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R. F. REIDINGER, JR., J. L. LIBAY and A. LAWRENCE KOLZ

Biologists, National Crop Protection Center, University of the Philippines at Los Baños, College, Laguna, Philippines; and Electronics Engineer, Denver Wildlife Research Center, Building 16, Federal Center, Lakewood, CO 80225 USA (also present address of first author). Present address of second author is 2736 Brookdale Ave., Oakland, CA 94602 U.S.A.

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In preliminary trials, 14 designs of pulsed charge electrical barriers (designed to repel rather than kill rats) made from locally available materials were tested for their ability to keep ricefield rats, *Rattus rattus mindanensis*, within small enclosures. The most effective design was selected for a small field trial to determine effectiveness in excluding rats from rice paddies. During the 22-day trial, electrical function of the barrier was monitored; rat activity and damage near, and within, the fenced plot were compared with those of a nearby plot; and rat damage at harvest was compared with that of six additional nearby paddies. The fence operated continuously during the trial, and maintained at least 5 kv on the electrodes for 15 of 18 days of observations. At harvest, rat damage (percentage of cut tillers per hill) was significantly ($P < 0.05$) greater in the unfenced plot (median = 15.8%), and in four of six paddies (medians = 4.3%-18.2%) surrounding the plots, than in the fenced area (median = 0.0%). Damage reflected both the effectiveness of the barrier and a higher level of rat activity in the unfenced than in the fenced plot at the onset of the study. Alterations to reduce penetration by rats of dikes beneath the barrier, and to further reduce hazards to wildlife, would improve the present design.

INTRODUCTION

Lethal electrical barriers have been used to a limited extent for over a decade in the Philippines to protect rice fields from rat damage. Ramos (1969, 1970) described the construction and operation of lethal electrical barriers still used to protect about 65 ha of experimental and varietal rice paddies at the International Rice Research Institute (IRRI). On several occasions, we (JLL and RFR) have met Filipino farmers who constructed lethal fences to protect crops. The designs were highly innovative and constructed from locally available materials. For example, one farmer used steel wires for electrodes attached to bamboo stakes (wrapped with plastic for insulation) at about 1 m intervals. By placing the stakes in a near vertical position on top of dikes and using four to seven parallel electrodes each separated by 2 to 4 cm, the electrodes also served as the fence (for a more detailed description of construction, operation, and effectiveness, see unpub-

lished Annual Report of the Rodent Research Center, National Crop Protection Center, University of the Philippines at Los Baños, College, Laguna, 1974).

Effectiveness of electrical barriers, of course, depends on such factors as design, operation, and intensity of rat infestations. Lethal barriers have disadvantages including : (a) electrical hazards to humans, wildlife, and domestic animals; (b) a tendency to short-circuit and become inoperative whenever animals contact, but are not immediately released from, electrodes, and (c) a high operational cost, in part for labor to patrol and correct short-circuits along activated barriers, frequently limiting operation to the crepuscular (i.e., dawn, dusk) or nocturnal activities of most rats (Shumake et al., 1979). Further, we speculate that killing rats by this method may be disadvantageous to crop protection. Had the rats survived, they may have learned subsequently to avoid the barrier, and, being territorial, served as a "biological buffer" to prevent other more distant rats from contacting the barrier. With death, however, the territories become available to dispersing rodents who, being naive to the effect of the barrier, also contact it and die, and so on. Thus, one can envision a continued movement of rats toward a lethal fence and a relatively high and constant rate of electrocution. Although unproven, this notion is supported by observations of the lethal fences at IRRI. In operation for over a decade, up to 20,000 rats are still killed yearly to protect about 65 ha of rice fields (unpublished observations by staff at the National Crop Protection Center, University of the Philippines at Los Baños, College, Laguna). Obviously, with such continued high levels of activity, batteries operating the fences must be recharged frequently, and a night-crew (about 30 employees) must be retained to patrol the fences. Naive rats continue to challenge the barriers and enter paddies during the day or at night when the barriers become temporarily inoperative.

For these reasons, Shumake et al., (1979) developed a prototype "nonlethal" electrical barrier and tested it in laboratory, enclosure, and small-scale field trials. In a trial comparing this prototype with lethal barriers at IRRI, the "nonlethal" barrier afforded better protection (x=0.23% cut tillers) than the lethal barriers (x = 2.05% cut tillers), required fewer battery charges (one or less per battery per month than the lethal barriers (once per battery daily), and operated continuously without the need for night crews to patrol fences. Although such improvements would reduce costs for crop protection when compared with lethal barriers, Shumake et al. (1979) considered that primary uses would still be to protect crops with high cash value or at experimental research institutes. However, they felt that adapting the design to incorporate locally available materials might help to further reduce costs and permit a more general application.

We report here results from a small-scale field trial of a pulsed-charge electrical barrier modified from the design of Shumake et al. (1979) to incorporate materials available locally at relatively low costs. We used plastic fish netting instead of metal chicken wire for fencing. Both are available locally, but fish netting is less expensive. We replaced the four electrodes in the prototype with three, and used 35 gauge steel wire available locally at

lower cost than the 18 gauge wire used in the prototype. Following the innovation (described above) of a farmer, we replaced plastic and ceramic insulators with bamboo stakes wrapped with plastic, and used plastic ties (from a local grocery store) to secure the electrodes to stakes. To reduce opportunities for short-circuits and maximize space for rice plants, we placed the barrier on top of dikes rather than in the paddy. To our knowledge, fence chargers are not manufactured in the Philippines. We used a charger available from New Zealand that performed well under humid conditions in preliminary tests and that delivered current to electrodes in pulses to reduce electrical hazard.

MATERIALS AND METHODS

Selection of Barrier Design and Charger

In preliminary enclosure trials, we tested the original prototype described by Shumake et al. (1979) and 13 variations that incorporated local materials. Each enclosure was 3.5 X 3.5 m and consisted of a barrier design with electrodes facing inwards. For each trial, six to 20 ricefield rats *(Rattus rattus mindanensis)* were placed within each enclosure. We observed enclosures both at night and during the day to determine the most effective designs.

With the prototype, the lower two electrodes (6.3 cm above the ground) effectively shocked most rats, but allowed some to contact the wire fencing and explore beneath the electrodes. Rats that jumped over, or were not repelled by the lower electrodes, climbed rapidly to the top of the barrier and escaped. Upper electrodes (31 cm above the ground) appeared relatively ineffective in preventing such escapes. The first variation consisted of nylon fish netting (0.6 cm mesh), supported by bamboo, to form a vertical barrier. Six electrode wires, running parallel to the ground, were woven into the bottom 15 cm of netting at about 1.9 to 2.5 cm intervals. Rats were shocked when they tried to climb or push through the barrier. However, some rats learned to escape by jumping above the electrodes and climbing over the net. The second variation was a 36 cm vertical fish net barrier with six horizontal electrodes. The electrodes were parallel to the netting and the ground about 2.5 cm above the ground, separated by about 1.9 cm, and wired for alternate electrical polarity. When rats crawled under or climbed onto the wire grid, and received a shock, they would seldom recover and escape. Most received successive shocks and died (even at a low charger electrical rate). The first three trials suggested that a vertical grid of electrodes would deter most, but not all, rats, whereas a horizontal grid would kill most rats. In the remaining eleven trials, we tested different angles for grids of electrodes, and different shapes for the top of the netting to develop a configuration that would reliably shock rats and yet allow their escape in the desired direction. The configuration that appeared most effective (Figure 1) was used for the field trial.

The barriers were activated by a fence charger (Gallagher Model E12 or a Speedrite Model MK4) both manufactured in New Zealand. These char-

gers nominally pulse at a rate of about once per second and deliver a current pulse greater than 5 amps into a 500-ohm load. Although not yet approved by Underwriters' Laboratories, the chargers comply with safety standards for several countries, and no human fatalities have been reported. Both chargers have solid state circuitry that performed reliably under the humid conditions of our trials, and electrified even partially short-circuited fences. We chose the Gallagher Model E12 for the subsequent field trial because its rate could be slowed to about one pulse every 2 sec.

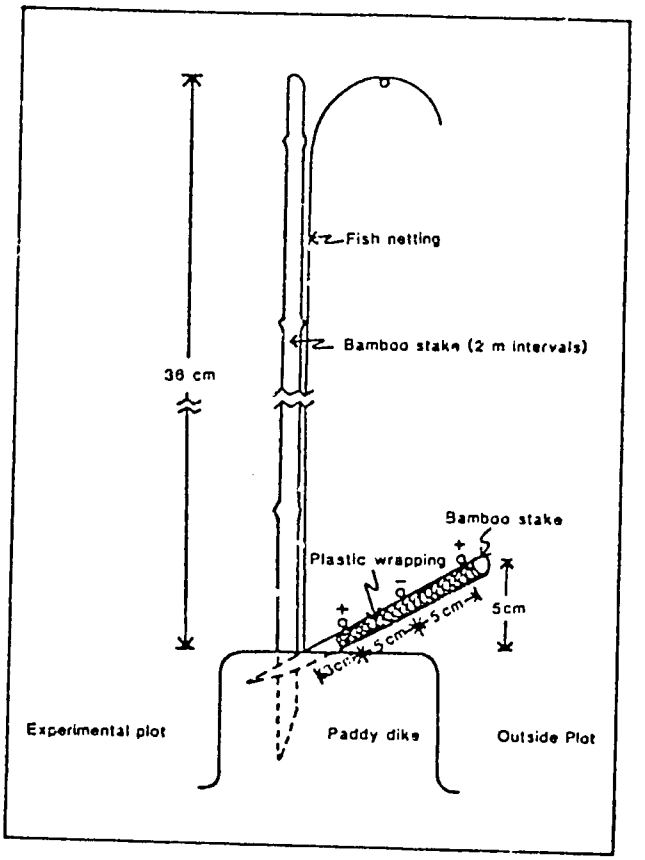

Fig. 1. Barrier design and charger used for the field trial.

Selection of Field Sites and Barrier Construction

Two paddies were selected within a ricefield on a farm near Lumban, Laguna. Each paddy was approximately 35 x 35 m and planted with a high yielding variety of rice (IR-26) at 24 days before harvest. Paddies were separated by about 90 m, and surrounded by other paddies containing rice within 10 days of harvest. These paddies were selected partly because of evidence of rat damage, and because we anticipated even more intense rat infestations after the surrounding fields were harvested. One paddy was randomly selected for treatment, and enclosed by a barrier. The other paddy was left unfenced as a reference plot.

Barrier construction was completed in 1 day by staff of the Rodent Research Center (National Crop Protection Center). The barrier was placed on top of dikes, and consisted of pink nylon fish netting (about 0.6 cm mesh) suspended vertically on bamboo stakes (at about 2-m intervals) to a height of about 36 cm (Figure 1). An uncharged wire was suspended parallel to the netting and to, and about 36 cm above, the ground. Netting was draped over the wire. The top of the netting was curved outward (away from the protected plot) and downward to direct climbing rats away from the protected area. Short bamboo stakes, wrapped with plastic for insulation, were placed at 2-m intervals in the dike at the bottom of the netting for attachment of electrodes. The stakes faced away from the protected plot and were angled so that the outermost electrode would be 13 cm from the bottom of the netting and 5 cm above the dike (Figure 1). Three electrodes, 35 gauge wire available locally, were suspended on the stakes parallel to the netting and to the ground. The electrodes were secured to the stakes with plastic ties and set at 3 cm, 8 cm, and 13 cm from the bottom of the netting. During the first 2 days of observations, we felt the plastic-wrapped stakes were insufficient insulators (line voltage was less than 5 kv). On the third day, we replaced these stakes with wooden ones coated with varnish.

The electrodes were activated by the Gallagher Model E12 charger, set to deliver one electrical pulse per second. The outermost and innermost electrodes were positive, the middle electrode negative (Figure 1). The charger, in turn, was powered by a locally available 12 volt car battery. The fence was activated and tested immediately after its construction.

Collection of Data

We observed rat activity in and around each experimental plot, function of the electrical barrier, and extent of rat damage in the experimental plots and surrounding rice paddies.

Rat activity was measured, using tracking tiles (West et al., 1976), for three periods (each consisting of 3 consecutive days) beginning the fourth, eleventh, and twentieth days after construction of the barrier. For the treated plot, 10 tracking tiles were placed near dikes in the paddies outside of the plot and 10 tracking tiles along the barrier within the plot. Tracking tiles were placed in analogous locations in the treated plots. Fresh ink was placed on all tiles in late afternoon, and checked the following morning. Tiles having evidence of rat activity (e.g., foot or tail prints) were recorded as positive. In addition to tracking tiles, rat activity was measured with snap traps for a 3-day period beginning the fourth day after installation of the barrier. As with tracking tiles, 10 traps were set inside and 10 outside each plot. Traps were baited with coconut each evening, and rats collected the following morning.

Except for 4 days (fifteenth through the eighteenth days after installing the barrier), daily observations were made on the operation of the electrical barrier. Every morning, the barrier was inspected for signs of malfunc-

tion. Killed animals were removed from the barrier or vicinity, and records were kept of all such killings. In addition, signs of rat activity, such as burrowing, were recorded. Several times daily, readings were made on the condition of the battery using a standard battery tester, and voltage was measured on the electrodes.

Damage was appraised twice in each experimental plot; once, during the first 2 days following installation of the barrier, and again during the nineteenth and twentieth days after installation, 3 days before removal of the fence and harvest. In addition, three paddies (one east, one south, one west) surrounding each experimental plot, but located 20 to 30 m from it, were also assessed for rat damage. Assessments were conducted from the fourth throughout the ninth day after installation of the barrier in these six paddies, several days before harvesting. Damage was assessed using the tiller cutting index (West et al., 1975). Briefly, 97 hills were randomly selected within each paddy, and the total number of tillers, and number of rat damaged tillers, were recorded for each hill. Rat damage was expressed as percentage of damaged tillers per hill. For the two experimental plots, the same hills were assessed during the pre-treatment and post-treatment appraisals.

Analysis of Data

Data on tracking tiles were reported as the percentage of positive tiles. The percentages were assessed using an analysis of variance for a three-factor mixed design (Linton et al., 1975). One factor (between) was treatment having two levels (fenced plot, unfenced plot). The second factor (also between) was location of the tracking tiles with two levels (inside, outside of plots). The third factor (within) was period having three levels (4 to 6, 11 to 13, and 20 to 22 days after installation of the barrier). For analyses, daily percentages of positive tiles were treated as independent scores. Unconfounded means (i.e., means from the same columns or rows) of factors having significant effects were separated using Bonferroni t statistics (Games, 1971).

Histograms indicated that the data on rat damage (expressed as percentages of cut tillers per hill) were skewed. Consequently, nonparametric tests (Linton et al., 1975) were used for statistical analyses with hills as experimental units. Within plots, results from damage surveys after installation of the barrier were compared with results from surveys before harvest using the Friedman test. Data from the fenced and unfenced plots were analyzed separately. Between plots (fenced, unfenced), results of damage surveys were compared using the rank-sums test. Data from the two survey periods (after installation of the barrier and before harvest) were analyzed separately. Finally, data from damage surveys at harvest in the paddies surrounding the plots and from the experimental plot were compared using the Kruskal-Wallis H statistic. Differences between medians were tested for significance following Ryan's specific comparisons procedure. Because the same data were being tested multiple times in these nonparametric tests, $\alpha = 0.01$ rather than $\alpha = 0.05$ was set as the level of statistical significance.

RESULTS

Rat Activity

Overall, significantly ($F(1,8) = 21.3$, $P < 0.01$) more tracking tiles were positive in or near the reference plot ($\bar{x}_s = 35.0$; 3.89) than in or near the fenced plot ($\bar{x}_s = 17.2$; 5.41). Regardless of the locations of tiles, more ($F(2, 16) = 16.1$, $P < 0.01$) were tracked during the last period ($\bar{x}_s = 44.2$; 6.3) than the two earlier periods ($\bar{x}_s$, first period, = 18.3; 5.0; and, $\bar{x}_s$, second period, = 15.8; 3.8) (Table 1). Interaction between locations and periods was also significant ($F(2, 16) = 4.2$, $P < 0.05$). More tiles located inside the fences (data from treated and reference plots combined) were tracked during the third period (days 20 to 22) than either the first (days 4 to 6) or second (days 11 to 13) period.

Table 1. Comparison of rat activity at two experimental rice field plots. An electrical barrier surrounded one treated plot; the reference plot was unfenced. Activity was assessed during three periods. Ten tracking tiles were placed inside and 10 tiles outside but near each plot. Results are presented as mean (of 3 days) percentage of the positive tiles (i.e., contained rat footprints or tail markings).

Period (Days after installation of barrier)	Positive tiles (Mean Percentage + Standard Error)					
	Inside plot			Outside plot		
	Treated	Reference	Both	Treated	Reference	Both
4-6	0.0 ± 0.0	30.0 ± 5.8	15.0 ± 7.2	6.7 ± 3.3	36.7 ± 6.7	21.7 ± 7.5
11-13	3.3 ± 3.3	16.7 ± 3.3	10.0 ± 3.6	3.3 ± 8.8	30.0 ± 5.8	21.7 ± 6.0
20-22	60.0 ± 5.8	46.7 ± 12.0	53.3 ± 6.7	0.0 ± 11.6	50.0 ± 11.6	35.0 ± 9.9

A total of 23 rats, all *R. rattus mindanesis*, were caught during the 3-day trapping period. Twelve were caught within, and nine near, the reference plot. The remaining two rats were caught inside the fenced plot.

During the 18 days of daily observations, 49 animals were found dead, usually near the barrier. Most were toads (29) and frogs (8), but also included were four rats, five caterpillars, a bird, a snake, and a lizard (skink). Nonetheless, a charge of at least 1 kv was maintained continuously on the electrodes, and over 5 kv was measured for 15 of the 18 days. Hydrometer readings indicated the need for a battery recharge three times, or about every 6 to 7 days. Two rat burrows penetrating the dike below the fencing were observed during the first day of operation, and one was reopened the second day. No additional burrows were observed until the last 3 days of operating the barrier. We then saw seven burrows that had penetrated the dike.

Within the fenced plot, the median level of damage was zero during both surveys and damage was not significantly different (Friedman test, $X^2 = 5.45$, $P<0.01$). However, a greater range of damage (0 to 19.3% was found during the survey at harvest than during the earlier survey (0 to 13.3%, Table 2). Damage was significantly greater (Friedman test, $X^2 = 34.9$, $P < 0.01$) within the unfenced plot at harvest (median = 15.8%) than immediately after installation of the barrier (median = 0). After installation of the barrier (rank-sums test, $z = 4.5$, $P < 0.01$) and at harvest (rank-sums test, $z = 8.7$, $P < 0.01$), rat damage was greater in the unfenced than the fenced plot (Table 2). At harvest there were differences (Kruskal-Wallis test, $H = 16.8$, $P < 0.01$) in levels of rat damage between paddies. The fenced plot and two of the paddies had lower levels (median = 0.0%) of damage than the other four paddies surrounding experimental plots (Table 2).

Table 2. Rat damage (expressed as percentage of tillers cut by rats per hill) in two experimental plots and nearby paddies, on a farm near Lumban, Laguna. An electrical barrier surrounded one experimental plot; the other plot was unfenced. Nearby paddies were 20 to 30 m from experimental plots, and unfenced. N = 97 hills per plot. Results are expressed as medians and ranges (in parentheses) because data were skewed.

Plot	Cut Tillers (Percentage per Hill)	
	After Installation of Barrier	At Harvest
Fenced	0.0 (0.0-13.3)	0.0 (0.0- 19.3)
Unfenced	0.0 (0.0-37.5)	15.8 (0.0- 38.9)*
Paddies near fenced plot		
1	—	0.0 (0.0- 60.0)
2	—	6.1 (0.0-100.0)*
3	—	7.7 (0.0- 90.5)*
Paddies near unfenced plot		
1	—	0.0 (0.0- 88.9)
2	—	4.3 (0.0- 91.7)*
3	—	18.2 (0.0- 64.3)*

*Based on nonparametric tests, rat damage at harvest was significantly greater ($P < 0.05$) than damage in the fenced plots.

DISCUSSION

Interpretation of our results is complicated in that measurements, taken shortly after construction of the barrier, indicated a higher level of rat activity in the reference plot than the treated plot. More tracking tiles were positive in or near the reference than the fenced plot (Table 1), and 21

of 23 rats were caught in or near the reference plot. Rat damage was also greater in the unfenced than the fenced plot. Thus, the lower level of damage that occurred in the fenced plot at harvest (Table 2) must be viewed as an interaction of the effectiveness of the barrier and of differences in levels of rat activity that existed between the plots before the barrier was installed. At harvest, five paddies (unfenced plot, four nearby paddies) of eight surveyed had median levels of rat damage ranging from 4.3 to 18.2% (Table 2). Only three (fenced plot, two nearby paddies) still had median levels equalling zero. Of these three, rat damage ranged from only 0.0 to 19.3%within the fenced plot, but as high as 60.0% and 88.9% in the other two plots.

Following rice harvest from the surrounding paddies, rat activity increased dramatically with both the fenced and the unfenced plots (Table 1, days 20 to 22). Increases coincided with an increase in numbers of active burrows that penetrated beneath the fencing. Rats entering through these burrows may have partly accounted for further rat damage within the fenced plot. Such invasions indicate a potential vulnerability in the present design that, if confirmed, will require attention in future designs. Modifications to correct this problem may be difficult. Moving the barrier from the top of the dike into the paddy would (a) reduce available rice-growing area, and, (b) required redesign of the electrical barrier to accommodate paddy water whose depth fluctuates both daily and during the course of the growing season.

Electrically, the barrier performed satisfactorily, maintaining at least 5 kv on the electrodes most of the 18 days. Three observations merit additional comment. First, we had to recharge the battery every 6 to 7 days, whereas Shumake et al. (1977) recharged batteries for their prototype only once monthly or less. Perhaps, varnished wood provides less insulation than the plastic or ceramic insulators used in the prototype or the quality of our batteries was not as good. However, both the present design and the prototype were activated continuously without the need for night crews and the daily battery charges required for lethal electrical barriers (Ramos, 1969; 1970).

Second, the term nonlethal electrical barrier, as used previously (e.g., Shumake et al., 1979), may be somewhat of a misnomer with the present barrier since four rats as well as other wildlife were killed. Although impacts on non-target wildlife were minor, and certainly less than would be expected for a lethal barrier, it would also seem possible to further reduce impact on non-target wildlife by altering the electrical parameters of the present design.

Third, we found it particularly interesting that the netting, an inexpensive plastic vulnerable to gnawing, was not penetrated by rats during the study. Apparently, the electrodes were effective in preventing contact of sufficient duration to allow gnawing and penetration of the netting.

In summary, our results show that a pulsed-charge electrical barrier can be constructed from materials available locally (except the charger) in the Philippines, and such a barrier can be effective in reducing rat damage to crops. Alterations to reduce penetration by rats of dikes beneath the barrier, and further reduce hazards to wildlife, would improve the present design.

NOTE

Reference to trade names does not imply endorsement of commercial products by the Governments of the United States or of the Philippines.

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