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The Dynamics of Rats and Mice Populations Inhabiting Wheat-Sugarcane Based Croplands in Central Punjab (Pakistan)

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Abstract.- The study was carried out on a 100-acre block of wheat-sugarcane based cropland of central Punjab (Pakistan). Apart from wheat and sugarcane, crops of cotton, fodders and vegetables were also grown in the study block. All these five crops were snap-trapped for rats and mice each month from August (1993) to June (1994). From 6665 trap nights, 689 animals belonging to the lesser bandicoot rat (*Bandicota bengalensis),* house mouse (*Mus musculus),* metad or soft-furred field rat, (*Millardia meltada*) and Indian gerbil (*Tatera indica)* were caught; the overall trap success for the fields under sugarcane, fodders, cotton, wheat and vegetables were 16.2%, 11.7%, 8.9%, 6.4% and 5.3%, respectively. The house mouse was numerically predominant in all the crops except for the sugarcane crop where the mouse, the bandicoot rat and metad had comparable trap successes. The murid populations of the cane, fodder, cotton and vegetable crops generally peaked in the fall and then declined rapidly but at varying rates. Colonization of the wheat fields was initiated by the house mice in January. From February to May, the combined trap success of the four murid species in the wheat fields varied between 6.4 -7.7%. The estimated annual rate of reproduction for the bandicoot rat population, with 0.472 prevalence of pregnancy (P), 8.41 incidence of pregnancy (F), and with a litter size of 7.1, was 59.7 young / female / year. The annual rate of reproduction of the house mouse population was 66.6 (P=.507; F =9.0; litter size = 7.4), for the metad population it was 51.2 (P=.458; F= 8.7; litter size = 5.9) and for the gerbil population it was 26.1(P=.222; F=4.0; litter size =6.2).

Key words.- *Bandicota bengalensis, Mus musculus, Millardia meltada, Tatera indica*

INTRODUCTION

The canal irrigated wheat-sugarcane based agrosystem of central Punjab is a multi-cropped system in which crops of wheat, sugarcane, vegetables and cotton feature regularly. Fields of varying sizes of all these crops occur in juxtaposition giving the croplands a semblance of a vegetational mosaic. Near urban areas the acreage of fodder and vegetable crops increases, while in the environs of sugar-mills areas under sugarcane tend to be larger. On average, the area of the wheat and sugarcane fields in the wheat-cane agrosystem of central Punjab is respectively 50-60% and 15-20% of the total cropped area.

The vegetational heterogeneity resulting from multi-cropping appears to have a favourable effect on the murid populations that inhabit the agrosystem round the year. Removal of food and cover at harvest in such a complex system has relatively little adverse effect on these populations which shift to adjacent or nearby fields having sufficient food and cover.

Success of the short-tailed bandicoot rat (*Bandicota bengalensis*), house mouse (*Mus musclus*), and metad or soft-furred field rat (*Millardia meltada*) in the irrigated croplands of the central Punjab has been attributed to the presence of sugarcane fields which serve as a relatively stable habitat and which is available for 9 to 10 months in a year (Beg *et al*., 1979). These species are known to maintain almost year round resident populations in the cane fields of Lower Sindh where they freely move between the cane and cereal crops causing significant damage to all these crops (Smiet *et al*., 1980). In the wheat-sugarcane based croplands of central Punjab, cane fields serve as important centers of the murids' activities that extend to the nearby field of other crops (Beg *et al.*, 1980). Apart from these species, the Indian gerbil (*Tatera indica)* thrives in the patches of scrublands that occur in the midst of the croplands or in the interfaces where croplands and scrublands meet. The gerbil frequents the croplands regularly, especially the wheat, cotton and fodder fields and may even burrow in there, at

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least, for sometime. It also visits the cane field but it rarely burrows in here (Beg and Ajmal, 1977; Beg *et al*., 1980).

A 100-acre block of cropland that represented the wheat-sugarcane based croplands of central Punjab (Pakistan) was chosen for this study. Randomly selected fields under different crops of the study block were trapped every month from August, 1993 through June, 1999 for the rodents. Trap success (or index of relative density) data was used to assess changes in the relative densities of the populations of *B. bengalensis, M. musculus, M. meltada,* and *T.indica* at different times of the year and in the stands of different crops. This paper also documents information on the seasonal changes in the rates of reproduction of the four murid populations.

Study area

Our study block was located in the vicinity of 'chak' (village) 61. J. B. of district Faisalabad of central Punjab. Central Punjab is a part of the Indus plain that lies between the rivers Chenab and Ravi. About a century ago, before the introduction of the irrigation canals, the natural vegetation of this part of the Indus plain was the tropical thorn forest which was characterized by the presence of *Salvadora oleoides* and *Capparis aphylla*, while shrubs of *Salsola foetida* and *Suaeda fruticosa* thrived on alkaline patches of soil. Near creeks, tamarisk was common (Anon., 1908; Parker, 1924).

At the beginning of the 20^{th} centaury, when canal irrigation was introduced in the area, the tropical thorn forest began to be replaced rapidly by croplands. Today, about 80% of the total land area of Faisalabad and its adjoining districts is irrigated. Most of the irrigated land is under such crops as wheat, sugarcane, rice, cotton, fodder and vegetables.

In the midst of the croplands occur scrublands of varying sizes. Such scrublands are favoured by the Indian gerbil and the field mouse (*Mus booduga*). At some places seepage from the irrigation canals has resulted in waterlogged or marshy areas which are populated by a variety of resident and non-resident aquatic birds. Sandy uplands vegetated with tall grasses near such wetlands are favorite habitats of the bandicoot rat and the short-tailed mole rat (*Nesokia indica*). Among other ecological features of the landscape of central Punjab are the networks of irrigation canals and highways the major ones of which are flanked by belts of forest plantation that are often interrupted by scrubby portions, which may be inhabited by the gerbil and field mouse. The banks of the irrigation and drainage canals, and flood embankments are favoured by *N. indica* (Hussain, 1992). Another important component of the landscape of the rural central Punjab are the villages and farmhouses. They are scattered allover the cultivations (Taber *et al*., 1967) and are inhabited by four communsal species of small mammals namely, the house rat (*Rattus rattus*), house mouse (*Mus musculus*), house shrew (*Suncus murinus*), and the Indian gerbil (Roberts, 1997). The house rat is strictly an indoor species while the other three species affect the croplands also. The house shrew and the house mouse occur in cultivated areas. The northern palm squirrel (*Fumabulus pennanti*) is also a hanger-on of man. Its distribution is tied to the human habitations. Besides these small mammals relict populations of bush rat (*Golunda elioti*), Baluchistan gerbil (*Gerbillus nanus*), Indian hairy-footed gerbil (*Gerbillus gleadowi*) and Indian desert jird (*Meriones hurrianae*) occur in central Punjab (Taber *et al*., 1967; Hassan and Beg, 2005). The pygmy shrew (*Suncus etruscus*) has been reported from the wet and vegetated banks of a drainage canal (Mahmood-ul-Hassan *et al*., 2000).

A wide variety of mammals and birds affect the agrosystem of the central Punjab (Taber *et al.*, 1967; Beg and Qureshi, 1972, 1976, 1980; Qureshi and Beg, 1975). Mammalian predators like the Indian jackal (*Canis aureus*), common red fox (*Vulpes vulpes pusilla*), Bengal fox (*Vulpus bengalensis*), small Indian mongoose (*Herpestes javanica*), large Indian mongoose (*Herpestes edwardsi*), and jungle cat (*Felis chaus*) occur associated with the agrosystems. Small mammals are important staples of the diet of these carnivores (Khan and Beg, 1986; Niazi, 1984). Among the diurnal raptors, the Black-winged Kite (*Elanus caeruleus*), White-eyed Buzzard (*Butastur teesa*), Indian Sparrow hawk (*Accipiter badius*), and Pariah Kite (*Milvus migrans*) are common in the study area (Roberts, 1997).

The rats and mice, which are forced to come out of their burrows when the harvested wheat and sugarcane fields are flooded with irrigation water, are caught by Pariah Kites and the House Crows (*Corvus splendens*). Among the nocturnal birds of prey, two species of owl viz. the Barn Owl (*Tyto alba*), and the Spotted Owlet (*Athene brama*) are important predators of the agrosystems of the Punjab (Mahmood-ul-Hassan *et al*., 2007; Beg *et al*., 1990; Shah *et al*., 2004).

A 100-acre block of the wheat-sugarcane based cropland located about 15 km west of Faisalabad city (31^0 $25^/$ N, 73^0 $07^/$E) near village 61 J.B. was chosen for this study. The climate of Faisalabad and its adjoining districts is of subtropical monsoon type, with the mean maximum and minimum temperatures for the hottest (June) and the coldest (January) months are 40^0 C and $27^{\ 0}$ C, and 19^0 C and $4^{\ 0}$ C, respectively. During the hot and dry period, which extends from mid-April to the end of June, the day temperature shoots up, winds blow accelerating evapotranspiration, and there is no rain of importance. December-January is the coldest period of the year when the night temperature often falls below freezing point while the day temperature rarely rises above 22^0 C. The rainfall is highly seasonal. The annual average rainfall for Faisalabad is 39 cm of which about 65% falls during late June-August. The patterns of temperature and rainfall result in two periods of growth, one from about late February through early April, and the other from about August through September (Taber *et al*., 1967)

MATERIALS AND METHODS

This study on the rat and mice populations was largely confined to a 100-acre block of wheat-sugarcane based croplands of central Punjab. The vegetational composition of this block is given in Table I which documents information on the acreage of various crops present in the block in different months of the year. The table also provides information about the area of the various field crops that were sampled for rats and mice during the 11 months (from August, 1993 through June, 1994) of this study. Generally, eight acres of randomly selected fields under different crops were snap-trapped each month except for December and June when 11 and 7 acres were sampled.

Each month a new set of fields was used for the samplings. The monthly trappings lasted for five consecutive nights. Each night on each acre of the selected fields, 10 rat snap traps (17cm x 9cm) and five mouse snap traps (12cm x 6cm) were operated. The traps were set at five stations each of which carried two rat traps and one mouse trap. Four of the stations were located at about 6m inside the one acre field from its four corners and the fifth station was located at about the center of the field.

Trap success (number of animals captured ÷ trap nights), an index of relative density, was used for comparing the abundance of the rats and mice populations affecting the fields at different times of the year.

The traps were set in the evening and collected the next morning at about sun rise. Each of the trapped specimens was given a field number and brought to the laboratory for identification, and autopsy. Additionally, larger samples of the rats and mice were simultaneously taken from almost similar croplands located, at least, 2km away from the study block. This was done to enlarge the reproduction data without further stressing the murid populations of the study block.

The rate of reproduction, that is, the number of young produced per female per season per year of reproduction was computed following Southwick (1966) who defined incidence of pregnancy, F, as

$$\mathbf{F = P\ (t/v)}$$

where, **P** is prevalence of pregnancy, **t** is sampling time in days that is, the period of time during which a population has been producing young, and **v** is time in days of gestation during which pregnancy is macroscopically visible.

Example: Of the 27 adult females in the spring sample of *B.bengalensis* 16 were pregnant (see Table III). Thus, P = 16÷27 = 0.592. The average litter size for the season was 7.1, while t = 90 days and v = 17 days. So, F = 0.592 (90/17) =3.20. Thus, the rate of reproduction for the spring season = 3.20 x 7.1 = 27.8 young/female/three months of the spring season.

Table I.- **Monthly changes in the acreage of different standing crops during the monthly surveys of the study block of the wheat-sugarcane based cropland. The figures given in parentheses indicate the area (in acre) of the fields that were sampled for the rats and mice in different months of this study.**

Month	Acreage of the crop and fallow lands					
	Sugarcane	Fodder	Vegetable	Cotton	Wheat	Fallow fields
1993						
August	25(2)	36(3)	8(11)	16(2)	-	15
September	19(2)	35(3)	6(1)	16(2)	-	24
October	17(2)	24(3)	17(1)	13(2)	-	29
November	17(2)	20(3)	11(1)	12(2)	-	49
December	11(2)	10(3)	11(3)	3(3)	53(0)	12
1994						
January	11(3)	9(1)	12(1)	-	60(3)	8
February	6(1)	11(2)	13(1)	-	60(4)	10
March	5(1)	11(2)	15(0)	-	60(5)	9
April	7(0)	12(1)	14(2)	-	50(5)	17
May	7(1)	15(3.5)	18(2)	12(0)	9(1.5)	39
June	7(3)	35(2)	9(0)	12(0)		37

RESULTS

Trap success as an index of relative density

Table I provides information about changes in the acreage of various crops of the study block in different months of the year, while the trap success data in different crops and on different species are documented in Table II. Four species of murid rodents, namely the lesser bandicoot rat, *Bandicota bengalensis*, the house mouse *Mus musculus*, the soft-furred field rat or metad *Millardia meltada*, and Indian gerbil *Tatera indica*, were represented in the samples of trapped animals.

After the harvesting of wheat was over in May, the rodents, particularly the mice and metads, colonized the sugarcane and fodder (*viz.* millet, sorghum and maize) fields in fairly good numbers in May-June (Fig. 1). During this hot and dry period vegetation cover was scanty, both in the croplands and in the non-crop areas, and the sugarcane and fodder crops were still in initial stages of growth. The bandicoot rats inhabited grassy and damp banks of the irrigation ditches, while the gerbils confined themselves to the patches of scrublands that existed in the study block or close to it. Intuitively, the rodents might have become more susceptible to predation during May-June.

The murid populations continued building up in the sugarcane, fodder, cotton and vegetable fields which generally peaked in October. Past the fall peaks, the trap success of the rats and mice in all these crops began declining at varying rates; the decline in the cane population being the slowest one (Fig. 1). *M. meltada*, and *B. bengalensis* and *M. musculus* averaged better trap success during the 10

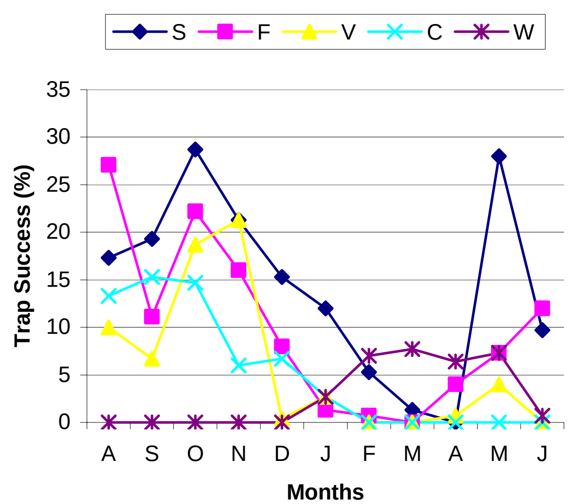

Fig. 1. Variation in the, combined monthly trap success of the four murid species in the sugarcane (S), fodder (F), cotton (C), wheat (W), and vegetable (V) crops of the study block.

months of the trappings in the cane fields (Table II). The gerbil was recorded from the cane fields only occasionally.

Except for the wheat fields, the house mouse was predominant in the fields of all the crops; its average trap success in the various crops ranged from 3.1% to 6.7 %(Table II). The average trap success for the metad varied from 0.9% to 5.9%; among its better populated crops were sugarcane (5.9%), fodder (3.6%), and cotton (3.2%). In the bandicoot rat the trap success ranged from 0.1% (in the cotton fields) to 5.0% (in the sugarcane fields). The Indian gerbil did not appear to inhabit any of the crops of the study block for long times except for the cotton fields from where it was recorded during five consecutive months (Table II). The average trap success of this rat varied from 0.2% (both in the sugarcane and vegetable fields) to 1.6% (in the cotton fields). In the fodder and wheat fields its index of relatively density was 0.5% and 0.6%, respectively. It seems the gerbil favoured the crops which offered relatively dry conditions.

The bandicoot rat's trap success combined for all the crops was 1.7%, for the house mouse it was 4.9%, for the metad 3.2%, and for the gerbil it was 0.6%. The combined trap success for all the four species in the sugarcane fields was 16.2%, it was 11.7% in the fodder fields, 5.4% in the vegetable fields, 9.8% in the cotton fields, and 6.4% in the wheat fields. The overall trap success that is, the combined trap success for all the species and crops was 10.3% (Table II).

To know whether the combined trap successes of the four murid species in different crops were independent, the ratio method of chi-square was employed. The results revealed a significant deviation from independence indicating that the crops and trap success were associated at a significant level (X^2 = 104.2; p<.01; df = 4). The sugarcane and fodder crops showed remarkably high trap success, while the vegetables and wheat crops evidenced remarkably low trap success; trap success for the cotton crop approximated the average.

Reproduction

The prevalence of pregnancy (P), the time period (t) during which a given species produced young, the duration of gestation (v) during which pregnancy was macroscopically visible, the average litter size, and incidence of pregnancy (F) were used, following Southwick (1966), for estimating the potential rate of reproduction of the bandicoot rat, house mouse, metad, and Indian gerbil. Table III provides information on the seasonal changes in P, litter size, F and rates of reproduction in the four species.

Pregnant females of each of the four species were present in all the seasonal samples (Table III). However, in the winter samples, pregnant females were recorded in the second half of February only except for one gravid house mouse that was taken in the first half of this month.

The bandicoot rat and the Indian gerbil achieved maximum P in the spring and the next best one in the summer. In contrast, the house mouse and the metad evidenced maximum P in the summer and the next best one in the spring. But, all the four species averaged larger embryonic litter size in the spring. However, they were at variance with respect to the season of the next large litter size; the bandicoot rat and the gerbil evidenced it in the summer, while the house mouse and metad in the fall.

In spite of the seasonal disparity in P and litter size, all the four species achieved the best rates of reproduction in the spring, less in the summer, and lesser in the fall. The two larger rats (*viz*. the bandicoot rat and the gerbil) were able to achieve high rates of reproduction in the spring by attaining high P, F, and large litters, while the other two species (*viz*. the house mouse and the metad) produced a similar result but by producing larger litters in the spring and by attaining somewhat smaller P and F values than in the summer season. The annual rate of reproduction for the four species was estimated to be 59.7, 66.6, 51.2 and 26.1 young/female/year, respectively. The reproduction data for the winter season was not used in this comparison on account of the smallness of the samples. However, this season's data was considered for estimating the annual (*i.e.* the February-November) rate of reproduction.

The seasonal production of the young was maximum in the spring, less in the summer, lesser in the fall, and the least in the winter in all the four species. The bandicoot rat made the maximum

Table II.- **Trap success (%) of *Bandicota begalensis* (Bb), *Mus musculus* (Mms), *Millardia meltada* (Mma) and *Tatera indica* (Ti) in the fields of different crops of the study block.**

Month	Area sampled	Trap night	Trap success (no. animals caught)				
			Bb	Mms	Mma	Ti	Combined
			a. Sugarcane				
August 1993	2	150	2.7(4)	8.7(13)	5.3(8)	0.7(1)	17.3(26)
September	2	150	5.3(8)	4.0(6)	10.0(15)	-	19.3(29)
October	2	150	6.0(9)	13.3(20)	9.3(14)	-	28.7(43)
November	2	150	10.7(16)	4.7(7)	6.0(9)	-	21.3(32)
December	2	150	7.3(11)	-	7.3(11)	0.7(1)	15.3(23)
January 1994	3	225	6.2(14)	3.1(7)	2.8(6)	-	12.0(27)
February	1	75	5.3(4)	-	-	-	5.3(4)
March	1	75	-	1.3(1)	-	-	1.3(1)
April	-	-	-	-	-	-	-
May	1	75	1.3(1)	8.0(6)	18.7(14)	-	28.0(21)
June	2.8	185	1.1(2)	5.4(10)	2.7(5)	0.5	9.7(18)
Total/Average	**18.5**	**1385**	**5.0(69)**	**5.1(70)**	**5.9(82)**	**0.2(2)**	**16.2(224)**
			b. Fodder				
August 1993	3	225	3.6(8)	11.6(26)	11.1(25)	0.9(2)	27.1(61)
September	3	225	-	6.2(14)	4.0(9)	0.9(2)	11.1(25)
October	3	225	-	14.7(33)	7.6(17)	-	22.2(50)
November	3	225	0.4(1)	12.9(29)	2.2(5)	0.4(1)	16.0(36)
December	3	225	0.4(1)	6.7(15)(	0.9(2)	-	8.0(18)
January 1994	1	75	-	-	1.3(1)	-	1.3(1)
February	2	150	0.7(1)	-	-	-	0.7(1)
March	2	150	-	-	-	-	-
April	1	75	-	4.0(3)	-	-	4.0(3)
May	3.5	260	1.9(5)	2.7(7)	0.8(2)	1.9(5)	7.3(19)
June	2	150	1.3(2)	3.3(5)	7.3(11)	-	12.0(18)
Total/Average	**26.5**	**1985**	**0.9(18)**	**6.7(132)**	**3.6(72)**	**0.5(10)**	**11.7(232)**
			c. Vegetables				
August 1993	1	75	-	5.3(4)	4.0(3)	1.3(1)	10.7(8)
September	1	75	-	4.0(3)	2.7(2)	-	6.7(5)
October	1	75	-	16.0(12)	2.7(2)	-	18.7(14)
November	1	75	-	14.7(11)	6.7(5)	-	21.3(16)
December	3	225	-	-	-	0.4(1)	0.4(1)
January 1994	1	75	-	2.7(2)	-	-	2.7(2)
February	1	75	-	-	-	-	-
March	-	-	-	-	-	-	-
April	2	150	-	0.7(1)	-	-	0.7(1)
May	2	150	0.7(1)	2.0(3)	1.3(2)	-	4.0(6)
June	**13.0**	**975**	**0.1(1)**	**3.7(36)**	**1.4(14)**	**0.2(2)**	**5.4(53)**
			d. Cotton				
August 1993	2	150	-	6.7(10)	2.3(5)	3.3(5)	13.3(20)
September	2	150	-	4.7(7)	7.3(11)	3.3(5)	15.3(23)
October	2	150	-	11.3(17)	2.7(4)	0.7(1)	14.7(22)
November	2	150	-	2.0(3)	2.7(4)	1.3(2)	6.0(9)
December	3	225	-	3.1(7)	2.7(6)	0.9(2)	6.7(15)
January 1994	1.5	110	1.3(1)	1.8(2)	-	-	2.7(3)
Total/Average	**12.5**	**935**	**0.1(1)**	**4.9(46)**	**3.2(30)**	**1.6(15)**	**9.8(92)**
			e. Wheat				
January 1994	3	225	-	2.7(6)	-	-	2.7(6)
February	4	300	0.3(1)	4.7(14)	1.3(4)	0.7(2)	7.0(21)
March	5	375	2.1(8)	3.2(12)	2.4(9)	-	7.7(29)
April	5	375	3.2(12)	1.3(5)	-	1.9(7)	6.4(24)
May	1.5	110	1.8(2)	5.5(6)	-	-	7.3(8)
Total/Average	**18.5**	**1385**	**1.7(23)**	**3.10(43)**	**0.9(13)**	**0.7(9)**	**6.4(88)**
Tot/Av for all crops and months	**89.0**	**6665**	**1.7(112)**	**4.9(327)**	**3.2(211)**	**0.6(38)**	**10.3(689)**

Table III.- Potential rate of reproduction of the four murid populations that inhabited the wheat-sugarcane based cropland of the central Punjab. The numbers of pregnant females are given in parentheses.

Seasonal/ Annual	Adult females (Preg. females)	Prev. of pregnancy, P	Embryonic litter size $\bar{X}$±SE	Incidence of pregnancy, F	No. young/female/ season/ (months)
			B. bengalensis		
Fall	15(6)	0.400	5.0±0.780	2.14	10.7
Winter	7(1)	0.143	9.0 -	0.54	4.9
Spring	27(16)	0.592	8.7±0.648	3.20	27.8
Summer	23(11)	0.478	5.7±0.576	2.59	14.8
Annual	72(34)	0.472	7.1±0.004	8.41	59.7
			M. musculus		
Fall	30(13)	0.433	6.3±0.416	2.62	16.5
Winter	11(2)	0.182	7.5±0.353	0.34	2.6
Spring	53(29)	0.457	8.9±0.316	2.80	24.9
Summer	40(24)	0.600	6.1±0.404	3.68	22.4
Annual	134(68)	0.507	7.4±0.231	9.00	66.6
			M. meltada		
Fall	37(12)	0.324	6.4±0.248	1.92	12.6
Winter	25(2)	0.080	7.0±0.000	0.17	1.2
Spring	40(24)	0.600	7.1±0.310	3.45	24.5
Summer	53(33)	0.623	4.9±0.223	3.58	17.5
Annual	155(71)	0.458	5.9±0.519	8.70	51.2
			T. indica		
Fall	28(6)	0.214	5.7±0.559	1.15	6.6
Winter	39(4)	0.102	5.0±1.370	0.17	0.9
Spring	37(12)	0.324	7.5±0.600	1.75	13.2
Summer	31(8)	0.258	6.7±0.343	1.40	9.4
Annual	135(30)	0.222	6.2±0.197	4.00	26.1

Note: Following Southwick (1966), five days were deducted from the gestation periods *B. bengalensis* (Fulk *et al*., 1964), *M. musculus* (Southwick, 1966), *M. meltada* (Bindra *et al*., 1968), and *T. indica* (Asdell, 1964) to compute 'v' the length of macroscopically visible pregnancy which was respectively of 17, 15, 16, and 17 days long. The sampling time (or production time) t was of 91, 28, 92, and 92 days for the fall, winter, spring, and summer seasons. In the winter season the production time was of 28 days only.

reproductive investment during spring seasons. The house mouse population was different from the bandicoot rat population as it maintained generally higher rate of reproduction over the four seasons of the year. Perhaps for this reason, an average female mouse of the wheat-cane system showed the highest potential for producing young per annum. The metad and the gerbil populations distributed their seasonal reproductive efforts more evenly than did the bandicoot rat population, but their reproductive efforts were of lower intensities.

The annual prevalence of pregnancies (P) among the four murid populations deviated significantly from independence (X^2 = 27.577; $p<.005$; df = 3). The bandicoot rat, house mouse, and metad had considerably high P values while that of the gerbil was below the average. However, the annual embryonic litters of the four populations were not different with respect to their size (F = 0.457; $p>0.5$; df = 12). Thus, the variation in the annual rates of reproduction of these murid populations was more due to P rather than due to litter size alone.

DISCUSSION

Multicropping is a widespread and common practice in the wheat-sugarcane agrosystem of central Punjab. Harvesting two to three crops from the same field in about a year's time is not uncommon. In our multicropped farm system, the processes of plowing, sowing and harvesting continue almost round the year. Harvesting of fodder (gramineous) and cotton crops generally extends from August through November. The harvested fields are usually flooded with water before being ploughed and prepared for sowing with wheat and leguminous fodder crops (*viz.*, Lucerne and clover). The cane crop has a protracted period of harvesting which usually starts from November-December and may continue beyond February. Due to these disturbances and physiognomic changes, not only the vegetation cover and food but also the rodent populations are in a state of flux almost throughout the year.

Trap success

In the study block, the rodent populations had been found strongly associated with the cane and fodder crops, less strongly with the cotton crop and weakly with the wheat and vegetable crops. In addition to the food, the stands of tall and dense cane, fodder (gramineous) and cotton plants perhaps provided better protection against raptors, and shelter against climatic stress than did the other crops of the study block. After the latter two crops had been harvested by November, the cane fields might have become a more important habitat for the bandicoot rat, house mouse and the metad populations. Besides food and shelter, the cane fields provided proximity to the fast improving food resources of the wheat fields. Perhaps, for these reasons the rats and mice of the wheat-cane cropland favoured the cane and gramineous fodder better than the other crops.

All the four murid species of the croplands ceased to reproduce from December to mid-February. Except for the gerbils, which generally do not inhabit the cane fields, individuals of the other three populations presumably remained concentrated in the cane fields till the wheat fields began offering sufficient food and cover in February-March and ultimately became the centers of spring reproduction.

The cane fields in central Punjab harbor the rodent populations for six to nine months (Beg *et al.,* 1979) and play an important role in sustaining the reproductively quiescent populations of the bandicoot rat, the house mouse and the metad from December to mid-February. In lower Sindh, these species are known to maintain almost year round resident populations in the cane fields and regularly forage in the nearby cereal fields causing damage to the crops (Smiet *et al.*, 1980).

But, our trapping data indicated that the rats and mice in the cane fields continually declined after October (Fig. 1). Possibly they either, moved out of the study block, or suffered high mortality, or in the presence of rich and abundant food available in cane and wheat fields their preference for the bait declined. As for the possibility of their moving out of the study block was concerned, it might be pointed out that our study block was surrounded by a vast expanse of similar croplands in which, as in our study block food condition had been rapidly improving. There was no cropped or non-cropped area in the vicinity which could apparently offer better opportunities than did the study block. As the rodent populations of the adjacent croplands had been not exposed to monthly removals through snap-trapping, possibly the croplands of our study block offered somewhat better food and shelter opportunities than did the surrounding areas. However, the presence of many active burrows of the bandicoot rat in the cane fields, and signs of digging (for wheat grains), and piles of cut tillers and fecal droppings of the rats and mice in the wheat fields betrayed their presence. Furthermore, the fact that sugarcane and wheat had been reported to be the staples of the diets of these murids during the fall and winter months give credence to our above inference (Beg *et al.,* 1992, 1994; Butt *et al.,* 2003).

A comparison of the trap success data of Durr-i-Shahwar *et al.* (1999) for the multicropped wheat-rice based croplands of Hafizabad (Punjab) with our wheat-cane cropland data revealed that the overall trap success for this cropland was 4.3% as compared to 10.3% recorded in the wheat-cane croplands (Table IV). This was remarkable in view of the fact that the wheat-rice agrosystem had two periods, one extending from August to November (rice fields) and the other from February to May (wheat fields), during which a surfeit of nutritious food had been available in the rice and wheat fields. In the wheat-rice study block of Hafizabad sugarcane was present over just a half acre plot. Harvesting of the rice and fodder (gramineous) crops had been completed in November. The rodent populations, on being deprived of the food and cover of the rice and fodder fields, had available to them no refuge crop like the cane crop sugarcane of

Table IV.- **A comparison of the trap success data of different murid species inhabiting the wheat-rice based cropland of northeastern Punjab with those from the wheat-sugarcane based cropland of central Punjab.**

Species	Wheat-rice cropland (Durr-i-Shahwar *et al*., 1999)		Wheat-cane cropland (This study)	
	Trap success (%)	Trap night	Trap success (%)	Trap night
Farm crops				
B. bengalensis	2.1(157)	7425	1.7(112)	6665
M. musculus	1.5(114)	7425	4.9(327)	6665
M. meltada	0.7(49)	7425	3.2(211)	6665
T. indica	-	-	0.6(38)	6665
All spp. and crops	4.3(317)	7425	10.3(688)	6665
Field crops				
Sugarcane	2.5(14)	975	16.2(224)	1385
Wheat	3.5(76)	2175	6.4(88)	1385
Fodder	3.9(50)	1275	11.7(232)	1985
Cotton	-	-	9.8(92)	935
Rice	4.8(79)	1650	-	-
Vegetables	6.5(88)	1350	5.4(53)	975
All crops and spp.	4.3(317)	7425	10.3(688)	6665

the wheat-cane system that would provide them shelter and food till sufficient food and cover had been available in the wheat fields in February-March. Possibly, the rodent populations, of the wheat-rice system had suffered heavy mortality, especially during December-February, the period of reproductive quiescence (Durr-i-Shahwar, 1999). However, the murid communities of both the wheat-rice and wheat-cane agrosystems faced almost a similar stressful condition after the wheat crop had been reaped in April-May; May and June are hot and dry months during which vegetation cover is sparse and stunted both in the croplands as well as in the non-cropped areas.

Rate of reproduction

The length of reproduction time (t), prevalence of pregnancy (P), litter size and incidence of pregnancy (F) are important parameters of reproduction. These parameters haves been used in a number of studies for estimating the potential rate of reproduction of the bandicoot rat, house mouse, metad, and the Indian gerbil populations in different parts of their ranges (Table V).

The bandicoot rat population of our study area ceased to reproduce during December to January, while a more northern population of this rat residing the wheat-rice agrosystem of Hafizabad district (Punjab, Pakistan) did not breed from December through February (Durr-i-Shahwar *et al*., 1999). Further north, the rat's Potohar Plateau (Punjab) population appeared to have a t of about six-month duration (Hussain *et al.,* 2002). In the Indian Punjab the rat does not breed in January-February, and September (Bindra and Sagar, 1977). However, the southwestern population of the rat in Lower Sindh (Pakistan) breeds over most of the year (Smiet *et al*., 1980; Fulk *et al*., 1981). Both indoor and outdoor populations of the rat in Bengal (India), and Rangoon (Myanmar) breed round the year (Spillett, 1968; Chakarborty, 1977; Walton *et al*., 1978).

The bandicoot rat living in the wheat-rice agrosystem of Hafizabad evidenced the highest rate of reproduction by attaining high P and by producing several enlarged litters (Table V). In spite of having greater t, slightly higher P, and much larger F, the grains godown population of Kolkata had lower rate of reproduction than the wheat-rice population apparently because the latter population produced larger litters. Likewise, the oilcake godown population which had greater t, better P and F than the wheat-sugarcane population could achieved slightly better rate of reproduction because

Table V.- **A comparison of the rates of reproduction of some selected populations of *Bandicota bengalensis*, *Mus musculus*, *Millardia meltada*, and *Tatera indica*. (t, the length of the reproduction time).**

Habitat and locality	Prev. of preg. P	Emb. litter size	Incid. of preg. F	No. young/ female/t	Source (t in months)
			Bandicota bengalensis		
Oilcake and rice husk godown Kolkata (India).	0.494	5.9	10.6	62.6	Spillett (1968) (t=12)
Grain godown, Kolkota (India).	0.558	6.4	12.0	76.6	Spillett (1968) (t=12)
Rice fields, Lower Sindh (Pakistan).	0.148	8.9	1.6	28.2	Fulk *et al*., (1981) (t=7)
Sugarcane fields, Lower Sindh (Pakistan).	0.308	6.5	6.7	43.6	Smiet *et al*. (1980) (t=5)
Wheat-rice agrosystem, Hafizabad, Punjab (Pakistan).	0.555	10.2	9.0	91.8	Durr-i-Shahwar *et al*., (1999) (t=9)
Wheat-cane agrosystem, central Punjab (Pakistan).	0.472	7.1	8.4	59.7	This study (t=10)
			Mus musculus		
Wheat-rice agrosystem, Hafizabad, Punjab (Pakistan).	0.510	6.6	9.7	64.0	Durr-i-Shahwar *et al*., (1999) (t=9)
Wheat-sugarcane agrosystem, central Punjab (Pakistan).	0.511	6.2	9.7	60.0	Khan (1982) (t=10)
Wheat-sugarcane agrosystem, central Punjab (Pakistan).	0.507	7.4	9.0	66.6	This study (t=10)
			Millardia meltada		
Wheat-rice agrosystem, Hafizabad, Punjab (Pakistan).	0.480	6.0	8.3	49.5	Durr-i-Shahwar *et al*., (1999) (t=9)
Wheat-sugarcane agrosystem, central Punjab (Pakistan).	0.541	5.3	10.2	54.3	Khan (1982) (t=10)
Wheat-sugarcane agrosystem, central Punjab (Pakistan).	0.458	5.9	8.7	51.2	This study (t=10)
			Tatera indica		
Wheat-sugarcane agrosystem, central Punjab (Pakistan).	0.336	6.76	6.0	40.6	Khan and Beg (1986) (t=10)
Wheat-sugarcane agrosystem, central Punjab (Pakistan).	0.222	6.2	4.0	26.1	This study (t=10)

it produced larger litter. The wheat-rice population of the rat attained higher rate of reproduction than the wheat-cane population by having better P, larger litters, and somewhat higher F (Table V).

The spring and the fall seasons of the wheat-rice agrosystem of Hafizabad was remarkable for its surfeit of high energy food, vast expanses of vegetation cover in the wheat and rice fields, and perhaps a minimal competition among their murid populations. Thus, in the wheat-rice cropland, the bandicoot rat had two seasons of ecological release, while the wheat-cane population had only one such season.

The bandicoot rat population of the rice fields of Lower Sindh evidenced great fluctuation in P related to the availability of food. It achieved high rate of reproduction by producing many large litters during the months the rice crop was maturing and ripening (Fulk *et al*., 1981). But, the sugarcane population of the same area showed little fluctuation in P. However, the overall P was high in the sugarcane population (Smiet *et al*., 1980) (Table V).

Mus musculus populations of central Punjab and Lower Sindh bred round the year but at a markedly lower rate during the cold winter months (Rana and Beg, 1976; Khan, 1982; Smiet *et al*., 1980). In the wheat-cane croplands of our study block, no pregnant female was found breeding during December-January, while the period of reproductive quiescence in the mouse population of the wheat-rice agrosystem of Hafizabad extended from December-February (Durr-i-Shahwar *et al*., 1999).

Three local populations of the mouse, one from the wheat-rice agrosystem of Hafizabad district and the other two from the wheat-sugarcane agrosystem of Faisalabad district showed little difference with respect to their annual rates of reproduction which ranged from 60.0 to 66.6 (Table V).

Millardia meltada population of the wheat-cane agrosystem of Central Punjab does not breed in December to January, while those of the Indian Punjab and Hafizabad remain reproductively inactive from December through February (Guraya and Gupta, 1977; Durr-i-Shahwar *et al*., 1999). In Lower Sindh, the metad does not reproduce during December to January (Smiet *et al*., 1980) or slow down its pregnancy rate during the winter months (Fulk *et al*., 1981). However, in the warmer climate of the Mysore state of India it breeds round the year.

The rate of reproduction of three local populations of the metad from Punjab (Pakistan) ranged from 49.6 to 54.3 (Table V). The wheat-rice and the wheat-cane populations were closely similar with respect to their P, litter size, and F. Consequently, their rates of reproduction were comparable.

The breeding season of the Indian gerbil has been reported to be 6 to 12 months long in a year (Phillips, 1923; Prasad, 1961; Prakash, 1962). The gerbil populations residing the Punjab scrubland and the croplands of central Punjab do not breed during the winter months (Beg and Ajmal, 1977; Khan and Beg, 1986). These two local populations evidenced relatively a very low rate of reproduction which was due mainly to low P (Table V).

Just a cursory look at the rates of reproduction of the three murid populations of the wheat-sugarcane and the wheat-rice agrosystems would be sufficient to conclude that it was only the bandicoot rat which responded, by reproducing prolifically, to the surfeit of food and cover of the wheat and rice crops. Furthermore, the trap success for the bandicoot rat in the wheat-rice system was somewhat better than what it was recorded for the wheat-cane population, while the opposite was true for the house mouse and the metad populations (Table IV).

Perhaps near absence of a relatively stable habitat like the cane fields from the wheat-rice croplands rendered the house mouse and metad populations more vulnerable to mortality forces after the paddy and graminous fodder crops had been completely removed in October-November preceding the sowing of the wheat crop which would not be inhabitable for the rodents before January. The bandicoot rat, because of its semi-subterranean habits, might have been less prone to predation during late fall and winter. Or, the mouse and metad populations found the trap-bait a less attractive food source.

The guild of the murid rodents that affect the wheat-cane agrosystem of central Punjab causes significant damage to such important crops as wheat, rice, sugarcane and peanut allover Pakistan (Greaves *et al*., 1975, 1977; Beg *et al*., 1977, 1978, 1979; Fulk *et al*., 1981, Brooks *et al*., 1988; Hussain *et al*., 2003). The members of the guild are a part of the agro-ecosystem and are linked directly or indirectly to its other components. For example, the barn owl (*Tyto alba*) and the spotted owlet (*Athene brama*), heavily depend on the small mammals (including the house shrew *Suncus murinus*) of the agrosystem for food (Mahmood-ul-Hassan *et al*., 2000, 2007; Shah *et al*., 2004). The rats and mice are also important staples of the diets of the Indian jackal (*Canis aureus*), jungle cat (*Felis chaus*), red fox (*Vulpus vulpus pusilla*), small Indian mongoose (*Herpestes javanicus*) and grey Indian mongoose (*Herpestes edwardsi*) which are like the owls associated with the croplands (Niazi, 1984; Khan and Beg, 1986; Roberts, 1997).

Thus, the populations of small mammals should be managed carefully by reducing the carrying capacity of the agrosystem for the murid populations under consideration. Possibly, this can be done in the wheat-cane based agrosystem of central Punjab by shortening the length of the sowing and harvesting periods of the wheat, sugarcane and graminous fodder crops. The underlying idea is to deprive the rodents of the food and shelter and make them more vulnerable to predation and the elements.

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