Vegetation cover and food availability shapes the foraging activity of rodent pests in and around maize fields.

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Abstract:

Evidence-based information for smallholder farmers on where and when to conduct rodent management is vital given that most are resource poor and depend on agriculture for food and income. However, there is scarce information on how the foraging activity of rodent pests changes over agricultural cropping seasons. We used the concepts of giving-up-density (GUD) and landscape of fear to monitor how the foraging activity of rodent pests changes in and around maize (*Zea mays*) fields over the cropping season. We tested the hypothesis that the foraging activity of rodent pests will be influenced by vegetation cover, perceived predation risk and food availability. *Mastomys natalensis* was the dominant species in all maize fields (n = 3, 87.05% of the total captures). We observed that the foraging activity of rodents was influenced by vegetation cover and food availability. During the germination stage, rodent activity in the natural habitat and along the border was higher than inside the maize fields. During land preparation, planting, weeding, maize tasselling, maturity, and post-harvest stages, there was no difference in the foraging activity in and around the maize fields. During the harvest stage, the foraging activity was higher in the maize fields than along the border and in the natural habitat. These results can be used to guide smallholder farmers where and when to focus rodent control measures during different stages of the cropping season. An additional approach would be to develop strategies that could potentially increase rodent fear perceptions in cropping landscapes.

***Keywords*:** Rodent pests, *Mastomys natalensis*, foraging activity, maize field, giving-up-density, landscape of fear

1. Introduction

Rodent pests damage maize crops before and after harvest (Skonhoft *et al.*, 2006; Swanepoel *et al.*, 2017). Mostly, rodent pests damage maize crops during the germination (Mulungu *et al.*, 2005) and maturation stages (Mulungu, 2017). At the germination stage, rodents dig up and consume germinating maize seeds (Mulungu *et al.*, 2007) leading to either a regular distribution of damage in mosaic fields or a more random distribution in monoculture fields (Mulungu *et al.*, 2005). At the maturation stage, rodents consume both fresh and dry grains when the maize plants are standing or on the ground (Mulungu, 2017). Population dynamics and competition for available food resources partly accounts for observed heterogeneous damage patterns (Mohr *et al.*, 2003). Predation risk, land preparation methods and soil type can also account for the heterogrenous damage by indirectly or directly affecting the population dynamics of rodents (Mulungu *et al.*, 2005). Therefore, either random or stratified sampling methods could be used to assess rodent damage in maize fields (Mulungu *et al.*, 2007). In maize cropping systems, little is known both about how the foraging activity of rodent pests changes over the cropping season and how this may affect crop damage, particularly in relation to harbourage provided by field margin vegetation and the maize crop itself. Maintaining field margin vegetation is increasingly recognised as important in facilitating crop pollination and conservation biological control of insect pests (Arnold *et al.*, 2021; Ochieng *et al.*, 2022), but such vegetation could potentially exacerbate the presence of rodent pests (Jacob, 2008; Rodríguez-Pastor *et al.*, 2016).

Understanding the foraging activity of rodent pests is important to enable sustainable control to reduce their impact and damage (Belmain, 2010; Krijger *et al.*, 2017). Foraging activity has been strongly correlated with vegetation cover in several studies. In Philippines, *Rattus tanezumi* spent more time foraging at the centre of the rice fields than on the field edges (border), where there was less vegetation cover (Jones *et al.*, 2017). Evidence suggests that rodents in agricultural landscapes spend more time foraging in areas where they perceive the least fear from predation (Ylonen *et al.*, 2002). Understanding how the foraging activity of rodents changes over the maize growing season could help to develop management strategies that incorporate the 'landscape of fear' (LOF) concept (Laundré *et al.*, 2001) and thereby reduce rodent foraging in cropping areas. Furthermore, evidence-based information on where and when to conduct rodent management can help to prevent rodent outbreaks and is vital given that most farmers are resource poor and depend on agriculture for food and income (Swanepoel *et al.*, 2017; Taylor *et al.*, 2012).

To monitor and/or map the foraging activity of rodents across the maize growing season, one technique that can be exploited is the giving-up-density (GUD) approach, which attempts to characterise the LOF for a species in a habitat. The LoF is “the spatially explicit distribution of perceived predation risk as seen by a prey population” (Bleicher, 2017; Gaynor *et al.*, 2019). The perceived predation risk (cost of foraging) of a population can be measured by the GUD (Brown and Kotler, 2004). According to Johnson and Horn (2008), a forager abandons a patch quickly when the perceived risk of predation is high, leaving behind greater density of food compared to when the perceived risk of predation is low. In many crops, landscape features can affect both domestic and wild predators that prey on rodents (Pita *et al.*, 2009; Fischer and Schröder, 2014; St. George and Johnson, 2021), as can the presence of farmers regularly tending their fields who may influence the spatial behaviour of rodents (Jones *et al.*, 2017). Rodents use both direct (predator odours) and indirect (habitat type and weather conditions) cues to assess the risk of predation in a particular patch (Orrock *et al.*, 2004).

GUDs have been successfully used to understand the foraging activity of rodents in rice fields (Jones *et al.*, 2017), maize fields (Mohr *et al.*, 2003), wheatfields (Ylonen *et al.*, 2002) and in natural habitats (Wheeler and Hik, 2014; Yang *et al.*, 2016; Loggins *et al.*, 2019). Despite the application of GUD studies on rodents, few papers directly apply GUDs to assess rodent management strategies (Krijger *et al.*, 2017). Currently, most rodent management strategies in maize cropping systems do not incorporate the rodent’s landscape of fear which could increase their efficiency and reduce damage to maize crops. To address these shortcomings and highlight how GUD studies could refine management strategies beyond the usual measures of abundance or activity, the current study interprets the results with consideration of rodent pest management strategies by recommending areas (in and around maize fields) where farmers should focus pest control during different times of the maize cropping season, i.e., areas where rodents perceive the lowest levels of predation

(Krijger *et al.*, 2017). This is the first application of GUDs and LOF in Africa to understand how the foraging activity of rodent pest species in and around maize fields changes across a growing season.

We tested the hypothesis that the foraging activity of rodents in a maize cropping system is influenced by vegetation cover and food availability. We predicted that rodents will have: (i) lower foraging activity in the maize fields than along the border and in the adjacent natural habitat during the land preparation, planting, germination and post-harvest stages (when the maize fields have less vegetation cover and less food resources (grains)); (ii) equal foraging activity in maize fields and adjacent natural habitat from the weeding to maize tasselling stages when the vegetation cover in the maize fields increases; and (iii) the foraging activity will be higher in the maize fields than the adjacent habitat during the maturity, and harvest stages due to increased food resources (maize grains) and vegetation cover. This study will help to understand how different habitats may affect anti-predator and foraging activity and could guide rodent damage assessments (Jones *et al.*, 2017) and guide future ecologically-based rodent management strategies (Krijger *et al.*, 2017) in maize cropping systems.

2. Materials and methods

2.1. Experimental Design

Four maize fields located adjacent to a natural habitat in Luto agricultural camp, Kitwe, Zambia (located between 12.94S,28.17E and 12.93S,28.20E) were selected for this study (Fig. 1). The maize fields ranged from 2 to 4 hectares.

Prior to the main study, a pilot study was conducted to establish the best food (e.g., groundnuts, sunflower kernels, or pumpkin seeds), feeder (e.g., plastic, or wooden trays) and substrate type (sand or soil from the fields) for GUD estimates (Bedoya-Perez *et al.*, 2013). The pilot study involved placing 20 seeds of a single type (groundnuts, sunflower kernels, or pumpkin seeds) in separate plastic or wooden trays (18 buried and 2 placed on the top) filled with either sand or soil from the fields. Trays contained small drainage holes in the bottom to allow rain water to drain through. The trays were left in fields for three consecutive nights, counting the number of seeds remaining each morning, and resetting to 20 seeds each night. Pilot data indicated sunflower kernels and pumpkin seeds were more difficult to recover than groundnuts when counting the number of seeds remaining, especially if it had rained. Hence, we settled for groundnuts as the best food for the main study. Plastic trays were preferred over wooden trays because wooden trays were soaked by the rains making them difficult to carry around. Rodent activity was generally lower in trays filled with sand, possibly because the sand increased neophobic behaviour of rodents as sand is not commonly found in the area. Therefore, we used soils from the fields as the substrate type for the main study. Thus the main study was developed using four plastic trays with 20 m spacing between the trays (Ylonen *et al.*, 2002) which were placed along five transects. The first transect was laid along the border (field edge) of the maize field (transect #3), and two were at 20 m and 40 m either side of the border transect in maize fields (transects 1 and 2) and natural habitat (transects 4 and 5), respectively (Fig. 2).

Twenty groundnuts were placed in each tray, 18 buried in soil and 2 placed on the top (Jones *et al.*, 2017). The foraging activity was monitored for three consecutive days (in the morning), with trays restocked with 20 groundnuts each day. The GUD was assessed by counting the number of seeds remaining in the tray (Brown, 1988). To confirm rodent activity at the feeding patches, a Bushnell Trophy Cam HD Essential Trail camera trap was placed in one patch per field at the beginning of the study (Fig. 3) (see Bedoya-Perez et al., (2013)). The camera traps were set to record 24 h per day with a 30 s delay between detections (Williams *et al.*, 2018; Rich *et al.*, 2017). The following parameters were set on the camera traps; take three photos (8M pixel) per trigger, sensor level at auto, NV shutter at medium and time stamp on. The camera traps were set 20 cm (Ramesh and Downs, 2015; Meek *et al.*, 2012) above the ground on a wooden pole. The plastic tray was placed 1.5 m in front of the camera trap (Glen *et al.*, 2016; Meek *et al.*, 2012).

Foraging activity was assessed monthly (4-week intervals) during the maize growing season (October to July), while the populations of rodents in the maize fields were monitored monthly following the capture-mark-recapture (CMR) procedure in fields 1-3 as part of another study which examined the population dynamics of small mammals in maize fields (Imakando, 2021). A 70 m x 70 m permanent trapping grid was established in the centre of each maize field. Each trapping grid had seven trap lines, 10 m apart. Seven trapping stations, 10 m apart, were marked on each trap line. One Sherman live-trap, baited with a mixture of peanut butter and maize bran, was set in each trapping station. The traps were set in the evening and checked in the morning for three consecutive days in each grid. On the first capture, all animals were toe-clipped using sterile scissors. This study was initially conducted during the 2018/2019 maize cropping season and repeated in the 2019/2020 maize cropping season.

2.2. Statistical analysis

An independent samples t-test, with Levene's Test for equality of variance, was used to compare the GUD results from 2018/2019 and 2019/2020 cropping seasons. A two-way ANOVA using general linear mixed-effects model "package lme4" (Bates *et al.*, 2019) was used to analyse the effect of distance (transect location) and crop stage on angular transformed GUDs (proportion of groundnuts remaining) (Laundré *et al.*, 2001; Kasuya, 2004). Tukey's post hoc comparisons were conducted on distance (transects) and crop stage using the package 'multcomp' (Hothorn *et al.*, 2019). All analyses were conducted in R version 3.6.1 (R Core Team, 2019). We used the minimum number of animals known to be alive (MNA) method to calculate the population of rodents during each stage.

3. Results

3.1. Rodent species and population dynamics.

From the CMR data, the most common rodent species in maize fields was *Mastomys natalensis* (87.05% of the total captures, Table 1).

Table 1

Species composition of small mammals (rodents and shrews) captured in three maize fields in Kitwe, Zambia, with species ordered by overall abundance. The numbers in brackets are percentage composition of each species.

	Fields			
species	Luto 1	Luto 2	Luto 3	Overall
Mastomys natalensis	131 (72.78%)	396 (91.45%)	347 (88.75%)	874 (87.05%)
Mus minutoides	23 (12.78%)	15 (3.46%)	18 (4.60%)	56 (5.58%)
Crocidura hirta	14 (7.78%)	6 (1.39%)	11 (2.05%)	28 (2.79%)

Steatomys pratensis	2 (1.11%)	3 (0.69%)	11 (2.81%)	16 (1.59%)
Saccostomus campestris	5 (2.78%)	7 (1.62%)	1 (0.26%)	13 (1.29%)
Gerbilliscus leucogaster	3 (1.67%)	6 (1.67%)	1 (0.26%)	10 (1.00%)
Elephantulus brachyrhynchus	0 (0%)	0 (0%)	2 (0.51%)	2 (0.2%)
Rattus rattus	1 (0.56%)	0 (0%)	1 (0.26%)	2 (0.2%)
Lemniscomys rosalia	0 (0%)	0 (0%)	1 (0.26%)	1 (0.1%)
Acomys spinosissimus	0 (0%)	0 (0%)	1 (0.26%)	1 (0.1%)
Arvicanthis niloticus	1 (0.56%)	0 (0%)	0 (0%)	1 (0.1%)
Total	180 (100%)	433 (100 %)	391 (100 %)	1004 (100%)
Species richness	8	6	10	11
Shannon-weaver Diversity index	0.97	0.42	0.56	0.56

The density of rodents was low during the planting period and increased as the vegetation increased in the maize fields. The highest rodent density in maize fields was observed during the harvest stage and just before the fields are cleared (May-June). Population density reduced during land preparation post-harvest, especially after clearing of the fields (Fig. 4).

3.2. Changes in the foraging activity of rodent pest species in and around maize fields.

Motion sensitive camera traps confirmed that *M. natalensis* was the rodent species that frequently visited the GUDs. An independent samples t-test was conducted to examine GUD differences between the 2018/2019 and 2019/2022 cropping seasons. Levene's Test for equality of variances showed no violations, $p = 0.289$. In general, the GUD results from the 2018/2019 season and 2019/2020 season were not significant different (t (88) = 1.201, $p = 0.233$), so the data were combined during the analyses. Due to differences in the planting and harvest times between farmers, the results from December and January were combined as "germination stage" while the results from June and July were combined as "post-harvest" during the analyses, but these were separated when constructing a heat map on spatial use. In general, the foraging activity of rodents was highest (i.e., lowest GUD) during the germination stage (mean GUD = 50.5) while lowest during the land preparation and post-harvest stages (mean GUD = 58.0 at both crop stages). From the two-way ANOVA, overall, there was a significant effect of distance for crop stage ($F_{7,40}$ = 11.228, p < 0.001) and the interaction between the effects of distance and crop stage on the GUD ($F_{28,40}$ = 4.723, p < 0.001), but no effect of distance on the GUD ($F_{4,40}$ = 1.631, p = 0.185).

For distance from the edge of crops and natural habitat (transect), Tukey's post-hoc tests revealed that rodent activity was affected during maize germination and harvest stages, whereas rodent activity was similar on all transects during the other stages (see Supplementary Table S2). During the maize germination stage, rodent activity was higher on transect 5 (40 m into the natural habitat; mean GUD = 37) than on transects 1 (mean GUD = 59; t = - 6.551, p < 0.001), 2 (mean GUD = 58; t = - 6.039, p < 0.001) and 3 (mean GUD = 53; t = - 3.941, p = 0.001). Additionally, rodent activity was higher on transect 4 (20 meters into the natural forest; mean GUD = 43) than on transects 1 (t = - 4.528, p < 0.001), and 2 (t = - 4.016, p <0.001) during the germination stage. However, rodent activity during the harvest stage was higher on transect 1 (40 meters into the maize field; mean GUD = 50) than on transects 3 (mean GUD = 59; t = 2.935, p = 0.034), 4 (mean GUD = 60; t = 3.277, p = 0.013) and 5 (mean GUD = 59; t = 2.817, p = 0.047).

Rodent activity was higher during the germination stage than during land preparation, planting, weeding, maturation, harvest and post-harvest crop stages [(LP vs. G; z = - 5.690, p < 0.001); (P vs. G; z = - 4.757, p < 0.001); (G vs. W; z =

3.401, p = 0.015); (G vs. M; z = 3.409, p = 0.015); (G vs. H; z = 5.418, $p < 0.001$); and (G vs. PH; z = 6.757, $p < 0.001$)]. Rodent activity also was higher during the maize tasselling stage than land preparation (z = - 3.154, p = 0.034); and higher during the weeding stage than harvest stage (z = 3.262, p = 0.024) (see Supplementary Table S3). The changes in the foraging activity of rodents in and around maize fields can be summarised using a heat map (Fig. 5).

4. Discussion

This is the first study to document how the foraging activity of rodents in and around maize fields changes across the growing season. As predicted, the foraging activity of rodents over the maize growing season was influenced by vegetation cover and food availability. Higher rodent activity occurred in the adjacent natural habitat than along and inside the maize field during the germination period. Uniform/equal rodent activity in the adjacent natural habitat, along the border and inside maize fields occurred during the land preparation, planting, weeding, maize tasselling, maturity, and post-harvest stages. During the harvesting period rodent activity was significantly higher inside the maize fields than along the border and adjacent natural habitat. These results provide evidence-based information on how rodent foraging activity changes across the maize growing season. Krijger et al., (2017) suggested that focusing rodent pest management in those areas where rodents perceived the lowest predation risk could be more effective and efficient. Therefore, in management terms, our findings suggest that farmers are likely to have greater success managing rodent pests during the germination of the maize crop by focusing rodent control measures in the natural habitats adjacent to the maize fields rather than inside or along the edge of maize fields. From the weeding to maturation stages, equal success would be achieved if rodent control measures are concentrated inside, along the edge of maize fields or in the natural habitat adjacent to the maize fields. During the harvest stage, greater success in managing rodent pests could be achieved if rodent control measures are concentrated inside the maize fields than if rodent control measures are concentrated along the field border or in the natural habitat adjacent to the maize fields. However, it is necessary to survey the species composition in all the habitats before application of control measures to minimize non-target implications of rodent control in natural habitats. Therefore, our findings can be used by small holder farmers to focus rodent management strategies efficiently and effectively at different stages in the maize cropping season, which in turn will reduce the cost for controlling rodent pest species and losses of the crops.

Earlier work in maize fields in Tanzania have shown that vegetation cover plays an important role in the foraging, habitat preference and population dynamics of rodents, particularly *M. natalensis* (Leirs *et al.*, 1996; Mohr *et al.*, 2003). Leirs et al., (1996) reported that *M. natalensis* preferred (i.e., was more active in) areas with vegetation cover while tending to avoid open spaces, especially during periods of low density. Corroborating this finding, Mohr *et al.,* (2003) used GUD and video evidence to show that *M. natalensis* perceived lower predation risk in feeding patches with cover than in open patches. Elsewhere, research on the foraging activity of other rodents using GUDs suggests that rodent foraging activity is shaped by the perceived predation risk (Ylonen *et al.*, 2002; Orrock *et al.*, 2004; Wheeler and Hik, 2014; Jones *et al.*, 2017). Jones *et al*. (2017) found that the foraging activity of *Rattus tanezumi* in rice fields in the Philippines was shaped by the perceived predation risk whereby more damage was observed in the middle of the rice fields (with more vegetation cover) than on the borders and rice bund, with no vegetation. Ylonen et al. (2002) reported that prior to harvest of wheat in southern Australia, house mice, *Mus domesticus*, were mainly in the crop. Similarly, Oldfield mice, *Peromyscus polionotus*, in South Carolina, USA, were found to remove more seeds in areas with vegetation cover than outside of cover (Orrock *et al.*, 2004). In Canada, the arctic ground squirrel, *Urocitellus parryii*, exhibited habitat specific strategies to minimise predation risk by foraging more in tundra and shrub-tundra habitats while avoiding the shrub-dominated habitat, which reduced their visibility and increased predation risk (Wheeler and Hik, 2014). All of these studies highlight the importance of vegetation cover as a feature of small mammal behaviour to avoid predation, which aligns with the conclusions from our study.

Increased rodent activity around maize fields during the germination stage was reported in other studies (Stenseth *et al.*, 2003; Mulungu *et al.*, 2007). However, the findings in our study indicate that rodent activity was only high in the adjacent natural habitat and along the border during germination of the maize crop. This indicates that, during the germination stage, the perceived predation risk was higher inside the maize fields than along the border and adjacent natural habitat, corroborating the studies by Johnson and Horn (2008) and Jones et al., (2017), who reported that rodents perceived open areas to be riskier than areas with cover. Similarly, Key (1990) found that pre-harvest maize damage from the African ground squirrel occurred at the edges of the fields than in the middle and that they used the edges of the field for refuge when disturbed while feeding in the fields. However, when farming methods that lead to less disturbance to rodent burrows and increased cover and food supply, such as conservation agriculture, mice become resident in fields all the time, rather than retreating to field edges (Ruscoe *et al.,* 2022). This indicates that foraging activity of rodents in maize fields is shaped by their perceived predation risk. Therefore, high GUDs during the land preparation stage on all transects may be because at this stage the maize fields were cleared and, even in the natural habitat, the vegetation cover is dry and minimal.

As the height of maize and vegetation increased inside the maize fields (from the weeding to maturation stages), there was no difference in the mean GUD between the natural habitat and maize field transects indicating that the perceived predation was equal in the forest, along the margin and inside the maize field. This further supports the contention that rodent foraging activity is shaped by vegetation cover (Brown, 1988; Mohr *et al.*, 2003). Vegetative cover provides shelter for rodents, leading to reduced detection probability and capture by predators (Banasiak and Shrader, 2016) and thus reduces the perceived predation risk and increases the foraging activity of rodent species (Loggins *et al.*, 2019). A limitation of our study is that we are unable to comment on whether the different rodent species found in the study area respond to vegetation cover in the same way. Further studies, for example using camera traps, are recommended to understand whether there are detectible differences in the way different small mammal species within the same habitat respond to GUDs, vegetation cover and predation risk. As our study area is dominated by *M. natalensis*, we can expect our results closely align with the behaviour of this species.

Increased rodent activity inside the maize fields compared to along the border and adjacent habitat during the harvest stage suggests that, at this stage, the foraging activity was shaped by both vegetation and increased availability of food resources (Sluydts *et al.*, 2007). In addition, the harvest stage (May) coincided with the peak rodent population (see Fig. 4) in maize fields. When presented with patches of equal vegetation cover, food availability becomes important in explaining the foraging activity of rodents. This finding supports the hypothesis that rodents select to forage in habitats and microhabitats where the perceived risk of predation is low (Brown, 1988; Jacob and Brown, 2000; Ylonen *et al.*, 2002). These findings support the suggestion that rodent management during the harvest stage would be more successful by placing baits inside the maize field than along the border or adjacent natural habitat.

In conclusion, GUD was successfully used to monitor rodent foraging activity in and around maize fields over the maize cropping season. Rodent activity was driven by vegetation cover and food availability. Based on our findings, during the germination period, rodent control measures should be concentrated along the maize fields edges and in the natural habitat adjacent to maize fields while during the harvest period rodent control measures should be concentrated inside the maize fields. This information will help smallholder farmers to be more efficient and effective in rodent control by focusing their management strategies in areas of perceived reduced predation risk (Krijger *et al.*, 2017). We recommend further research, such as using rodenticide baits or methods of trapping (e.g., linear trap barrier) at different times of the growing season and at different distances from the maize field, to assess the effect on rodent population dynamics and associated crop losses. Follow up studies should also collect and include data on plant biomass on field edges and within fields to track the changes over time and then assess how these changes affect rodent foraging activity. Additionally, farming practices such as tractor ploughing and management of the vegetation around fields margins can be used to increase predation risk (Brown *et al.,* 2004: Massawe *et al.,* 2006). Target rodent pest species and non-target impacts should be surveyed in adjacent natural habitats, particularly as these habitats provide a range of ecosystem services beneficial to agricultural production (Hatt *et al.*, 2017; Lindell *et al.*, 2018; Mkenda *et al.*, 2019) where trade-offs between the management of rodents, insects, and weeds as well as crop pollination services need careful cost-benefit assessments (Wegner and Pascual, 2011; Wratten *et al.*, 2012; Williams *et al.*, 2018).

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Author contributions

ICI and SRB conceived the topic. ICI, SRB, MFG and GRS conceived the research. ICI conducted the field work and analyzed the data. All the authors contributed to the writing of the manuscript.

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Figure legends:

Fig. 1. Map showing the location of the four maize fields in Luto agricultural camp, Kitwe, Copperbelt Province, Zambia.

Fig 2. Layout of GUD trays in and around maize fields. The distance between the trays and transects was 20 m.

Fig. 3. Camera trap image of *Mastomys natalensis* feeding from a tray used in assessing giving up density. Camera type (Bushnell Trophy Cam HD Essential Trail Camera) produces a 'black' infrared flash that does not disturb mammal behaviour.

Fig. 4. Mean monthly rodent abundance (minimum number known to be alive) in maize fields (n = 3) in Kitwe, Zambia. The letters below the months represents seasons; WW, warm-wet season (November to April); CD, cold-dry season (April to August); HD, hot-dry season (September to October).

Fig. 5. Heat map showing rodent foraging activity across the maize growing season. The lower the mean GUD, the higher the rodent foraging activity and vice versa. The letters on the x-axis represent crop stage; LP = land preparation (October); P = planting stage (November); G = germination stages (December and January); W =

weeding stage (February); MT = maize tasselling stage (March); M = maturity stage (April); H = harvesting stage (May); and PH = post-harvest stage (June and July).