Proceedings of the Eighteenth Vertebrate Pest Conference (1998)

Vertebrate Pest Conference Proceedings collection

January 1998

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ABSTRACT: Baker Performance Chemical Incorporated entered into a cooperative agreement with the National Wildlife Research Center to evaluate acrolein as a fumigant for controlling northern pocket gophers (*Thomomys talpoides*). In October 1996, a 44.5 ha (110 acre) irrigated alfalfa hay field was selected as the study site in Franklin County, Washington. Eight treatment units (TUs), six fumigated and two control, were established on the study site. On the six fumigated TUs, 58.9% of the sample plots were inactive, whereas, all sample plots (100%) on the two control TUs were active. The 58.9% mean reduction in pocket gopher activity on the six fumigated TUs was below the minimum efficacy standard of 70% established by the Environmental Protection Agency (EPA 1982). Possible reasons for the pocket gophers surviving the acrolein treatment are discussed.

Proc. 18th Vertebr. Pest Conf. (R.O. Baker & A.C. Crabb, Eds.) Published at Univ. of Calif., Davis. 1998.

INTRODUCTION

In 1995, the Baker Performance Chemical Incorporated (BPCI) entered into a cooperative agreement with the National Wildlife Research Center (NWRC) to evaluate acrolein as a fumigant for controlling pocket gophers. Since the early 1950s, acrolein has been registered with the Environmental Protection Agency (EPA) as an aquatic herbicide. In 1992, O'Connell and Clark demonstrated its effectiveness as a fumigant for controlling California ground squirrels (*Spermophilus beecheyi*). They inserted 20 cc of acrolein into the burrow systems of ground squirrels and sealed the burrows. The ground squirrel population was reduced by more than 90%. Acrolein is now registered under the special local needs (SLN) section of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) as a fumigant in eight western states for controlling ground squirrels. The BPCI wanted to expand the registration of acrolein as a fumigant to include pocket gophers.

To provide the required efficacy data to add pocket gopher claims to the registration label, a study protocol was drafted to outline the procedure for evaluating acrolein for controlling northern pocket gopher (*Thomomys talpoides*) populations in alfalfa. In October 1996, the study was conducted in Franklin County, Washington. The study site was established in an irrigated alfalfa field containing a high population of northern pocket gophers. Pocket gopher activity was monitored before and after the acrolein was applied underground. The null hypotheses tested were: 1) that the efficacy was the same on the fumigated and control areas; and 2) that pocket gopher activity was reduced to <70% on the six fumigated treatment units (TUs).

MATERIALS AND METHODS

Study Site Location

A 44.5 ha irrigated alfalfa field containing northern pocket gophers was selected as the study site. Its location was approximately 16.6 km southwest of Basin City, Franklin County, Washington. The elevation of the area was 198 m above sea level.

Weather

The mean maximum daytime temperature during the 14-day study was 12°C (range 9 to 16°C) and the mean minimum nighttime temperature was 0.8°C (range -1 to 7°C). Between October 16 and 29, 1996, measurable rain occurred on seven days, totaling 2.54 cm of moisture, and a trace occurred on October 23, 1996. On the days of fumigation, October 25 and 26, the highest daily temperature was 12°C and 11.6°C, respectively.

Treatment Unit Establishment

On October 16, 1996, eight treatment units were established within the alfalfa hay field. All TUs were square, measured 0.40 ha and flags defined their boundaries. To reduce pocket gophers residing outside each TU from immigrating onto the TU after fumigation, a 7.6 m buffer zone (BZ) surrounded each TU, and were fumigated as well. Combined, each TU and associated TU and associated BZ measured 0.62 ha. A minimum distance of 50 m separated each TU and its BZ from other TUs and their respective BZs.

Pocket Gopher Activity Measurements (Open-hole Index)

The open-hole index (OH) (Richens 1967; Barnes et al. 1970) was employed to measure the efficacy of the acrolein as a fumigant to control populations of northern pocket gophers. The OH index measures the presence or absence of a pocket gopher within an underground burrow system by relying on the pocket gophers' propensity to close any open burrow within its home range. Normally, in the fall season, only a single pocket gopher would occupy a burrow system. Access to the burrow was created by either opening a closed entrance covered by soil (mound), a feeder plug on the surface, or by probing the ground around a mound or feeder plug with a metal rod until a tunnel system was located and then making an opening. All open holes were marked with a flag. Forty-eight hours later, an examination of the open burrow was made to determine if a pocket gopher closed the burrow with a soil plug. A closed hole (i.e., soil plug) classified the burrow system as active. Conversely, a burrow system remaining open was classified as inactive.

Establishing Sample Plots

On October 17, 1996, all previous pocket gopher signs were erased by leveling the mounds and scraping soil over the feeder plugs on all eight TUs and their associated BZs. On October 18, 1996, the eight TUs were examined and all freshly constructed mounds or feeder plugs observed were flagged. On October 19, 1996, fresh mounds or feeder plugs continued to be flagged, and on each of three TUs (5, 6, and 7) 15 sample plots were established in areas containing fresh mounds or feeder plugs. Each of these sample plots was circular with a 5.21 m radius and measured 0.008 ha (1/50th acre). The center of each sample plot was marked with a numbered wire-stem flag and the boundaries of each sample plot were defined. No overlapping of the boundaries occurred among the sample plots. Then, on October 20, 1996, sample plots were established on TUs 2, 3, 4, and 8. On October 21, 1996 all new active mounds or feeder plugs on the seven TUs were flagged, including those in the BZ. Then, on October 22, 1996, the 15 sample plots were established on TU 1 and all fresh mounds or feeder plugs were flagged on the 120 sample plots on the eight TUs.

Pretreatment Open-hole Index

The next step in the OH index involved opening all flagged active burrow systems on the 120 sample plots. On October 23, 1996, all burrow systems associated with the fresh mounds or feeder plugs were opened on each sample plot. Pocket gopher closure of the open burrow systems on the eight TUs was recorded on October 25 (48h). Upon completion of the pretreatment OH index, fumigation began.

Fumigation of Burrows

The treatments (six fumigation, two control) were randomly assigned to the eight TUs. Then, a second random selection occurred that placed one control and three treated TUs in Block I and the remainder in Block II, as follows:

Block I	Block II
TU 5 control	TU 3 control
TU 1 treated	TU 4 treated
TU 2 treated	TU 7 treated
TU 6 treated	TU 8 treated

On October 25, 1996, before fumigation, the metering device on the acrolein applicator was calibrated to insert 20 cc of fumigant into each active burrow system. Blocks I and II were fumigated on October 25 and 26, 1996, respectively. On the acrolein treated TUs, each active burrow system was opened on: 1) the sample plots; 2) each active burrow system outside the sample plots but inside the TU; and 3) all active burrow systems within the BZ associated with each TU. After all active burrow systems were opened on a TU, fumigation occurred. If a burrow entrance opened up into a "T," then both sides of the "T" were treated with acrolein. After treatment with acrolein, burrow entrances were sealed with soil, and a flag was placed at the site. After fumigation, these flags were collected and counted to determine the number of application sites. In those burrow systems where the soil could come in contact with the acrolein, paper was placed at the opening of the burrow system before sealing with the soil. On the control TUs, the active burrow systems were opened as described for the fumigated TUs, but no acrolein was applied. Instead, all open systems were then closed with soil and flagged.

Post-treatment Open-hole Index

On October 26 and 27, 1996, the treated burrow systems on the 60 sample plots were reopened on each of Blocks I and II, respectively. Any fresh mounds constructed post-fumigation on the sample plots were also opened. On October 28 and 29, 1996, the number of opened burrow systems closed by pocket gophers was recorded for Blocks I and II, respectively.

Statistics

Pre- and post-fumigation, no variability occurred on the two control TUs as 100% of the sample plots were active. Only treated TUs displayed variability. The data from the six fumigated TUs for the open-hole index were combined to produce an overall mean estimate and 95% confidence limits for the reduction in pocket gopher activity.

RESULTS

Pretreatment Open-hole Index

Block I. Pocket gophers were active on all (100%) of the 60 sample plots. Overall, 367 holes were opened on 60 sample plots on four TUs. On the three TUs scheduled to be fumigated, pocket gophers closed 239 (92.3%) of 259 holes opened on 45 sample plots. Pocket gophers closed 101 (93.5%) of 108 holes that were opened on the 15 sample plots on the control TU. Pocket gophers closed 100% of the open holes on 32 (71.1%) of the 45 sample plots on three TUs scheduled to be fumigated, and on 11 (73.3%) of the 15 sample plots on the control TU.

Block II. Pocket gophers were active on all (100%) of the 60 sample plots. Overall, 372 holes were opened on 60 sample plots on four TUs. On the three TUs scheduled to be fumigated, pocket gophers closed 268 (94.7%) of 283 holes opened on 45 sample plots. Pocket gophers closed 78 (87.6%) of 89 holes that were opened on the 15 sample plots on the control TU. Pocket gophers closed 100% of the open holes on 39 (86.7%) of the 45 sample plots on three TUs scheduled to be fumigated and 7 (46.7%) of the 15 sample plots on the control TU.

Fumigation

A composite of all fumigated holes for Blocks I and II is summarized in Tables 1 and 2, respectively.

Postreatment Open-hole Index

Block I. Pocket gopher activity declined on the three TUs that were fumigated with the acrolein as 27 (60.0%) of the 45 sample plots were inactive, however, pocket gophers remained active on 15 of the 15 (100%) sample plots on the control TU. On the control TU, pocket gophers closed 88 (94.6%) of the 93 holes opened on the

Table 1. A composite of all fumigated holes for Block I.

TU Number and Treatment	Fumigated Holes			
	Sample Plots	Outside Sample Plots, but Inside the TU	Buffer Zone	Total
5 - control	101	47	45	193
1 - fumigated	73	9	23	105
2 - fumigated	95	29	62	186
6 - fumigated	70	29	32	131
Total	339	114	162	615
x̄	84.8	28.5	40.5	153.8
SD	15.5	15.5	16.9	42.7

Table 2. A composite of all fumigated holes for Block II.

TU Number and Treatment	Fumigated Holes			
	Sample Plots	Outside Sample Plots, but Inside the TU	Buffer Zone	Total
3 - control	84	18	38	140
4 - fumigated	128	40	64	232
7 - fumigated	62	18	52	132
8 - fumigated	77	29	29	135
Total	351	105	183	639
x̄	87.8	26.2	45.8	159.8
SD	28.4	10.5	15.4	48.3

15 sample plots. On the three fumigated TUs, pocket gophers closed 34 (14.2%) of 240 opened holes on the 45 sample plots. Also, declining on the fumigated TUs, was the number of sample plots where pocket gophers closed 100% of the opened holes. On the three fumigated TUs, 100% closure occurred on only 3 (6.7%) of the 45 sample plots. Whereas, on the control TU, pocket gophers closed 100% of the opened holes on 11 (73.3%) of the 15 sample plots.

Block II. Pocket gopher activity declined on the three TUs that were fumigated with acrolein as 26 (57.8%) of the 45 sample plots were inactive. However, pocket gophers remained active at 15 of the 15 (100%) sample plots on the control TU. On the control TU, pocket gophers closed 78 (95.1%) of the 82 holes opened on the 15 sample plots. On the three fumigated TUs, pocket gophers closed 38 (14.3%) of 265 opened holes on the 45 sample plots. Also, declining on the fumigated TUs, was the number of sample plots where pocket gophers closed 100% of the opened holes. On the three fumigated TUs, none (0.0%) of the 45 sample plots had 100% closure. Whereas, on the control TU, pocket gophers closed 100% of the opened holes on 12 (80.0%) of the 15 sample plots.

Statistics

The number of active sample plots compiled for both pre- and post-treatment are listed in Table 3.

Table 3. The number of active sample plots compiled for both pre- and post-treatment.

Fumigated Sample Plots			Control Sample Plots		
Plot Number	Pre-treatment	Post-treatment	Plot Number	Pre-treatment	Post-treatment
TU 1	15/15	6/15	TU 3	15/15	15/15
TU 2	15/15	4/15	TU 5	15/15	15/15
TU 4	15/15	10/15			
TU 6	15/15	8/15			
TU 7	15/15	4/15			
TU 8	15/15	5/15			
Total	90/90	37/90		30/30	30/30
Active	100%	41.1%		100%	100%
Inactive	0%	58.9%		0%	0%

The 95% confidence limits were calculated for the 58.9% reduction as follows: i.e., the 95% upper and lower confidence limits were 69.1% and 48.7%, respectively.

DISCUSSION

The first null hypothesis test was rejected because a difference occurred in pocket gopher activity post-treatment between the fumigated and control TUs. However, the second null hypothesis was not rejected as the mean reduction in pocket gopher activity was <70%. The 58.9% mean reduction with 95% confidence limits of 48.7% to 69.1% approached, but did not encompass the 70% minimum standard for reduction in pocket gopher activity that was established by the EPA for verifying efficacy of fumigants (EPA 1982).

The 58.9% reduction in activity observed in this study is the highest percent reduction reported for pocket gopher control with a passive fumigant. Passive refers to the fact that the gas diffuses on its own throughout the burrow system. The previously registered Animal and Plant Health Inspection Service (APHIS) 85 g 8-ingredient gas cartridge (EPA Reg. No. 56228-2) for controlling burrowing rodents has never exceeded a 30% reduction in northern pocket gopher activity. Two field studies have been reported for this gas cartridge—in Montana, Sullins and Sullivan (1993) reported only an 8% reduction in pocket gopher activity after they fumigated a minimum of 20 pocket gopher burrow systems with one gas cartridge each. In an Idaho study, Rost (1978) reported reductions on three TUs of 15%, 22%, and 30% with a mean reduction in pocket gopher activity of 22%. On each of these TUs, 20 pocket gopher burrow systems were fumigated with two gas cartridges each, one on each side of the point of entry.

The APHIS/WS recently registered a 145 g, two-active ingredient (sodium nitrate and charcoal) gas cartridge (EPA Reg. No. 56228-2). As partial fulfillment of the registration requirements, this cartridge was tested on northern pocket gophers. On three fumigated areas, pocket gopher activity declined 7.1%, 13.3%, and 30.8% for an average decline of 17.1% (Matschke et al. 1995). Because this gas cartridge failed to achieve 70% or greater control, pocket gophers were removed from the label.

Three other fumigants, methyl bromide, chloropicrin, and nitrocellulose film bombs were evaluated for controlling Valley pocket gophers (*Thomomys bottae*). Pocket gopher activity declined about 50% for each of these compounds (Miller 1954). Two other compounds that Miller tested were even less effective, Hydrocyanic acid gas (HCN) and carbon bisulfide (CS).

Efficacy (mortality) appears to increase when fumigants are forced into the pocket gopher burrow systems by external pressure; however, data to support this observation are limited. When auto engine exhaust was pumped into the burrow systems of plains pocket gophers (*Geomys bursarius*), mortality was observed in 11 (85%) of 13 animals that were radio-tagged (Matschke unpublished data). Plesse (1984) reported that exhaust from a rototiller gasoline engine along with the gas generated by the 8-ingredient gas cartridges (EPA Reg. No. 56228-2) proved lethal to valley pocket gophers, but no mortality data were presented. Blonk (1951) reported that calcium cyanide powder was more effective in killing pocket gophers when blown into a tunnel system with compressed air than when applied with a hand pump. He estimated that compressed air carrying the calcium cyanide powder traveled 45.7 m (150 ft) in the tunnel system in 1.5 minutes. The degree of control was not specified, but this method was promoted to replace trapping to control pocket gophers along canal banks in (Blonk 1951).

Factors which contribute to a 40% pocket gopher survival rate after acrolein treatment are unknown. Miller (1957) discussed several factors that might contribute to pocket gopher survival following such treatment with fumigants; the first was the extreme length of the burrow system with its network of side tunnels that the toxic gas must fill. Second, the tunnel is a closed system and contains dead air; and third, the toxic gas may be lost through absorption by the moist or porous soil lining the tunnel.

Regarding the first factor, not enough is known about the variability in the length of the burrow systems of northern pocket gophers. This raises the question of whether or not the pocket gophers that died inhabited only short burrow systems. The second factor may also have been a major reason for pocket gopher survival. The dead air in a closed burrow system delays the diffusion of the toxic gas, making it difficult to move through the tunnel system, even under pressure. If some distance exists between the point of entry of the acrolein and the pocket gopher, the animal may react by plugging off the burrow system before the fumigant reaches a lethal concentration. Regarding the third factor, a 58.9% reduction in pocket gopher activity in this study was recorded when a sandy soil covered the study site. Had this been a loam or clay soil, a greater reduction in pocket gopher activity may have occurred.

Reinvasion and dosage rate are two factors that could have influenced the results. But in this study, reinvasion was probably not a factor. Information from two previous studies where pocket gophers were kill-trapped support this concept (Matschke et al. 1996; Matschke et al. 1997). Pocket gophers were trapped for five consecutive days on 0.47 ha TUs, with a 7.6 m buffer zone surrounding each TU. No trapping occurred in the buffer zone. The data show trapping success declined over time. Among the total of 47 animals trapped on both studies, the number of animals trapped on days 1 to 5 was 18 (38.8%), 16 (34.0%), 10 (21.3%), 2 (4.2%), and 1 (2.1%), respectively. If reinvasion were a major factor, trapping success would not have declined from 38.8% to 2.1% during the five days. Also observed on both studies was the sharp decline of fresh mounds on the two TUs, and they were abundant in the non-trapped BZs. In addition, the BZ in the present study was fumigated and the length of time from fumigation to completion of the open-hole index was four days.

Based on limited data available from this study, the 20 cc acrolein dosage may be inadequate. The data from seven sample plots containing one hole each, representing just one burrow system for each sample plot, showed that only three (43%) out of seven sample plots were inactive after fumigation (Figure 1). When the dosage was increased to 40 cc (two treated holes per sample plot), seven (100%) out of seven of the sample plots were inactive, but these sample plots could have contained only a single burrow system each receiving 40 cc of acrolein. The data suggest that as the number of fumigated holes increases per sample plot, no corresponding increase in efficacy was observed (Figure 1).

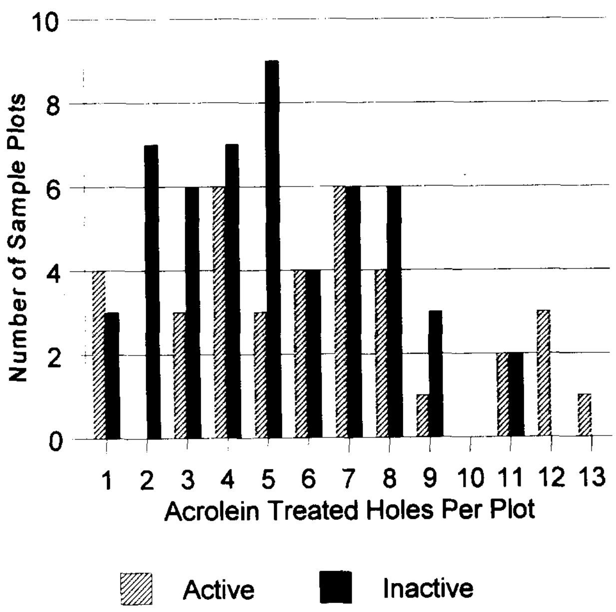

Figure 1. The relationship between the number of active and inactive sample plots and the number of treated holes per sample plot.

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