Fumigation of Burrowing Rodents with Carbon Monoxide: A Comparison to Alternative Management Options

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ABSTRACT: Pocket gophers and ground squirrels cause extensive damage to many crops. Pressurized exhaust injection devices are increasingly used for managing these rodents, although no data was available to support their use. Therefore, we established a study to: 1) determine the efficacy of pressurized exhaust machines for pocket gopher and ground squirrel management; 2) compare these results to other burrow fumigant options; and 3) compare their cost effectiveness. Specifically, we tested two different pressurized exhaust machines for both ground squirrels and pocket gophers: the Pressurized Exhaust Rodent Controller (PERC), and the Cheetah rodent control machine. For California ground squirrels, efficacy for the PERC machine was greater in moist soils ($\bar{x}$ = 100%) than in drier soils ($\bar{x}$ = 66%). Initial treatments using the PERC machine were more expensive than other burrow fumigation options, given the large cost of the machine. However, costs quickly dropped below that of gas cartridges (~44 days), and eventually dropped below that of aluminum phosphide if used extensively (~830 days). Efficacy for the Cheetah rodent control machine was far less encouraging for California ground squirrels, with results showing increased squirrel numbers at treatment sites ($\bar{x}$ = -15%) post-treatment. For pocket gophers, aluminum phosphide ($\bar{x}$ = 86%) and trapping ($\bar{x}$ = 81%) proved to be more effective than PERC applications ($\bar{x}$ = 56%) in heavy organic soils. We observed somewhat greater PERC efficacy in mineral soils ($\bar{x}$ = 68%), suggesting potential variability in efficacy across soil types. At this point, the use of the PERC machine appears to be a viable option for inclusion into Integrated Pest Management programs for burrowing rodents where alternative options are limited; the Cheetah rodent control machine showed no utility for ground squirrel management in our study. More extensive testing of pressurized exhaust devices in differing soil types and under variable moisture levels is needed to determine their utility across a broader spectrum of treatment situations.

KEY WORDS: Belding ground squirrel, burrow fumigant, carbon monoxide, Cheetah rodent control machine, California ground squirrel, *Otospermophilus* spp., pocket gopher, Pressurized Exhaust Rodent Controller, *Thomomys* spp., *Urocitellus beldingi*

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INTRODUCTION

Rodents such as pocket gophers (Geomyidae) and ground squirrels (Sciuridae) can cause extensive damage to a variety of crops throughout North America (Howard and Chiles 1959, Sauer 1984, Whisson et al. 2000, Baldwin et al. 2014). While a variety of methods have been used to help manage these rodent populations [e.g., trapping, rodenticides, flood irrigation (Marsh 1992, 1994)], burrow fumigations have been shown to be one of the more effective tools for managing burrowing rodents (Salmon et al. 1982, Hygnstrom and VerCaurten 2000, Baker 2004, Baldwin and Holtz 2010, Baldwin et al. 2014). Burrow fumigants are gases that are introduced into burrow systems with the intent of lethal control of the target species. Despite being more time-consuming to implement therefore more costly than some of the aforementioned management strategies (Salmon and Schmidt 1984, Marsh 1992, 1994), the increased cost is often offset by a number of benefits which include: 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) they seldom require handling of animals after treatment, which reduces the risk of disease and parasite transmittance to humans; and 5) they can be highly efficacious. As a result of these benefits, burrow fumigants are often included as part of an integrated pest management (IPM) program for burrowing rodents (Marovich et al. 2002, Baldwin et al. 2016)

Until recently, only 2 burrow fumigants were registered for use in California: gas cartridges and aluminum phosphide. Gas cartridges are pyrotechnic devices that have been around since the 1940s (Savarie et al. 1980). Gas cartridges, while burning, create carbon monoxide, which asphyxiates the animal within the burrow system. Aluminum phosphide is available in pellet or tablet formulations, which when introduced into moist environments release phosphine gas that is toxic to vertebrates and invertebrates alike (Salmon et al. 1982, Baker 1992). There are both positive and negative attributes to each of the fumigants. Gas cartridges are less effective, particularly for pocket gophers, but their use is far less restricted. Aluminum phosphide tends to be more efficacious and

cost effective but has far more restrictions governing where it can be legally used (Salmon et al. 1982, Baldwin 2012). The opportunity exists for the development of another burrow fumigant to minimize or alleviate some of these limitations.

California Assembly Bill 634, which was passed in 2011, legalized the use of pressurized exhaust for managing burrowing rodent pests. There are a several commercial machines available for use, including the Pressurized Exhaust Rodent Controller (PERC; H & M Gopher Control, Tulelake, CA) and the Cheetah rodent control machine (Cheetah Industries, Paso Robles, CA). The PERC machine consists of a small 4-cycle gasoline-powered engine that creates exhaust that is pumped through coils to cool the emissions, and it stores the exhaust in a large tank. The pressurized exhaust contains 25,000 ppm of carbon monoxide (HMGC 2016), which is injected into a burrow system via a hose and probe. The PERC machine comes in various engine + tank sizes, fitted with 2-6 probes per unit, thereby allowing for treatment of multiple burrow systems at once. The Cheetah rodent control machine is a modified leaf blower that is comprised of a 2-cycle gasoline engine, producing over 25,000 ppm of carbon monoxide (CRCM 2016), and a single exhaust tube that extends from the engine, allowing application of exhaust into a burrow system.

Since the passing of California Assembly Bill 634, the use of pressurized exhaust machines has increased throughout the state of California as well as other parts of North America. Initially, data were lacking on both the efficacy and cost effectiveness of these machines. Therefore, we initiated a series of studies to look at their efficacy and potential utility for control for both ground squirrels and pocket gophers. A brief summary of our findings is highlighted below. See Orloff (2012), Baldwin and Meinerz (2016), and Baldwin et al. (2016, 2017a) for a complete review of these projects.

GROUND SQUIRRELS

PERC Efficacy and Cost Effectiveness for California Ground Squirrels

Initial testing of the PERC machine showed good efficacy (efficacy = 76%) for Belding's ground squirrels (*Urocitellus beldingi*; Orloff 2012), but no studies had been conducted on the efficacy of the PERC machine with California ground squirrels (*Otospermophilus* spp.). Our study was not only the first attempt to test the PERC machine on a different ground squirrel species, but also to test it with multiple soil types and moisture levels. Two study sites were chosen: the first site was located outside of Livermore, CA and contained Positas gravelly loam soil, which was hard, dry, and full of cracks. The second site was located in Escalon, CA, where soils were classified as Madera sandy loam and contained substantially higher moisture content than the Livermore sites.

Efficacy results differed between the two study sites/ soil types. Although efficacy at the drier Livermore site fell below the desired 70% threshold, the observed levels were close ($\bar{x}$ = 66%). We observed a more substantial reduction in ground squirrel activity at the Escalon site following treatment ($\bar{x}$ = 100%). Soil moisture was a likely factor, given the known relationship between soil moisture and efficacy associated with burrow fumigants (Salmon et al. 1982). Still, observed efficacy was far

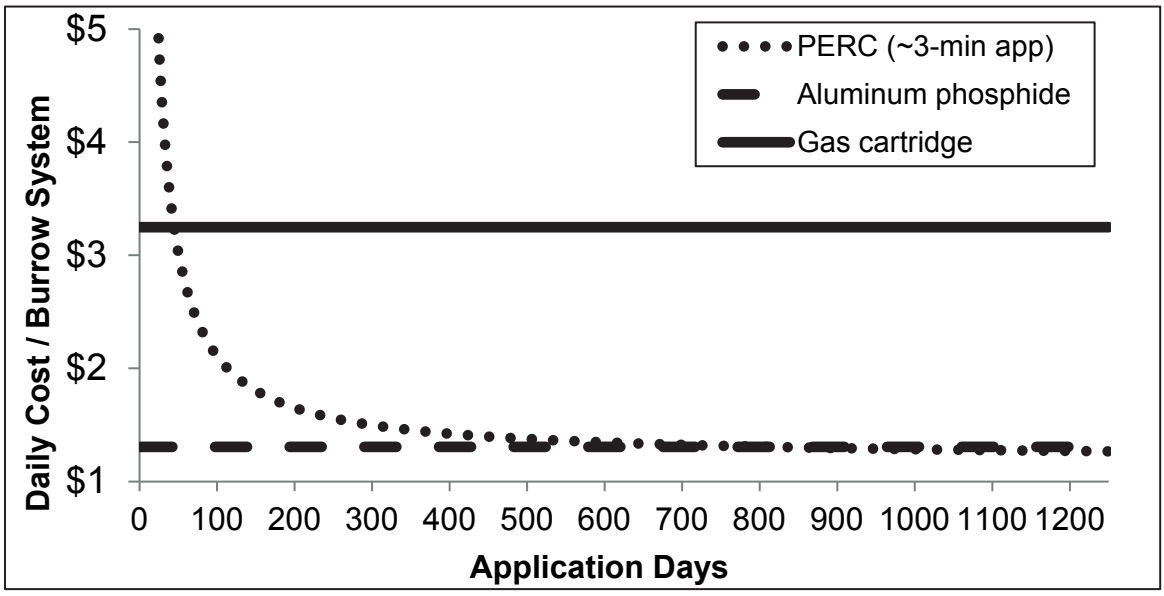

Figure 1. Comparative amortized daily labor plus fixed costs on a per-burrow system basis for 3 different management strategies for California ground squirrels. The vertical axis has been truncated at $5 per burrow system per day to better illustrate amortized costs after several days of application. For reference, initial fixed plus labor costs on a per-burrow system basis on Day 1 for 3-min Pressurized Exhaust Rodent Controller (PERC) application (app) was $93.

greater than what we would expect from other fumigation options, suggesting potential utility for this approach even when soils are dry. Further investigation of the impact of soil type and soil moisture on efficacy is warranted, given the disparity in efficacy associated with different soil conditions. See Baldwin et al. (2017a) for additional details on this investigation.

We were also interested in comparing financial costs of burrow fumigation via gas cartridges, aluminum phosphide, and the PERC machine. For this, we first calculated fixed costs for each of the treatment options, which included the cost of machines and daily fuel use for the PERC machine, and the per-burrow-system cost of tablets and cartridges for aluminum phosphide and gas cartridges. We also calculated labor costs at an assumed rate of $12 per hour. The initial per-burrow system treatment cost of using the PERC machine was quite high when compared to other fumigant approaches (Figure 1). However, the cost of the PERC machine applications on a per-burrow-system basis quickly dropped below that of gas cartridges, given the substantial cost of repeatedly purchasing these cartridges over time. Aluminum phosphide was the cheapest option unless the PERC machine was used for at least 830 days (Figure 1). A more in-depth discussion of the cost-effectiveness of the PERC machine for California ground squirrels can be found in Baldwin and Meinerz (2016).

Efficacy of the Cheetah Rodent Control Machine

Although a growing body of literature is available on efficacy of the PERC machine, to date no studies have assessed the utility of the Cheetah rodent control machine. Therefore, we set up a study to test the efficacy of the Cheetah rodent control machine for controlling California ground squirrels across 3 treatment plots in Fresno County, CA in March of 2012 in soils that ranged from sandy loam to Fallbrook very rocky sandy loam; soils were deemed sufficiently moist for effective use of a fumigant. For the Cheetah rodent control machine, we observed a greater number of California ground squirrels at treatment plots post-treatment ($\bar{x}$ efficacy = -15%), indicating no impact of this device on California ground squirrels. It is possible that results could vary in different soil conditions, but at this point the Cheetah rodent control machine does not appear to be a viable management tool for ground squirrels. See Baldwin and Meinerz (2016) for additional details on this investigation.

POCKET GOPHERS

Burrow Fumigation vs. Trapping

Trapping is a popular and effective tool often used in pocket gopher control (Smeltz 1992, Proulx 1997). Burrow fumigants (particularly aluminum phosphide) are another tool that is highly efficacious for managing pocket gopher populations (Marsh 1992, Baker 2004). Pressurized exhaust containing a high concentration of carbon monoxide is an alternative to aluminum phosphide, as it has shown some promise against pocket gophers with early reports of efficacy around 56% (Orloff 2012) for the PERC machine. The potential of these machines was worthy of further investigation, so we established a study to determine both the efficacy and cost effectiveness of the PERC machine for pocket gopher control and compared these results to two other commonly-used strategies: burrow fumigation via aluminum phosphide, and trapping.

A total of 9 study sites were established in alfalfa fields located along the California-Oregon border. The treatments took place over a 3-year period from 2012-2014, with a total of 3 fields treated per year. Aluminum phosphide ($\bar{x}$ = 81%) and trapping ($\bar{x}$ = 86%) proved to be more effective than PERC applications ($\bar{x}$ = 56%), with only the PERC machine failing to reach the desired 70% efficacy threshold. These findings are consistent with those of Orloff ($\bar{x}$ = 56%; Orloff 2012), suggesting that trapping and burrow fumigation with aluminum phosphide are more efficacious tools than the PERC machine for pocket gopher management. See Baldwin et al. (2016) for additional details of this study.

Additional PERC Testing

Both the moisture content and morphology of soils can substantially influence the efficacy of burrow fumigants (Miller 1957, Salmon et al. 1982, Proulx et al. 2011). Prior assessments of the efficacy of the PERC machine for pocket gophers found consistent results but were conducted in the same geographic area (Orloff 2012, Baldwin et al. 2016); additional testing of the PERC machine in other soil types was needed. Therefore, we tested the efficacy of the PERC machine on pocket gophers in two separate alfalfa fields approximately 24 km southeast of Yreka, CA in March 2014 in a fine loamy mineral soil conducive to burrow fumigation. This soil type was substantially different from those present at field sites tested by Orloff (2012) and Baldwin et al. (2016).

Efficacy for PERC treatments ranged from 65% to 70%. These values were greater than those reported in prior studies ($\bar{x}$ = 56%; Orloff 2012, Baldwin et al. 2016). The variability in efficacy observed between this investigation and prior studies may be due to soil type; this topic is worthy of further investigation. Greater detail on this study can be found in Baldwin et al. (2017a). At a minimum, the PERC machine does provide some relief from pocket gopher damage and may be considered as a potential tool for pocket gopher management when other more effective options are unavailable.

SUMMARY

With the number of tools available to mitigate rodent impacts shrinking due to legislative and regulatory changes (Eason et al. 2010), as well as supply limitations (e.g., limited importation of strychnine into the U.S., [Baldwin et al. 2017b]), the development and registration of pressurized exhaust machines provides a much needed tool for burrowing rodent control. The PERC machine in particular appears to hold promise for ground squirrel management. While the PERC machine can potentially be an effective tool for managing pocket gophers, it is not as effective for this species as it is for ground squirrels.

The PERC machine is also generally less effective than aluminum phosphide for managing pocket gophers. The Cheetah rodent control machine has so far proven to be an ineffective method in controlling ground squirrels. Both the type of soil as well as its moisture level can impact the efficacy of pressurized exhaust applications, as efficacy is generally greatest in moist soils. However, for California ground squirrels, the PERC machine still appears to be a viable option in dry soil conditions, thereby setting it apart from other fumigation options that tend to yield poor efficacy in dry soils.

It also bears noting that with limited use, the PERC machine does not appear to be as cost effective as trapping or aluminum phosphide for pocket gopher control. For example, Baldwin et al. (2016) determined that the PERC machine would have to be used for ~218 days before treatment costs per pocket gopher removed would drop below that for aluminum phosphide; treatment costs for the PERC machine never dropped below that of trapping. However, they pointed out that cost effectiveness would increase if efficacy could be increased. Likewise, the PERC machine is not initially the most cost-effective tool for ground squirrel management (aluminum phosphide and gas cartridges are initially less expensive), but with relatively minimal use the cost associated with using the PERC machine becomes more cost effective than gas cartridges, and it can eventually become more cost effective than aluminum phosphide if used extensively over time (Figure 1). At this point, the use of the PERC machine appears to be a viable option for inclusion into Integrated Pest Management programs for burrowing rodents where alternative options are limited (e.g., bans on the use of rodenticides or aluminum phosphide from some residential areas), and may have superior performance to traditional burrow fumigation tools under some circumstances. More extensive testing of alternative pressurized exhaust devices (e.g., BurrowRx; Quality Manufacturing & Distributing, Inc., El Cajon, CA) may show similar results and is worthy of investigation.

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