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Occurrence of Rodent Species in Agricultural Lands during Cropping and Non-Cropping Seasons of Pothwar Plateau, Pakistan

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ABSTRACT

Rodents form an important component of biodiversity of the agricultural lands and have been identified as destructive mammalian pests of agricultural crops at global level. They cause severe damage to various crops, directly and indirectly, by gnawing, spoilage, contamination and hoarding activities. The current study investigated the occurrence of different rodent species inside the crop fields and at field edges, associated with four major crops (wheat, groundnut, millet and maize) in the Pothwar Plateau. In all four crops, maximum number of rodent burrows was recorded at maturity stages of the crops. The maturity stage of wheat crop coincided with spring breeding season while the maturity stages of millet/maize and groundnut matched with monsoon/autumn breeding peak of the rodents in the study area. The burrow density recorded inside the wheat crop at various stages of growth and in uncultivated fields was significantly higher than those on field boundaries. The overall comparison of the rodent burrows occurrence in groundnut crop indicated a significantly higher number inside the crop as compared to the field edges at maturity stage. Similarly, maturity stage of the millet and maize crops attracted significantly higher population of rodents. On the other hand, at post-harvested and un-ploughed/non-crop fallow fields, higher number of rodent burrows were recorded on the field edges under wild vegetation which provided shelter and cover to the rodents. The study suggests that agricultural operations such as land preparation, ploughing, weeding, removal of crop cache and cutting of wild vegetation, should be encouraged to prevent establishment of rodent populations. Deep ploughing of fields immediately after harvest of crops would destroy the rodent burrow system and may expose animals to increased predation by raptors and other predators.

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NM and IH designed the study. NM collected the field data. NM, TM and IH analysed the data and wrote the manuscript.

Key words
Biodiversity, Rodents, Agriculture, Burrows, Crops, Pothwar.

INTRODUCTION

The Pothwar plateau situated in the north of Punjab (between latitudes 32° 33' and 34° 03' N and longitudes 71° 89' and 73° 37' E) is upland at 305-610 m above sea level. This undulated landscape is the result of a fragmentation process due to consistent soil erosion of the plateau. It has a total area of 1.82 million ha out of which only 0.61 million ha are cultivated; the remaining land is under gullies, scrub forest and rangeland which is being used for rough grazing. Climate of the plateau is semi-arid warm to hot with sub-tropical winter and monsoon (Punjab Barani Commission, 1976). Average farm size is 4.2 ha (Ahmad, 1991). Agro-ecosystem of the area can be defined as heterogeneous mosaics with temporal and spatial variations at diverse scales. Dry farming is the dominant land use. Wheat is a major winter crop with inter-cropping of grams, lentils and mustards. Dominant summer crops include sorghum, millet and groundnut (Beg *et al*., 1985; Ahmad, 1990).

The Pothwar plateau is a habitat of seven rodent species (Roberts, 1997); the lesser bandicoot rat (*Bandicota bengalensis*), the short-tailed mole rat (*Nesokia indica*), the Indian gerbil (*Tatera indica*), the soft-furred field rat (*Millardia meltada*), the desert jird (*Meriones hurrianae*), the bush rat (*Golunda ellioti*) and *Mus* species. Brooks *et al*. (1988) could record only the presence of *B. bengalensis*, *N. indica* and *T. indica* in groundnut crop. Another report by Hussain *et al*. (2003) revealed occurrence of five rodent species in the following order of dominance: *T. indica*, *B. bengalensis*, *Mus* spp., *G. ellioti* and *N. indica*. The first three species were considered to have pest status and that their relative abundance changed from season to season. The spring season, a period coinciding with maturity of wheat crop, was found favorable for all the species to show maximum breeding activities. Unlike the other species, the *T. indica* had stable population over all the seasons, which seems not to have any association with the cultivated crops but the wild vegetation on the field boundaries (Hussain *et al*., 2003). Khan et al. (2017) have reported the diversity of small mammals, particularly the rodent species of Muridae family, is remarkable in Pakistan and Rodents occupy a wide range of crop lands, natural habitats, including deserts, range lands and forests.

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Burrow counts are generally adopted for rodent population estimation since they are handy, quick and easily applicable for all practical purposes under field conditions. Although the method has some limitations with respect to diversified habitats, changes in species communities and local migratory habits. The burrows of rodent species can be distinguished on the basis of the shape and size of the entrances and species specific burrowing behavior/characteristics, fecal pellets and damage pattern of the vegetation. The objective of the current study was to provide a preliminary and brief account of species composition and determine the relative seasonal occurrence of rodent populations in cultivated croplands and on field boundaries under wild vegetation.

MATERIALS AND METHODS

Study area

The study was conducted by carrying out successive field observations and recording of data at selected 20 study sites at the agro-ecosystem in the four districts (Attock, Chakwal, Jhelum and Rawalpindi) of Pothwar plateau. The Pothwar upland region, commonly called the Pothwar (uneven) plateau, lies to the south of the northern mountains and is flanked in the west by the Indus River and on the east by the Jhelum River. It is typified by its denuded and broken terrain characterized by undulations and irregularities (Ahmad, 1991). The Pothwar ecosystem consists of non-cultivated (scrub forest and range land) and cultivated croplands. The cropland tracks also bear some wild vegetation on the thick field boundaries, kept undisturbed and intact for conservation of rain water.

Site selection

A preliminary survey was conducted for selection of potential study sites (five in each district) in the four districts. The sites were selected after consultation with local agriculture functionaries, farmers, considering logistic (road) approach to the sites and appropriate level of rodent infestation. Approximately, each experimental site was of 5.0 ha area, with contiguous cropland habitat. Each site was located about 4-5 km apart. Each site was visited once a month for data collection during growth period of respective field crops. The field data of all the four crops (wheat, groundnut, millet and maize) were recorded on pre-designed data sheets during the study period from April 2015 to May 2016.

Study design

Four types of major cropping system i.e. wheat, groundnut, millet and maize at 20 study sites, five in each district were selected to scan the rodent activities and species-wise occurrence by active burrow characteristics and counts. To determine the seasonal fluctuations in the rodent fauna in the cropland habitats, the burrow counts of rodent species was carried at various growth stages of the field crops. In wheat crop the rodent activities were recorded between October 2015 to May 2016 at the sowing, tillering, maturity/harvesting and in harvested fields and fallow non-crop fields. In groundnut crop the study was undertaken between September 2015 to March 2016 at sowing, peg formation, maturity/harvesting and in harvested fields and fallow non-crop fields. Traditionally millet and maize are the dominant summer crops of the Pothwar area; the data were collected from June to November 2015 at sowing, flowering/stalking, maturity/harvesting and in harvested fields and fallow non-crop fields.

Burrows of various rodent species were distinguished on the basis of the shape and size of the burrow entrances. In the study area three rodent species were observed, the lesser bandicoot rat (*B. bengalensis*), the short-tailed mole rat (*N. indica*), and the Indian gerbil (*T. indica*). The burrow of the bandicoot rat was characterized by the larger soil particles, visible burrow openings, and visible runways, crops and their residues scattered about in the area, and spindle-shaped fecal droppings. The *Nesokia* burrows can be differentiated from bandicoot rat mounds by their generally smaller soil particles pushed up from the tunnels and by the more capsule-shaped fecal droppings mixed into the mounded soil (Brooks *et al.*, 1988). The burrows of the *T. indica* were of simple patterns and easily identified by clear one or two surface openings (Jain, 1993).

In the study area live and active burrows were identified on the basis of fresh digging, size of soil particles, burrow openings, foot tracks, damage pattern to the surrounding crop plants and most importantly the fecal droppings. These were numbered and all openings were closed with excavated soil. The next morning, freshly opened entrances were recorded. Vegetation around the burrow openings was recorded. Systems with one or more burrows reopened were designated active. The burrows inside the crop fields were recorded in the same pattern. Comparison of rodent burrow counts for different crops and seasons were analyzed with analysis of variance (ANOVA). Least significance difference (LSD) test was employed to compare mean values, using the computer software Microsoft Excel 2010. The 95% level of significance was used in all tests.

RESULTS

The occurrence and movement of different rodent species in four major field crops at different growth stages, in fallow and uncultivated fields were recorded during the current study period as detailed below:

Wheat

Data on live rodent burrow counts at three growth stages of the crop (sowing, tillering and maturity/harvesting), in harvested fields and fallow non-crop fields revealed presence of three rodent species; the lesser bandicoot rat (*B. bengalensis*), the short-tailed mole rat (*N. indica*), and the Indian gerbil (*T. indica*). The order of dominance with respect to abundance was *B. bengalensis* > *N. indica* > *T. indica*.

At the sowing stage maximum burrows (0.99 ha^{-1}) of *B. bengalensis* were observed on the field boundaries, followed by *N. indica* (0.72 ha^{-1}) and least (0.33 ha^{-1}) for *T. indica*, while inside the crop fields, burrows of *N. indica* were found maximum (0.68 ha^{-1}), followed by *B. bengalensis* (0.66 ha^{-1}) and *T. indica* (0.31 ha^{-1}). At the tillering stage, field boundaries showed maximum burrows (0.82 ha^{-1}) for *B. bengalensis*, while least of *T. indica.*

During spring season which coincided with maturity of wheat crop, there were highest number of active burrows of *B. bengalensis* inside the crop field (2.96 ha^{-1}), followed by *N. indica* (1.62 ha^{-1}) and *T. indica* (0.56 ha^{-1}). At this stage of the crop, higher number of burrows was found inside the field area compared to the boundaries. The data collected from post-harvested and un-ploughed/non-crop fallow fields showed higher number of rodent burrows on field edges, under wild vegetation which provided shelter and cover to the rodents. Maximum burrow density was recorded (1.91 burrows ha^{-1}) for *B. bengalensis*, but least (0.31 ha^{-1}) for *T. indica* (Table I).

Statistical analysis using analysis of variance (ANOVA) and least significance difference (LSD) revealed significant differences ($p < 0.01$) in rodent burrows of all three species on field boundaries at various growth stages post-harvested and unploughed fields of the wheat crop in the Pothwar Plateau. Similarly, rodent burrow numbers also differed significantly for *T. indica* inside the wheat crop fields during all stages of the crop (Table I).

Groundnut

The burrow counts of three rodent species were made at various growth stages of the crop (Table II). At sowing stage, higher number of burrows (0.69 ha^{-1}) of *B. bengalensis* was recorded on the field boundaries of the groundnut crop than *N. indica* (0.39 ha^{-1}) and *T. indica* (0.16 ha^{-1}). Inside the crop fields, the burrows recorded per ha were found much less. At peg formation stage, more number of rodent burrows were observed inside the fields as compared to the field boundaries. With the formation of nuts, the rats started feeding on them as it is assumed to be the most favorite food for them. At maturity stage, the crop fields had moist soil with good stand of groundnut plants providing cover to the rodent burrows. At this stage, burrow density inside the crop fields was higher for *B. bengalensis* (2.03 ha^{-1}), *N. indica* (0.88 ha^{-1}) and *T. indica* (0.30 ha^{-1}) than recorded on the field boundaries: *B. bengalensis* (0.25 ha^{-1}), *N. indica* (0.21 ha^{-1}), and *T. indica* (0.20 ha^{-1}). However, in the un-ploughed/non-crop fallow fields, overall presence of burrows was relatively low, but much more number of burrows was recorded on the boundaries compared to those inside the fields.

Analysis of Variance (ANOVA), followed by Least Significance Difference (LSD) revealed significant differences ($p < 0.01$) in rodent burrows of *N. indica* and *T. indica* species on field boundaries at various growth stages post-harvested and unploughed groundnut fields (Table II).

Table I.- Statistical comparison of *B. bengalensis, N. indica* and *T. indica* burrows on field boundaries and inside during wheat crop season in four districts (Rawalpindi, Chakwal, Jhelum and Attock) of Pothwar plateau, Pakistan.

S No.	Crop stages	*Bandicota bengalensis*		*Nesokia indica*		*Tatera indica*	
		Boundaries	**Inside**	**Boundaries**	**Inside**	**Boundaries**	**Inside**
	Difference among all the crop stages	$F_{4, 15} = 11.6$ P = 0.000	$F_{4, 15} = 22.9$ P = 2.97	$F_{4, 15} = 4.16$ P = 0.01	$F_{4, 15} = 28.5$ P = 7.44	$F_{4, 15} = 2.13$ P = 0.12	$F_{4, 15} = 8.05$ P = 0.001
		Mean±SE*	**Mean±SE***	**Mean±SE***	**Mean±SE***	**Mean±SE***	**Mean±SE***
1.	Sowing	5.00 ± 1.06^{B}	3.38 ± 0.39^{BC}	3.74 ± 0.53^{AB}	3.50 ± 0.47^{BC}	1.66 ± 0.24^{AB}	1.60 ± 0.29^{BC}
2.	Tillering	4.27 ± 0.91^{BC}	2.87 ± 0.48^{CB}	2.7 ± 0.27^{BC}	3.31 ± 0.31^{BC}	2.14 ± 0.30^{A}	2.07 ± 0.23^{AB}
3.	Maturity	1.69 ± 0.15^{C}	15.06 ± 2.33^{A}	1.68 ± 0.32^{BC}	8.37 ± 0.85^{A}	1.48 ± 0.30^{CB}	2.87 ± 0.47^{A}
4.	Post-harvested field	9.76 ± 1.35^{A}	2.74 ± 0.32^{CB}	3.08 ± 0.35^{AB}	1.99 ± 0.19^{CB}	1.56 ± 0.22^{BC}	0.90 ± 0.10^{CB}
5.	Un-ploughed/ non-crop fallow fields	9.52 ± 1.22^{A}	4.26 ± 0.40^{BC}	3.07 ± 0.33^{AB}	2.15 ± 0.35^{CB}	1.06 ± 0.25^{CB}	1.04 ± 0.20^{BC}

* The column values superscripted by same letters are not significantly different from each other at 5% level of probability using LSD test.

Millet

Burrow density and rodent distribution were also recorded in the millet crop at three growth stages, in harvested fields and fallow non-crop fields (Table III). At the sowing stage, greater number of burrows rodent species were recorded on the field boundaries compared to the inside of crop fields. However, at maturity stage of millet crop during monsoon season, greater number of rodent burrows were found inside the crop fields for all three-rodent species. After this stage, the rodent populations moved out to the field boundaries immediately after the harvest of this crop, probably due to removal of crop cover providing good shelter from unfavorable weather conditions and predators. Statistical analysis using LSD showed significant differences ($p < 0.05$) in burrow density of rodent species on field boundaries and inside fields at various stages of millet crop (Table III).

Maize

Fall cultivation season of maize crop coincides with millet cultivation in the Pothwar plateau. Like the first three crops, the rodent activities in the maize crop were also assessed by counting their burrows. At flowering stage of this crop, more burrows of all three rodents' species were noted on field boundaries. However, observations at maturity stage of maize crop showed greater number of burrow counts inside the crop fields. After harvest of the maize crop, the burrow counts inside the fields again were found decreased and higher number of burrows was recorded on field boundaries. Statistical analysis showed significant differences in the burrow density of *N. indica* (P = 0.03) and *T. indica* (P = 0.003) on field boundaries and inside the crop fields (Table IV).

Table II.- Statistical comparison of *B. bengalensis, N. indica* and *T. indica* burrows on field boundaries and inside during groundnut crop season in four districts (Rawalpindi, Chakwal, Jhelum and Attock) of Pothwar plateau, Pakistan.

S No.	Crop stages	*Bandicota bengalensis*		*Nesokia indica*		*Tatera indica*	
		Boundaries	Inside	Boundaries	Inside	Boundaries	Inside
	Difference among all the crop stages	$F_{4, 15} = 22.7$ P = 3.2	$F_{4, 15} = 50.0$ P = 1.68	$F_{4, 15} = 8.11$ P = 0.001	$F_{4, 15} = 36.5$ P = 1.43	$F_{4, 15} = 9.12$ P = 0.00	$F_{4, 15} = 18.7$ P = 1.06
		Mean±SE*	**Mean±SE***	**Mean±SE***	**Mean±SE***	**Mean±SE***	**Mean±SE***
1.	Sowing	3.44 ± 0.22^{B}	2.16 ± 0.17^{BC}	2.52 ± 0.23^{A}	2.55 ± 0.21^{BC}	0.95 ± 0.10^{CB}	1.37 ± 0.10^{AB}
2.	Tillering	3.28 ± 0.29^{BC}	2.75 ± 0.17^{CB}	1.91 ± 0.04^{BC}	2.40 ± 0.25^{BC}	1.49 ± 0.06^{A}	1.24 ± 0.14^{BC}
3.	Maturity	1.32 ± 0.08^{C}	9.78 ± 0.94^{A}	1.10 ± 0.13^{CB}	6.03 ± 0.58^{A}	1.08 ± 0.07^{BC}	1.98 ± 0.21^{A}
4.	Post-harvested field	6.36 ± 0.57^{A}	1.55 ± 0.24^{CB}	2.06 ± 0.13^{A}	1.31 ± 0.14^{CB}	1.26 ± 0.11^{AB}	0.52 ± 0.09^{CB}
5.	Un-ploughed/ non-crop fallow fields	5.72 ± 0.67^{A}	2.68 ± 0.38^{BC}	1.87 ± 0.27^{BC}	1.38 ± 0.20^{CB}	0.89 ± 0.05^{CB}	0.74 ± 0.08^{CB}

* The column values superscripted by same letters are not significantly different from each other at 5% level of probability using LSD test.

Table III.- Statistical comparison of *B. bengalensis, N. indica* and *T. indica* burrows on field boundaries and inside during millet crop season in four districts (Rawalpindi, Chakwal, Jhelum and Attock) of Pothwar plateau, Pakistan.

S No.	Crop stages	*Bandicota bengalensis*		*Nesokia indica*		*Tatera indica*	
		Boundaries	Inside	Boundaries	Inside	Boundaries	Inside
	Difference among all the crop stages	$F_{4, 15} = 86.5$ P = 3.5	$F_{4, 15} = 87.0$ P = 3.4	$F_{4, 15} = 13.2$ P = 8.33	$F_{4, 15} = 268.4$ P = 9.2	$F_{4, 15} = 34.6$ P = 2.06	$F_{4, 15} = 16.1$ P = 2.56
		Mean±SE*	**Mean±SE***	**Mean±SE***	**Mean±SE***	**Mean±SE***	**Mean±SE***
1.	Sowing	3.32 ± 0.16^{BC}	2.11 ± 0.15^{BC}	2.30 ± 0.10^{A}	2.30 ± 0.05^{AB}	0.84 ± 0.03^{BC}	1.02 ± 0.04^{BC}
2.	Tillering	3.40 ± 0.18^{BC}	2.01 ± 0.16^{BC}	1.80 ± 0.09^{BC}	1.83 ± 0.03^{BC}	1.56 ± 0.04^{A}	1.14 ± 0.10^{AB}
3.	Maturity	3.19 ± 0.14^{CB}	5.13 ± 0.22^{A}	1.64 ± 0.04^{CB}	3.51 ± 0.10^{A}	0.87 ± 0.10^{BC}	1.17 ± 0.07^{A}
4.	Post-harvested field	5.85 ± 0.08^{A}	1.79 ± 0.10^{CB}	2.20 ± 0.08^{AB}	1.12 ± 0.04^{CB}	1.10 ± 0.03^{AB}	0.61 ± 0.01^{CB}
5.	Un-ploughed/ non-crop fallow fields	5.36 ± 0.10^{A}	1.94 ± 0.11^{CB}	2.16 ± 0.07^{BC}	1.44 ± 0.02^{BC}	0.76 ± 0.05^{CB}	0.69 ± 0.06^{BC}

* The column values superscripted by same letters are not significantly different from each other at 5% level of probability using LSD test.

Table IV.- Statistical comparison of *B. bengalensis, N. indica* and *T. indica* burrows on field boundaries and inside during maize crop season in four districts (Rawalpindi, Chakwal, Jhelum and Attock) of Pothwar plateau, Pakistan.

S No.	Crop stages	*Bandicota bengalensis*		*Nesokia indica*		*Tatera indica*	
		Boundaries	Inside	Boundaries	Inside	Boundaries	Inside
	Difference among all the crop stages	$F_{4, 15}$ = 22.5 P = 3.3	$F_{4, 15}$ = 33.8 P = 2.4	$F_{4, 15}$ = 3.55 P = 0.03	$F_{4, 15}$ = 14.7 P = 4.4	$F_{4, 15}$ = 6.13 P = 0.003	$F_{4, 15}$ = 12.4 P = 0.00
		Mean±SE*	Mean±SE*	Mean±SE*	Mean±SE*	Mean±SE*	Mean±SE*
1.	Sowing	3.33 ± 0.23^{BC}	2.65 ± 0.27^{BC}	2.44 ± 0.36^{A}	2.52 ± 0.50^{BC}	0.99 ± 0.13^{BC}	0.91 ± 0.11^{BC}
2.	Flowering	2.98 ± 0.28^{BC}	2.42 ± 0.07^{CB}	1.66 ± 0.24^{BC}	1.71 ± 0.26^{BC}	1.64 ± 0.17^{A}	1.49 ± 0.14^{AB}
3.	Maturity	1.61 ± 0.14^{CB}	10.3 ± 1.29^{A}	1.44 ± 0.17^{CB}	5.92 ± 0.92^{A}	1.00 ± 0.13^{BC}	1.83 ± 0.19^{A}
4.	Post-harvested field	7.00 ± 0.59^{A}	1.99 ± 0.25^{CB}	2.30 ± 0.05^{AB}	1.49 ± 0.12^{CB}	1.39 ± 0.07^{AB}	0.90 ± 0.11^{BC}
5.	Un-ploughed/ non-crop fallow fields	6.01 ± 0.79^{A}	2.60 ± 0.26^{BC}	2.23 ± 0.23^{BC}	1.60 ± 0.10^{CB}	0.90 ± 0.13^{CB}	0.82 ± 0.06^{CB}

* The column values superscripted by same letters are not significantly different from each other at 5% level of probability using LSD test.

DISCUSSION

The record of live rodent burrow counts in the current study comprised of three different species; the lesser bandicoot rat (*B. bengalensis*), the short-tailed mole rat (*N. indica*), and the Indian gerbil (*T. indica*). The mean number of *B. bengalensis* burrows recorded on field boundaries of wheat crop at various stages of growth and in uncultivated fields were significantly different ($F_{4, 15}$ = 11.6, P = 0.000) cumulatively, revealing more burrows on the boundaries of harvested wheat fields and un-ploughed/non-crop fallow fields. This pattern of burrow location indicated that rodent move out to the field boundaries immediately after harvest of the crop. Whereas the un-ploughed fallow fields provided stable habitat/vegetation on the boundaries which are preferred by this rat. Comparison of the bandicoot burrow occurrence indicated some significantly higher numbers inside the crop at maturity stage (P < 0.05). Rest of the crop stages were found unattractive for this species to move its burrows inside the fields. This behavior suggests to believe that wheat crop provided good shelter and energy rich food to the *B. bengalensis* at the maturity. This crop stage also corresponds to the breeding activity of this rodent in Pothwar agro-ecosystem (Hussain *et al.*, 2003).

Analysis of mean number of *N. indica* burrows recorded on field boundaries of wheat crop at various stages of growth and in uncultivated fields was cumulatively significantly different ($F_{4, 15}$ = 4.16, P = 0.01). The results showed that at tillering and maturity stages fewer burrows were observed at field edges as compared to their occurrence inside the fields. Comparison of other three observation stages did not show any significant difference from each other. Overall comparison of location of the *Nesokia* burrows indicated that various growth stages of wheat crop have cumulatively non-significant ($F_{4, 15}$ = 28.5, P = 7.44) effect on movement of this rodent. However, relative comparison of the mean values by LSD support to reveal that more (P > 0.05) burrows were recorded at maturity stage inside the fields as compared on the edges. Overall there was non-significant difference ($F_{4, 15}$ = 2.13, P = 0.12) among the burrow counts of *T. indica* recorded at various growth stages and in fallow fields. The population of *T. indica* was more or less stable at the field edges under wild vegetation; it utilized the resources of wild habitat at field edges during non-crop season for sustainability of its population. At the time of maturity stage of wheat crop during spring season, when the climatic condition were favorable and having security under crop shelter, this rat assumed to spend most of its time at surface feeding. Also, this species is known to leave the wheat fields well before the crop is harvested (Beg *et al.*, 1983) and it preferred uncultivated habitats during non-crop season (Srinivasachar, 1972; Advani, 1982).

The mean number of burrows recorded in the groundnut crop at various stages of its growth were not significantly different ($F_{4, 15}$ = 22.7, P = 3.2) cumulatively. These observations can be supported by extreme weather condition and lack of shelter and crop cover, rodent mortality due to unfavorable environmental conditions and predations (Siddique and Arshad, 2003). Moreover, bandicoot rat is a dominant species; inhabit crop field boundaries during the non-crop or early growth periods of the groundnut crop (Hussain *et al.*, 2003). Moreover, during the hot season (May-June) this species significantly reduces its breeding activity (Hussain *et al.*, 1992, 1994, 2002). The overall comparison of the bandicoot burrow occurrence in groundnut crop indicated some significantly higher numbers inside the crop at maturity stage (P > 0.05), due to plenty of food and good shelter/crop cover. Presence of maximum burrows at this stage could be related to higher surface movement of the rats due to crop cover, favorable climatic conditions and second peak in their breeding activities. In groundnut crop, *B. bengalensis* travels as much above ground as below, its burrows could occur anywhere. This rat makes burrows under groundnut plants and removes the nuts without killing the plants (Brooks *et al*., 1988). Moreover, frequent surfacing under the protective cover of crop could be related with larger burrow openings inside the crop fields (Hussain *et al*., 2016). It could be assumed that rodents move inside the crop fields when there is good supply of food and cover. Therefore, at this stage, the burrows were found at low frequency under wild vegetation of field edges.

It has been reported previously by various studies that at the nut formation, this rat move into the interior of fields and make extensive burrow systems (Malhi and Sheikher, 1986; Brooks *et al*., 1988). It becomes more fossorial species encountered in the field and damage groundnuts either by eating the roots, which kills the plants, or by eating the groundnuts only, by leaving behind a live but unproductive plant. Brooks at al. (1988) reported that burrow mounds of *Nesokia* rarely contained any eaten and empty shells of groundnuts indicating reliance of this species on roots and tubers of crop and grasses. The millet and maize crops mature during monsoon months which coincide with second peak in breeding of the bandicoot rat in croplands of Pothwar area (Hussain *et al*., 2003). The analysis of *N. indica* burrow prevalence and distribution data in millet crop showed significantly higher occurrence ($P < 0.05$) on field boundaries at sowing stage which moved inside crop fields at maturity ($P < 0.05$). In the absence of crop food, roots of grasses/shrubs such as *Cynodan dactylon, Saccharum munja, Dactyloctenium aegyptium* and *Sorghum halepense* play a very important role in the diet of *Nesokia* (Ahmed *et al*., 2007). These wild grasses provided shelter and food when there is no cultivation and at an early stage of crop growth.

The fields of the Pothwar area varied in size having thick undisturbed boundaries in order to conserve water. The farmers encourage growing herbs, shrubs and grasses on the field boundaries to stop land erosion during rainy season. The vegetation is also used for livestock grazing and to provide fuel wood. The outcome of this study support to suggest research and investigations on testing various ecologically-based rodent management practices *e.g.* management of non-crop habitats, cleaning of crop cache in post harvested fields, deep ploughing of crop fields after crop harvest which could destruct rodent burrows, management (cutting) of wild vegetation providing food and shelter to rodent population during non-crop periods. These ecologically-based methods would help to identify optimal timing, location and scale of management actions which are consistent with goals of sustainable agriculture with minimum environmental impact.

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Statement of conflict of interest

Authors have declared no conflict of interest.

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