152

153 where; Y_{ijk} = Yield, μ = general mean, $R = i^{\text{th}}$ replication effect, L_j = treatment level effect

154 and $(RL)_{ij}$ = Experimental error

155

156 **3. Results**

157 A multifactor ANOVA with LSD incorporating the parameters of season, growth stage
158 and damage level showed significant differences for each factor on mean yield (Table
159 1). The average yield for the wet season was 5.2 t/ha, which was significantly higher
160 from the dry season yield of 3.1 t/ha (LSD = 0.157, $P < 0.05$). For the cutting treatments
161 at the three growth stages, the mean yields at transplanting (4.5 t/ha) and vegetative
162 (4.4 t/ha) stages were not significantly different from each other ($P > 0.05$); however,
163 they were both significantly higher from the average yield at maturity (3.6 t/ha) (LSD =
164 0.192, $P < 0.05$). The average yields at each damage level were 4.9, 4.5, 4.2, 3.9 and 3.4
165 t/ha for damage levels of 0, 10, 20, 25, and 50 percent, respectively. All values were
166 significantly different from each other, except for 10 and 20 percent (LSD = 0.248, $P <$

167 0.05). Compensation in rice crop yield can be further observed through the significant
168 interaction between growth stage and damage level (Table 1). No other interactive
169 effects among parameters were noted. Observed differences by season, growth stage
170 and damage level were statistically confirmed by LSD tests performed after the
171 multifactor ANOVA (Table 2).

172 Percentage yield loss to rodents was calculated based on the difference
173 between yield in the untreated control plots where 0% of rice stem tillers were cut and
174 the loss observed when 10-50% of the tillers were cut (Fig. 2). From these data, the
175 compensatory ability of rice to regrow new tillers (which were not counted in this
176 study) is most apparent at the transplanting (14 DAS) stage in the wet season crop
177 where all percent damage levels have approximately the same effect on yield loss.
178 Percentage loss is observed to be overall higher in the dry season, at the maturity stage
179 (110 DAS) and among the higher rates of damage, particularly 25 and 50 percent.

180

181 **4. Discussion**

182 Farmers may assume that all rat damage results in proportionate yield reductions
183 (Mulungu et al. In press). However, our results indicate that the impact of rice crop
184 damage through the cutting of tillers on yields may be negligible, particularly if the
185 damage occurs early in the growing season at the transplanting (14 DAS) through
186 vegetative (45 DAS) stages of the crop. Our results indicate that tiller damage in these
187 earlier stages is less important in the rain-fed wet season crop than during the dry
188 season, arguably due to water stress to the crop during the dry season, and this is

189 supported by our data showing lower dry season yield. Unfortunately, our data indicate
190 that late damage at the time of maturity (110 DAS) results in significant percentage
191 yield loss, roughly approximate to the percentage of damage. Poche et al. (1981) and
192 My Phung et al. (2010) argued this is due to the fact that at such a late stage the crop
193 cannot produce more tillers to compensate for damage since very little time is available
194 for such compensatory growth. Similar findings were reported by Fulk and Akhtar
195 (1981) who showed that rice grain yield may not be affected by loss of tillers at their
196 early growth stages as the numbers of productive tillers are determined at the late
197 tillering stage. Likewise, Buckle et al. (1979) reported that compensation capacity of
198 rice damaged by rodents is higher at each growth stage than at maturity of the crop.
199 Aplin et al. (2003) explained the term compensation of rice in terms of tiller regrowth
200 and panicle filling. Cut tillers that regrow before maximum tillering are likely go through
201 normal panicle initiation. However, a tiller that is cut after the plant has entered the
202 panicle-initiation stage generally will not be able to produce a new panicle, but the
203 plant may compensate for this loss by diverting its resources into the remaining
204 panicles leading to panicles with larger or more numerous grains. Cuong et al. (2003)(
205 observed that the effect of rodent damage at different stages of rice growth was low
206 when rodent damage occurred at the seedling stage (15 – 20 DAS) when the plant was
207 able to compensate for the effect; but at tillering (35 – 40 DAS) and booting (55 – 60
208 DAS) stages there was no compensation effect. The author further observed that the
209 yield loss might be high and probably result in total yield loss when damage occurs at

210 the reproductive phase as there would not be sufficient time for compensation to
211 occur.

212 The lower yield observed during the dry season is probably attributed to
213 irregular irrigation and/or prolonged periods of water stress caused by insufficient
214 water supply (Nguyen & Ferrero 2006). Similar results have been reported by Yue et al.
215 (2006) who observed yield loss under drought stress and associated such loss with an
216 increase of spikelet sterility and a reduction in panicle filling rate as well as grain
217 weight. According to Sarvestani et al. (2008), water stress has negative impacts on rice
218 growth and development where the effects vary with phenological stages of the crop
219 which are generally more severe from the flowering stage onwards.

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

232

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304 Table 1. Multi-factor ANOVA on rice crop yield (t/ha) showing significant effects of
 305 season, growth stage and damage level on average yields. Significant interactive
 306 effects between growth stage and damage level suggest rice plant compensation has
 307 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

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312

313 Table 2. Effect on average rice crop yield (t/ha) through simulated rodent damage
 314 when different percentages of rice tillers have been cut at different crop growth stages
 315 in different seasons. Mean values followed by the same letter are not significantly
 316 different from each other (ANOVA with LSD, $P < 0.5$).

317

Interaction	Mean yield t/ha
Dry*Transplanting*0	3.933 g,h
Dry* Transplanting *10	3.800 h
Dry* Transplanting *20	3.633 h
Dry* Transplanting *25	3.000 i
Dry* Transplanting *50	2.900 i
Dry*Vegetative*0	4.100 f,g,h
Dry* Vegetative *10	3.733 h
Dry* Vegetative *20	3.833 g,h
Dry* Vegetative *25	3.000 i
Dry* Vegetative *50	2.467 i,j
Dry*Maturity*0	3.833 g,h
Dry*Maturity*10	2.567 i,j
Dry*Maturity*20	2.033 j,k
Dry*Maturity*25	1.967 j,k
Dry*Maturity*50	1.467 k
Wet* Transplanting *0	5.767 a,b
Wet* Transplanting *10	5.433 a,b
Wet* Transplanting *20	5.500 a,b
Wet* Transplanting *25	5.533 a,b
Wet* Transplanting *50	5.367 a,b,c
Wet* Vegetative *0	5.800 a
Wet* Vegetative *10	5.767 a,b
Wet* Vegetative *20	5.500 a,b
Wet* Vegetative *25	5.400 a,b
Wet* Vegetative *50	4.567 d,e,f
Wet*Maturity*0	5.767 a,b
Wet*Maturity*10	5.167 a,b,c,d
Wet*Maturity*20	4.767 c,d,e
Wet*Maturity*25	4.433 e,f,g
Wet*Maturity*50	3.767 h

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321 Figure 1. Map showing the location of field studies. Wet and dry season crops are

322 grown in the same area highlighted as the irrigated zone

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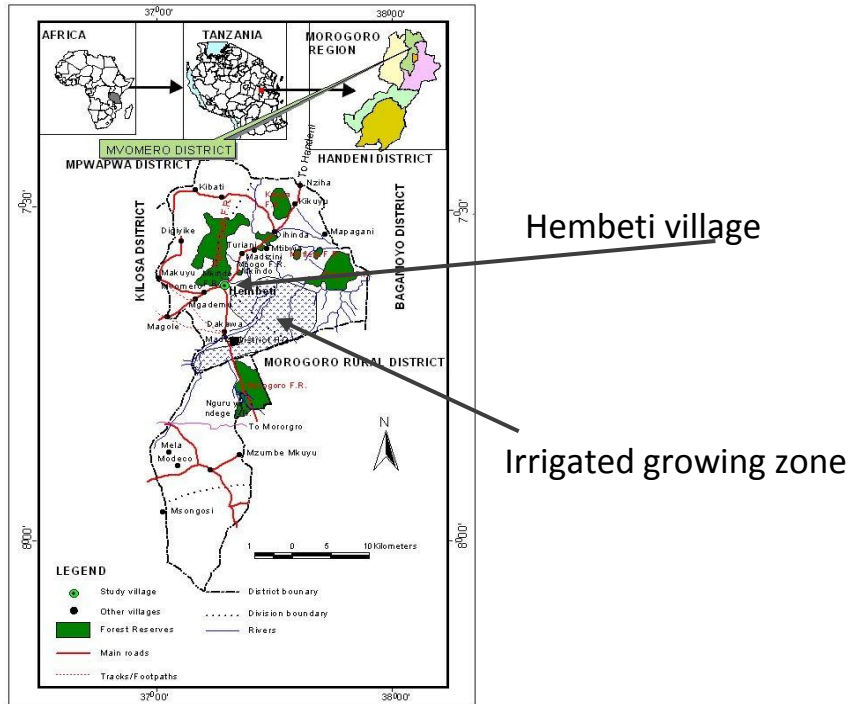
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334 Fig.

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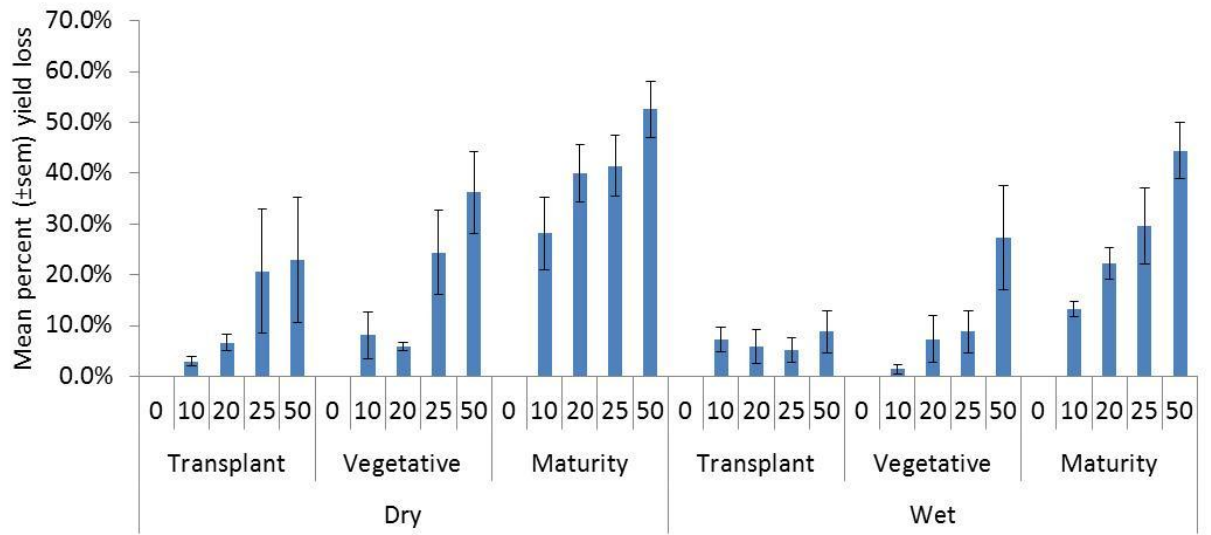
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338 Figure 2. Yield loss observed due to simulated rodent damage by cutting rice tillers at
 339 different percentages of each crop area at three different growth stages over two
 340 cropping seasons.

341



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