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Tools and Technology

Is Pressurized Exhaust an Effective Tool against Burrowing Rodents?

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ABSTRACT Burrow fumigants are lethal tools for mitigating rodent damage, but until recently, only gas cartridges and aluminum phosphide were registered for use in California, USA. In 2012, pressurized exhaust machines that emit carbon monoxide were legalized for use, although their efficacy was unknown. From 2014 through 2015, we assessed the efficacy of the Pressurized Exhaust Rodent Controller (PERC) for managing California ground squirrels (*Otospermophilus* spp.) and pocket gophers (*Thomomys bottae*) across various localities in California. The PERC machine proved effective for California ground squirrels (efficacy = 83%), although results were variable across the 2 study areas (efficacy = 66–100%), potentially due to differences in soil moisture or injection time across study sites. The PERC machine was moderately effective at controlling pocket gophers (efficacy = 68%), but performed better than in previous studies. Pressurized exhaust machines show promise as a tool for managing burrowing rodents.

KEY WORDS burrow fumigant, California, efficacy, ground squirrel, integrated pest management, *Otospermophilus* spp, pocket gopher, pressurized exhaust, *Thomomys* spp.

Burrow fumigants are one of the more effective tools for managing burrowing rodents (Salmon et al. 1982, Baker 2004, Baldwin and Holtz 2010, Baldwin et al. 2014). Burrow fumigants are gases introduced into burrow systems with the intent of lethal control of the target species. Although burrow fumigants can be more time-consuming to implement, and thus more costly than some alternative management strategies (Marsh 1992, 1994), this increased cost is often offset by a number of benefits including 1) direct targeting of rodents within the burrow system, 2) no reliance on bait acceptance that sometimes hinders rodenticide and trapping efforts, 3) no secondary toxicity concerns for scavengers and predators, 4) minimal handling of animals after treatment, reducing the risk of disease and parasite transmittance to humans, and 5) being highly efficacious. As such, burrow fumigants are often included as part of an integrated pest management (IPM) program for burrowing rodents (Baldwin et al. 2016).

Until recently, only 2 burrow fumigants were registered for use: gas cartridges and aluminum phosphide. Gas cartridges are pyrotechnic devices that, when lit, create carbon monoxide that asphyxiates the animal within the burrow system (Savarie et al. 1980). Aluminum phosphide is available in pellet or tablet formulations, which releases phosphine gas toxic to vertebrates when introduced into moist environments (Salmon et al. 1982, Baker 1992). Both fumigants have positive and negative attributes. Gas cartridges are less effective, particularly for pocket gophers (Geomyidae), but their use is less restrictive. Aluminum phosphide tends to be more efficacious and cost-effective, but also is far more restrictive on where it can be legally used (Salmon et al. 1982, Baldwin 2012). As such, there is an opportunity for the development of another burrow fumigant that could circumvent some of these shortcomings.

In 2011, California Assembly Bill 634 was passed that legalized the use of pressurized exhaust for managing burrowing rodent pests. One commercial machine that has been available for use since that time is the Pressurized Exhaust Rodent Controller (PERC; H & M Gopher Control, Tulelake, CA, USA). The PERC machine consists of a small gasoline-powered engine that creates exhaust that is pumped through coils to cool the emissions and stores the exhaust in a large tank. The pressurized exhaust contains 25,000 ppm of carbon monoxide, which is injected into a burrow system via a hose and probe (HMGC 2016). The PERC machine comes in various sizes ranging from 2 to 6 probes/unit, allowing for the treatment of multiple burrow systems at once.

Since the passing of California Assembly Bill 634, the use of pressurized exhaust machines has increased throughout California, USA, and in other parts of western North America (A. Hurlburt, H&M Gopher Control, personal communication), but relatively few data exist on

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their efficacy. Initial limited testing of the PERC machine suggested relatively good efficacy ($\bar{x}$ efficacy = 76%) for Belding's ground squirrel (*Urocitellus beldingi*), but only marginal efficacy ($\bar{x}$ efficacy = 56%) for pocket gophers (*Thomomys* spp.; Orloff 2012). Further testing for pocket gophers in northern California corroborated previous estimates ($\bar{x}$ efficacy = 56%; Baldwin et al. 2016), but no data have been collected for California ground squirrels (*Otospermophilus* spp.). Furthermore, although results for pocket gophers were consistent between Orloff (2012) and Baldwin et al. (2016), both studies were conducted in the same geographic area, and subsequently, the same soil types. This is of potential relevance given that burrow fumigants are substantially influenced by soil morphology and soil moisture (Miller 1957, Salmon et al. 1982, Proulx et al. 2011); the more porous the soil, the less effective it is at holding the fumigant within the burrow at a concentration sufficient to euthanize the target species. That said, pressurized exhaust machines inject carbon monoxide into burrow systems rapidly and in high concentrations. This may overcome some fumigant loss through cracks and pores in dry or more porous soils and make these devices more appropriate to use in these less ideal substrates. As such, we established several study locations to further test the use of pressurized exhaust machines in different soil types and moisture levels to provide additional data on the utility of these machines for managing burrowing rodents.

STUDY AREA

For this study, we relied upon donated PERC machines and labor to conduct field trials for both California ground squirrels and pocket gophers. As such, machines, applications strategies, and soil conditions were not always consistent throughout all study sites. However, this provided us with an opportunity to test the PERC machine across a variety of soil conditions and locations; thereby, allowing insight into how the PERC machine would work across a broad range of environmental conditions.

For California ground squirrels, we tested the PERC machine across 2 different study areas. Our first site was a pasture setting just outside of Livermore, California, during May 2014 (37°39′N, 121°45′W). The soil was Positas gravelly loam and classified very dry given a hard, dusty surface, with occasional cracks in the soil apparent throughout the study site. We also tested the efficacy of the PERC machine for California ground squirrels in moist soil conditions in an almond (*Prunus dulcis*) orchard approximately 8 km north of Escalon, California, during March 2015 (37°51′N, 121°03′W). Soil type was Madera sandy loam.

We tested the PERC machine against pocket gophers (*Thomomys bottae*) in 2 separate alfalfa (*Medicago sativa*) fields (41°37′N, 122°23′W) approximately 24 km southeast of Yreka, California, in March 2014. Soil type was defined as Louie loam, which is a fine, loamy mineral soil conducive to burrow fumigation.

METHODS

California Ground Squirrels

During 2014 in the Livermore area, we established 3, square in shape, 1.55-ha study plots (2 treatment and 1 control) that were randomly applied. Each plot contained a core area of 0.4 ha and a buffer zone that extended 61.25 m on all sides. The edges of all buffer zones were 50–100 m apart. This ensured independence of each sampled plot given minimal daily movements of California ground squirrels (mean radius of home range = 13.3 m; Boellstorff and Owings 1995) combined with the short duration of these sampling periods. Soils at the Livermore sites were verified as dry down to the burrow depth given that soil would not form a ball when squeezed together in the palm of a hand (Baker 2004).

We also established 2 study plots during 2015 in the Escalon area that were 0.4 ha in size. No buffer zone was included given few ground squirrels in outlying areas combined with time and resource constraints. Without a buffer, it was possible that ground squirrels could move into the vacated treatment area before posttreatment counts were concluded, but any such movements would only bias efficacy estimates low (i.e., true efficacy would be equivalent or greater than reported). No control was present in this study area given a relative lack of ground squirrels at other locations within the orchard. Study plots were separated by >200 m ensuring independence of sampled sites. Soils at the Escalon site were identified as moist given that they readily formed a ball in the hand when squeezed (Baker 2004).

Following Fagerstone (1984), we counted the number of ground squirrels observed through binoculars in each core area on 5 separate occasions at 5-min intervals. The same surveyor was used throughout the study; location of surveyor for these counts occurred at a fixed location outside the treatment plots where ground squirrels could not detect our presence. Ground squirrel counts occurred between 0700 and 1200 and again from 1445 to 1730 for 3 consecutive days to coincide with periods of relatively high activity for ground squirrels (Fitch 1948). This yielded 30 counts/core area. We used the maximum count for each sampling period to serve as a minimum number known estimate of ground squirrels present in each core area.

Following the completion of the ground squirrel counts, we went through the entire core and buffer areas of each treatment site and plugged all burrow systems with soil. We came back 2 days later to count the number of burrows reopened within the core area. This provided a corroborative estimate of ground squirrel activity pretreatment.

We initiated treatment applications following reopened ground squirrel burrow counts using the PERC 412 machine, which allowed for exhaust applications in up to 4 burrow openings at once. We treated all active burrows by inserting an exhaust probe 0.3 m into the burrow. We then plugged the opening around the probe with loose soil to seal the burrow. We pumped exhaust into the burrow system for 3 min and 6 min at the Livermore and Escalon sites, respectively (3-min minimum duration recommended by manufacturer; A. Hurlburt, personal communication). The longer injection time was driven by the increased size of burrow systems at the almond orchard sites. We believed additional injection time was needed to completely fill these burrow systems and adjusted our applications accordingly. Upon removal of the probe, we sealed the opening with additional sod or soil. While pumping exhaust into a burrow system, we observed other burrow openings in the immediate vicinity for air movement to determine whether they were connected to the burrow system that was being treated. If so, those openings were sealed as well. If not, those burrow systems were subsequently treated.

Two days after the completion of exhaust applications, we again initiated ground squirrel counts following the same procedure as that outlined for pretreatment counts. The day after completion of ground squirrel counts, we filled in all open burrow systems and subsequently counted reopened burrows 2 days later to again provide a corroborative measure of efficacy. We determined efficacy for both reopened burrow and ground squirrel counts using

$$\text{Efficacy}(\%) = [(\text{pretreatment} - \text{posttreatment}) / \text{ pretreatment}] \times 100$$

where pretreatment and posttreatment equal the number of reopened burrows or number of observed ground squirrels before and after treatment.

Pocket Gophers

We used the open-hole method to monitor the efficacy of PERC applications on pocket gophers, with a paired treatment plot and control plot (square in shape and each ~4 ha in size) in each field ($n = 2$; Engeman et al. 1993, 1999). Within both treatment and control plots, we established 20 9.2×9.2-m monitoring units that were focused on areas with fresh pocket gopher mounding activity. Each monitoring unit was $\geq$18.3 m (based on mean diam of male home range; Howard and Childs 1959) from adjacent monitoring units. All treatment and control plots were separated by $\geq$30 m to maintain independence. Also, no monitoring units were placed within 9.2 m of the border of the treatment plots to reduce the likelihood that individuals would reinvade treatment plots from outlying areas posttreatment. Within each monitoring unit, we opened 2 holes into pocket gopher burrow systems. Pocket gophers do not tolerate openings into their burrow systems; they plug holes with soil when encountered, thereby rendering this approach very sensitive to pocket gopher presence (Engeman et al. 1993, 1999). We checked breached burrows 2 days after opening holes to determine if they were plugged by pocket gophers. If either of the holes were plugged, we considered the monitoring unit occupied. This approach allowed us to determine efficacy by comparing the number of monitoring units occupied before and after treatment.

For application, we used the PERC 412 machine to inject exhaust into pocket gopher burrow systems for approximately 3 min (A. Hurlburt, personal communication). We then levelled all mounds within treatment areas to allow for rapid identification of new activity. One to 2 days posttreatment, we initiated another assessment of pocket gopher activity using the open-hole method. This second assessment allowed us to determine efficacy for the first treatment. We then conducted a second round of PERC treatments 3 days after completion of the second open-hole assessment given that approximately 20–30% of individuals are missed during each treatment session due to variable mounding activity (Richens 1965, Baldwin et al. 2016). The final assessment of pocket gopher activity was initiated the day following completion of the second PERC treatment. This quick turn-around time for assessing posttreatment activity greatly reduced the possibility of reinvasion by pocket gophers from adjacent burrow systems. No activities occurred in the control plots other than the use of the open-hole method for monitoring pocket gopher occupancy. Soil conditions were deemed relatively moist at all pocket gopher study sites.

Analysis

Generally for a rodenticide to be considered efficacious, it must obtain a field efficacy value of $\geq$70%, although lower efficacy levels are sometimes considered useful (Schneider 1982). We used this baseline as a relative indicator of usefulness for the PERC machine. Given the exploratory nature of this study, we have only provided descriptive statistics of our results. All aspects of this project were approved by the University of California, Davis' Institutional Animal Care and Use Committee (protocols 16864, 16915, 18626).

RESULTS

At the Livermore site, we observed a reduction in California ground squirrel counts (plot 1 = 24 pretreatment to 11 posttreatment, 54%; plot 2 = 13 to 3, 77%) and active burrow counts (plot 1 = 27 to 14, 48%; plot 2 = 19 to 0, 100%) following treatment. We did not observe any difference in California ground squirrel counts within the control plot ($n = 14$ before and after treatment period), indicating that the observed reduction in ground squirrels was due to the applied treatment. For the Escalon site, we observed a more substantial reduction in California ground squirrel (plot 1 = 6 to 0, 100%; plot 2 = 5 to 0, 100%) and active burrow counts (plot 1 = 45 to 0, 100%; plot 2 = 58 to 2, 97%) following PERC applications. Observed efficacy was relatively comparable to the targeted 70% threshold for the Livermore site, and far exceeded this value at the Escalon site, indicating that these applications were useful at reducing California ground squirrel numbers.

For pocket gophers, efficacy of initial PERC treatments ranged from 40% to 55% (plot 1 occupancy = 20 pretreatment to 9 posttreatment; plot 2 occupancy = 20 to 12). Efficacy increased to 65–70% (plot 1 occupancy = 20 to 6; plot 2 occupancy = 20 to 7) after a second treatment. Control plots showed almost no reduction in occupancy across treatment periods (first treatment 0–5%, second treatment = 0%) indicating that observed reductions were due to treatments.

DISCUSSION

The development and registration of the PERC machine appears to provide a much needed tool for ground squirrel

IPM programs (California ground squirrel efficacy range $= 54–100\%$ [$\bar{x} = 83\%$], Belding's ground squirrel $\bar{x} = 76\%$; Orloff 2012) with efficacy values intermediate to what has been reported for aluminum phosphide (California ground squirrel $\bar{x} = 99–100\%$, Belding's ground squirrel $\bar{x} = 94\%$; Salmon et al. 1982, Baldwin and Holtz 2010, Baldwin and Quinn 2012) and gas cartridges (California ground squirrel $\bar{x} = 50–74\%$, Belding's ground squirrel $\bar{x} = 100\%$; Salmon et al. 1982, Baldwin and Holtz 2010, Baldwin and Quinn 2012). Still, we observed substantial variability between study areas in this investigation. Soil moisture may be a factor influencing this variability given that dry soil conditions are far less conducive to effective use of burrow fumigants through increased soil porosity (Salmon et al. 1982). Although we could not control for soil moisture content, we observed substantially greater efficacy at sites with higher soil moisture than at dry sites (100% *vs.* 54–77%, respectively). Even with lower efficacy in dry soil conditions, the PERC machine may be more efficacious than aluminum phosphide for ground squirrel control in dry conditions (e.g., 47% in dry soils for Richardson's ground squirrels [*Urocitellus richardsonii*]; Proulx et al. 2011). These differences are not surprising given the very slow evolution of phosphine from aluminum phosphide tablets in dry soil conditions and suggest that repeated applications via the PERC machine may have some utility even in dry soils (Salmon et al. 1982, Baker 1992). Such an option would be particularly useful where other management options are either ineffective or unavailable (e.g., nut orchards where available nuts substantially reduce effectiveness of baiting and trapping programs; Salmon et al. 1982, Baldwin et al. 2014). As previously noted, we used longer injection times at the site with moist soil given the presence of larger burrow systems. Longer injection times likely increased concentrations of carbon monoxide, thereby influencing efficacy values. At this point, effects of soil moisture, soil type, and injection duration on efficacy are unclear and worthy of further investigation.

The PERC machine has not been as effective for pocket gophers as it has been for ground squirrels, but it still provided a substantial reduction in pocket gopher occupancy following treatment (efficacy = 65–70%). Furthermore, our observed efficacy was greater than values reported previously ($\bar{x} = 56\%$; Orloff 2012, Baldwin et al. 2016), perhaps because of differences in soil type. Regardless, the moderate to high levels of efficacy observed for the PERC machine are of particular note for managing burrowing rodents given current restrictions on the use of some alternative management tools in many settings. For example, some counties, municipalities, and school districts (e.g., East Bay Regional Park District [EBRPD], CA, USA; C. Brierly, EBRPD, personal communication) do not allow the use of certain rodenticides, aluminum phosphide, and traps given perceived human safety risks or risks to the environment. These same groups will allow the use of pressurized exhaust machines. In these situations, pressurized exhaust machines often provide the only practical and effective management option. Other advantages of the PERC machine include the ability to treat multiple burrow systems at once (Baldwin et al. 2016, Baldwin and Meinerz 2016), and potential to include the PERC machine in year-round IPM programs given reported efficacy in dry soil conditions. Ultimately, the best tool to use for managing burrowing rodents will vary depending on a number of factors; but at a minimum, the PERC machine appears to be an effective tool to include in the IPM toolbox for reducing burrowing rodent damage in a number of situations.

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