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Evaluating Habitat Manipulation as a Strategy for Rodent Control in Agricultural Ecosystems of Pothwar Region, Pakistan

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ABSTRACT: Habitat manipulation is an important technique that can be used for controlling rodent damage in agricultural ecosystems. It involves intentional manipulation of vegetation cover in habitats adjacent to active burrows of rodents to reduce shelter and food availability and to increase predation pressure. The current study was conducted in the Pothwar Plateau region of Pakistan during respective non-crop periods of wheat-groundnut (post-harvested and un-plowed/non-crop fallow lands). The purpose was to assess the impact of reduction in vegetation height of adjacent habitats (field borders) on rodent richness and abundance. The study area was divided into two sites: treated and non-treated. At the treated sites, habitat manipulation was carried out by removing crop cache and non-crop vegetation over 10 cm in height to a distance of approximately 20 m from the fields. The trapping sessions carried out at both treated and non-treated sites adjacent to wheat-groundnut fields were significantly different ($F_{2,6}$ = 13.2, P = 0.001) from each other, with the maximum number of rodents captured from non-treated sites. There was a significant difference in the overall abundance of rodents (P < 0.05) between crop stages and between treatments in both crops. The manipulation effect was observed with respect to damage to crops and yield production, significantly reducing damage within the associated croplands (P < 0.05). The outcomes of this study indicated a significant reduction of rodent population at treated sites due to changes in vegetation height and cover, which directly affect habitat and behavior attributes (e.g., food, shelter, movements, increased risk sensitivity, and feeding behavior) for rat. Rodents apparently were unable to reach levels where they could cause significant crop damage. This method is recommended as a cost-effective and easy application.

KEY WORDS: agricultural ecosystems, crop damage, habitat manipulation, Pakistan, rodent control, rodents, trapping

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INTRODUCTION

The Pothwar Plateau in Pakistan has sub-tropical dry scrub vegetation and is rich in floral diversity. Agricultural fields are flanked by thick, undisturbed field boundaries that are maintained to conserve water. Along the field boundaries, in addition to wild vegetation consisting of shrubs, are fast growing trees planted for browse and fodder purposes (Hussain et al. 2003). Several shrubs and grasses are native to this area, including the most abundant species of *Dodonaea viscosa*, *Justicia adhatoda*, *Saccharum griffithii*, *Cynodon dactylon* and *Rumex dentatus*, which provide shelter/cover and food to rodents when there is no cultivation or at an early stage of crop growth (Munawar et al. 2019). In the Pothwar region, rodents are major agricultural pests, causing significant economic losses and loss of livelihood among smallholder farmers. Several studies showed that rodent occurrence and distribution in agroecosystems varied mainly in relation with habitat type, habitat disturbance, interspecific segregation, and season (Kravetz and Polop 1983).

Habitat manipulation is an alternative approach to rodent control which focuses on the habitat surrounding the crop. This rodent control strategy acts by removing those habitat components that are central to the high rates of survival and/or reproduction that allow the rodent species to inflict significant economic damage. Control of rodents via habitat manipulation, therefore, requires a thorough understanding of the population ecology of the species concerned. The manipulation of adjacent non-crop habitats has been reported to significantly reduce rodent damage to sugarcane in both Hawaii and Australia (Sugihara et al. 1977). Despite the demonstrated effectiveness of habitat manipulation in the control of rodents, very few agricultural industries have implemented this technique. The studies of White et al. (1997) and Horskins et al. (1998) indicated the importance of including adjacent non-crop habitats as a component of Australian macadamia orchard systems.

In more recent years, the reliance on mortality-based control has been questioned. The use of poisons can pose a considerable threat to non-target species (Hegdal and Colvin 1988) and the environment because poisons are unspecific and highly toxic. New methods of control are being sought that address the cause of rodent populations reaching high densities in cropping systems. Ecologically based rodent management is an alternative approach to managing overabundant rodents in agricultural systems by combining a variety of control measures with timing targeted at key periods based on the biology of the pest species. The most common technique is reduction of vegetation in known and potential rodent refuge habitats. The selection of techniques depends on ecological issues, agronomy, environmental awareness, and socio-cultural considerations that need to be investigated before application. Fluctuations in vegetation height are the inevitable widespread and reoccurring result of farming action in agro-ecosystems. Open habitats, such as mown fields, are usually avoided by small mammals (Slade and Crain 2006).

As a management technique, reduction of vegetation height (removal of refuge, field sanitation) is often conducted to reduce shelter and food availability and to increase predation pressure on rodents. In this regard, keeping vegetation short is thought to reduce the abundance of pest rodents. This paper examines the potential for habitat manipulation as a rodent damage mitigation strategy. The focal aim of the current study was to investigate the effects of reduction in natural vegetation height adjacent to wheat-groundnut based cropping systems in the context of rodent pest management and to reduce rodent abundance, reproductive output, and damage to the crops.

METHODS

Study Area

The current study was carried out in the rural area of Pothwar Plateau (33° 30' 0'' N and 73° 0' 0'' W), which is upland at 305-610 m above sea level. The climate of the region is semi-arid warm to hot with sub-tropical winter and monsoon. Annual rainfall is high, especially in summer, averaging 630-708 mm (Sarwar et al. 2017). The study area comprises a well-drained undulating plain with low fertility and soft slopes. Rotational field crops such as wheat, groundnut, millet/maize, and seed crops, including sunflower, are grown. Natural vegetation is dominated by *Cynodon dactylon*, *Saccharum griffithii, Ziziphus nummularia*, *Achyranthes aspera*, and *Capparis deciduas* accompanied by the important tree species *Acacia modesta*, *Olea ferruginaea*, and *Tecomella undulata* (Munawar et al. 2018). The vegetation, however, has undergone marked alterations as a result of agriculture and cattle farming. At present, the Pothwar landscape consists of a matrix of crop/pasture fields surrounded by field borders with wild native grassland persisting in small remnants (patches) and other types of linear habitats. This area is included in a high land-use intensity region where cultivated, pasture fields for livestock and many of the linear habitats were removed to enlarge agricultural lands. These crop field borders constituted the sampling sites used in the present study.

Study Design

To study the impact of habitat manipulation at field boundaries of croplands, seasonal surveys were conducted in spring, summer, and autumn of 2018 in fallow lands during a non-crop season when the crops were already harvested. At each study site, two treated sites (T_1, T_2) and two non-treated sites (N_1, N_2) were selected adjacent to non-crop field borders of wheat and groundnut. The treated sites were 10 m wide, consisting of a thick ground layer with a dense cover of natural vegetation (weeds, shrubs, stubbles, etc.). These sites were temporally unstable due to habitat manipulation activities. The crop cache and natural vegetation were slashed on the crop field borders around active rodent burrows. The non-treatment sites were temporally stable, and these habitats were characterized by thick ground layer vegetation with an overstory of woody vegetation; they were rarely disturbed by growers/farmers and no manipulation was carried out, hence providing structurally complex crop and non-crop habitats for rodents. The comparisons were made between treated and non-treated sites after habitat manipulation based on rodent density, determined through trapping and damage assessment. Rodent species in this study were *Bandicota bengalensis* (lesser bandicoot rat), *Nesokia indica* (short-tailed bandicoot rat), *Tatera indica* (Indian gerbil), and *Golunda ellioti* (Indian bush rat). Trap dates and damage data were coincident with the seasonality of crops since the winter cycle of wheat crop is generally initiated in late autumn and finished in spring, whereas groundnut is sown in autumn and harvested before winter. The aestival crops (millet/maize) are sown in spring and harvested in late summer or early autumn.

Trapping Regime

The seasonal trapping was carried out to assess the occurrence and abundance of rodent species in the study area after habitat manipulation activities. Trapping grids were established within the treated and non-treated sites and monitored since March of 2018. Two sessions of trapping were conducted during the respective non-crop period (post-harvested and un-ploughed/ non-crop fallow fields) of wheat and groundnut crops. A total of 40 kill traps (located at 5 m intervals) were placed in each field border immediately after habitat manipulation. All traps were baited with peanut butter and guava and were checked every morning during two consecutive weeks (eight nights). The trapped rodent specimens were removed from the field and taken to the laboratory for species identification and measurement of external features (i.e., weight and length of body + tail).

Removal of Vegetation Cover

At 3-4 weeks prior to the respective sowing stage of wheat and groundnut crops, the natural wild vegetation from adjacent habitats was cut/slashed to greater than 10 cm in height. The area of cleared vegetation (treated sites) adjacent to the fields was approximately 500 m^2. During the respective flowering stage of the field crops, the vegetation was cleared again to minimize regeneration of shrubs, herbs, and weeds because the rainfall accelerates the growth of vegetation in the growing season.

Damage and Yield Assessments

Rodent damage assessment was carried out in wheat-groundnut crops during their respective growth stages (sowing, flowering/peg formation, and maturity), one to two weeks prior to harvest. Damage assessments were made inside the fields within the trapping grids (60 × 45 m). The rodent damage was sampled on the basis of the distance from the edge of the crop fields. Each trapping grid was divided into three equal-width strata parallel to the field in both crops. Each stratum was 20 m wide and 60 m long. Within each stratum, a line transect was placed at a randomly selected distance (8, 24, 49 m) from the field borders. Along each transect, a wooden quadrate of 1 m × 1 m was randomly placed every 4 m. The first quadrat was placed at least 2 m from the edge of the trapping grid. Observations were taken in an area of about 3.0 ha at already selected study sites and data were recorded fortnightly from both crops. In the wheat crop, the total number of tillers and number of tillers damaged inside the wooden quadrate was counted by using the following formula:

Table 1. The number of rodents captured using kill traps at treated and untreated sites over three consecutive sessions at various growth stages of wheat and groundnut crops.

Species	Crop stage	Treated site				Non-treated site			
		Wheat		Groundnut		Wheat		Groundnut	
		T_1	T_2	T_1	T_2	N_1	N_2	N_1	N_2
B. bengalensis	Sowing	1	0	0	0	4	2	3	4
	Flowering/Peg formation	2	0	3	2	5	3	6	7
	Maturity	4	5	4	6	7	5	6	8
N. indica	Sowing	0	0	0	0	2	1	3	4
	Flowering/Peg formation	0	0	1	0	2	3	4	5
	Maturity	2	0	2	1	4	3	5	4
T. indica	Sowing	2	0	0	2	2	1	1	1
	Flowering/Peg formation	0	0	1	0	2	0	2	2
	Maturity	1	0	2	0	2	3	3	3
G. ellioti	Sowing	1	0	0	1	1	1	1	0
	Flowering/Peg formation	0	0	0	1	0	1	1	0
	Maturity	0	0	0	0	1	0	0	0

% damage to tillers = (# tillers cut/total # tillers) × 100

In the groundnut crop, percent damage was estimated by using the formula following Nayak (2012):

% pod damage = (b + c/a + b + c) × 100

where
a = # of undamaged pods
b = # of scratched pods
c = # of freshly bitten pods

During the week prior to harvest, yield measurements were taken from a 2.5 × 4 m^2 quadrat at the center of each stratum. The unhulled reaped wheat and groundnut were dried to 14% moisture content and weighed to the nearest gram. Within one week of harvest, farmers were asked to estimate the yield harvested from the field for both crops that encompassed a trapping grid. Reference points were made using a GPS device to quantify the area of crop harvested. Farmers were also asked to give an estimate of the proportion of rodent damage to their plot and what they considered to be their major pest (e.g., insects, diseases, weeds) for their crops.

Statistical Analysis

To compare the relative abundance of rodents and the percentage of tillers cut by rodents between wheat and groundnut crops at different growth stages, and between treated and non-treated sites, the repeated measures ANOVA was used. Fisher's protected Least Significance Difference (LSD) test was applied to compare mean values at 5% level of probability.

RESULTS

The data on trapping of field rats in wheat-groundnut based cropping systems, carried out at treated (T_1 and T_2) and non-treated (N_1 and N_2) sites in agro-ecosystem of Pothwar Plateau, are summarized in Table 1. The results showed that the study area was composed of four rodent species; the dominance among species was found in the following descending order: *B. bengalensis* > *N. indica* > *T. indica* > *G. elliotí*.

Wheat

The mean abundance of rodents trapped in wheat differed significantly between treated and non-treated) sites; maximum numbers of rodents were captured from non-treated sites ($F_{2,6}$ = 12.03, P = 0.0002). The results showed that after removing vegetation cover, exposure of rodents to predators and competition for resources lead to a reduction in burrows in exposed unfavorable environment condition at treated sites (Table 1). The difference in mean abundance between treatment type and crop stages was also significantly different ($F_{2,6}$ = 3.37, P = 0.03) from each other. There was also a significant difference in overall abundance of rodents inside the crops between all growth stages of wheat ($P < 0.05$). The trapping data showed the number of rodents declined inside the croplands in the sowing and flowering stage, whereas at maturity stage, the trap success was higher, presumably due to presence of cover, shelter, and food. However, there was also a significant difference in abundance of rodents between the crop field ($F_{2,6}$ = 4.21, P = 0.065) and field borders ($F_{2,6}$ = 4.21, P = 0.712). The use of peanut butter and guava as a bait to lure the rodents for trapping were successful; this is consistent with

Munawar et al. (2019). Comparison of success between the two baits (guava and peanut butter) did not show any significant difference ($P > 0.05$).

Groundnut

In the groundnut crop, the statistical comparisons of reduction of rodent activity between treated and non-treated sites ($F_{2,6} = 23.4$, $P = 0.002$) were significant, whereas these differences were non-significant in overall comparisons of the groundnut crop across the growth stages (i.e., peg formation and maturity) ($F_{2,6} = 32.7$, $P = 0.09$). With the formation of nuts, the rats started feeding on them as it is assumed to be the most favorite food for them (Munawar et al. 2018). However, comparison of the mean abundance revealed that a greater ($P > 0.05$) estimated reduction in rodent density is reported at non-treated sites (Table 1).

Rodent Damage Assessment

There was a significant difference in the levels of damage between treated sites ($F_{2,6} = 2.301$, $P = 0.001$), which were highly manipulated/modified adjacent habitats, and non-treated sites, which were un-manipulated and stable habitats ($F_{2,6} = 0.101$, $P = 0.04$). Before habitat manipulation, there was no significant difference in damage levels between the treated sites and non-treated sites ($F_{2,6} = 21.4$, $P = 4.67$). However, after manipulation of adjacent habitats there was a significant reduction in damage at treated sites ($P < 0.05$) (Figure 1). Maximum damage was estimated at maturity stage in both crops (wheat and groundnut) during their respective seasons (Table 2). It was observed that rodents cause significant damage to crops in terms of stem/nut cutting, gnawing, spoilage, hoarding, and contamination.

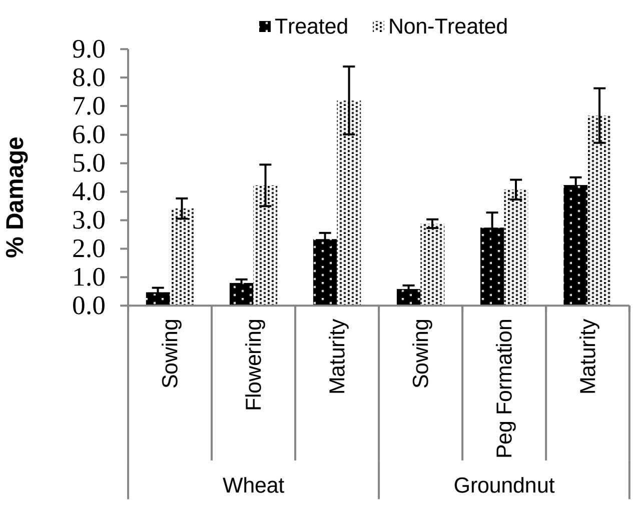

Figure 1. Comparison of percentage (%) damage in wheat and ground croplands by rodents at various growth stages of crop. (Mean ± S.E)

According to farmers' perceptions, rodents were reported to be the top pests causing damage to wheat and groundnut crops. Farmers also considered birds as pests; flocks of passerine birds [e.g. house sparrow (*Passer domesticus*), house crow (*Corvus splendens*), and common myna (*Acridotheres tristis*)] damage wheat crops at mature stages (Table 3). The attack of insects and fungal diseases on crops was also reported by various farmers, but this number is low; the most common diseases were rust, root rot, and smut. Weeds were a serious problem affecting the overall crop yield at the study area. In this study, farmers reported significant reduction in weeds after removal of non-crop vegetation (weeds, stubbles) at treated sites.

DISCUSSION

In the current study, habitat manipulation was carried out by reducing the amount of vegetation cover that had adversely impacted rodent abundance, distribution, population demography, and damage to wheat and groundnut crops during the growing season. The results revealed that reduction in vegetation cover at adjacent habitats to crops is an effective rodent pest management strategy resulting in higher yield productions for small-holder farmers in croplands of Pothwar region. The findings of the current study are consistent with those of Witmer (2013), who showed that habitat manipulations, such as pea gravel around seedlings and regular mowing to reduce ground vegetation height, may reduce rodent damage to seedlings. Our results suggest that a large rodent population utilizes the adjacent non-crop habitats and moves into the fields during the growing season to feed. This is consistent with damage distribution studies by White et al. (2017), which revealed that the majority of damage occurs in the first few rows of crops adjacent to large, temporally stable habitats. Our results also indicate that there may be a second, smaller population that lives within the orchard component of the system causing the low baseline damage that is seen in all orchards, regardless of adjacent habitat type.

Results of this study have shown that habitat manipulation reduces both burrow density and damage percentage. These findings are consistent with previous studies by Lemen and Clausen 1984) and Edge et al. (1995); however, the phenomenon disagrees with findings reported by Jacob (2003) and by Slade and Crain (2006). Removing vegetation height, consequently reducing the food supply, results in the reduction of rodent population density. Moreover, it may also decrease the standing vegetation height and alter the microclimate, which in turn would alter the plant growth strategy and decrease plant height. A shorter vegetation height increases the risk of exposure to predators and extreme weather conditions (Woodcock and Pywell 2009); therefore, rodents dig their burrows under taller plant communities.

Our damage and trapping results in the current study have confirmed that adjacent non-crop habitats play an important role in crop damage in field crops. The high degree damage associated with non-crop habitats was significantly reduced by the manipulation of the non-crop vegetation. The majority of the rodents were trapped at field boundaries from non-treated sites, indicating that they preferred to nest and dig burrows under wild vegetation which provided sufficient refuge habitat and

Table 2. Percentage of tillers damaged at three growth stages of the wheat-groundnut cropping system and yield (kg ha-1) at harvest per stratum at treated and non-treated sites.

Site	Stratum	Wheat: Sowing	Wheat: Flowering	Wheat: Maturity	Wheat: *Cumulative*	Wheat: *Yield ($kg\ ha^{-1}$)*	Groundnut: Sowing	Groundnut: Peg Formation	Groundnut: Maturity	Groundnut: *Cumulative*	Groundnut: *Yield ($kg\ ha^{-1}$)*
T_1	1	0.21	0.33	1.8	2.34	410	0.32	5.2	4.54	10.06	636
	2	0.16	0.57	2.7	3.43	560	0.65	2.11	5.52	8.28	400
	3	0.52	1.2	2.9	4.62	600	0.56	1.1	2.55	4.21	550
	Mean	**0.30**	**0.70**	**2.47**	**3.46**	**523**	**0.51**	**2.80**	**4.20**	**7.52**	**528**
T_2	1	0.12	1.1	2.2	3.42	950	1.12	1.95	3.9	6.97	680
	2	1.18	0.81	1.5	2.49	900	0.12	2.9	4.89	7.91	790
	3	0.66	0.8	2.9	4.36	850	0.72	3.17	4	7.89	930
	Mean	**0.32**	**0.90**	**2.20**	**3.42**	**900**	**0.65**	**2.67**	**4.26**	**7.55**	**800**
N_1	1	2	3.2	5.54	10.74	1570	2.28	4.9	6.19	13.37	2890
	2	2.9	1	3.1	7.00	2100	3.32	4.82	5.8	13.94	2800
	3	2.4	3.8	6.41	12.61	2390	3.2	2.8	5.09	11.09	3560
	Mean	**2.87**	**2.67**	**5.02**	**10.55**	**2020**	**1.57**	**4.17**	**5.69**	**11.43**	**3083**
N_2	1	3.92	5.31	6.09	15.32	3280	3.08	3.2	11.8	18.08	3370
	2	4.3	5.98	10.8	21.08	3500	2.86	4.87	4.97	12.70	3600
	3	4.92	6.01	11.28	22.21	2930	2.51	3.81	6.15	12.47	2690
	Mean	**4.38**	**5.77**	**9.39**	**19.54**	**3236**	**1.63**	**3.96**	**7.64**	**13.23**	**3220**

Percentage % damaged

Table 3. Detail of percentage (%) damage caused by the greatest pests in wheat-groundnut crops reported by farmers at treated (T_1, T_2) and non-treated (N_1, N_2) sites.

Site	Crops	Farmer's Perception of Percentage % Damage (n = 60)				
		Rodents	Weeds	Disease	Insects	Birds
Treated (T_1, T_2)	Wheat, groundnut	50	12	10	10	8
Non-Treated (N_1, N_2)	Wheat, groundnut	75	58	40	25	16

protected them from extreme temperature (heat, wind, rainfall, etc.) and enhanced potential breeding. We also found that the majority of the damage by rodents to the crops at all sites occurred during the maturity stage due to plenty of food, good shelter/crop cover and potential breeding; therefore, cropping patterns may play an important role not only in the intensity of rodent damage but also in the stage of the crops at which the majority of damage is inflicted. Our interpretation is that habitat manipulation causes rodents to move immediately from the treatment sites due to extreme weather conditions and lack of shelter and crop cover, rodent mortality due to unfavorable environmental conditions, and predations (Munawar et al. 2018). Such movement would incur increased energetic costs and predation risk; both are important considerations for rodent species in agricultural landscapes (Stuart et al. 2013). White et al. (1998) speculated that, where crops are able to sustain a rat population, habitat manipulation in adjacent areas may have little effect on the population. During the study, bush rat (*G. ellioti*) was caught only from adjacent habitats nested under non-crop vegetation. This rat species is very shy in behavior and mostly constructs nest-like burrows under thick vegetation. In treatment sites no nests and burrows were observed, which showed that habitat manipulation is an effective non-chemical technique for rodent control. Furthermore, Stuart et al. (2013) suggested that radio-tracking studies would be useful to ascertain field rats' natal nest locations before and after habitat manipulation. Crop yield estimates did not accurately reflect rodent damage because there were other factors, such as weeds, insect pests, birds, zoonotic diseases, inappropriate use of rodenticides (e.g., zinc phosphide), and crop contamination by livestock that affected wheat and groundnut yield at the study sites. In future studies, this may be overcome by using rodent exclusion plots and comparing yields taken from small enclosures that exclude rodents with yields taken from quadrats exposed to rodent damage.

Although the effect of different spatial scales was not explicitly assessed in this study (since all the rodent captures were made in the borders), our results suggest that border vegetation and surrounding habitat have influence over the rodent assemblage at the borders.

Potential nest sites within fields should be targeted also, and efforts should be made to remove potential breeding sites prior to the start of the main breeding season and any potential offspring during the main breeding season. This may be achieved by traditional methods such as community rat campaigns that use trapping, hunting, and flushing-out of rat burrows or by the appropriate use of rodenticides that are applied for a limited duration and are targeted specifically at the pest species.

Finally, we suggest adopting a multi-scale approach when assessing the distribution and abundance of rodent populations in agricultural landscapes for management reasons. Actions aimed at controlling rodent species may be particularly important given their role as viral disease reservoirs. It is important to understand the significant importance of field margins as they contribute to the production sustainability by enhancing beneficial species within crops and reducing pesticide use; further research on the predictability of these effects is needed. Our results indicated that habitat manipulation actions should be extended to target rodent populations mainly in adjacent fields but without neglecting border surroundings. Given the seasonal importance of cover for rodent occurrence, any control action on borders, such as manipulating vegetation, might best be implemented in summer during the non-crop season. Special caution should be taken to minimize consequences for coexisting non-target species (e.g., small mammals, birds, and wildlife of national importance).

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