# Fumigation of California Ground Squirrels Revisited: Are Fumigants an Effective Method for Controlling Ground Squirrels?

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**ABSTRACT:** Fumigation with either gas cartridges or aluminum phosphide is often considered to be an effective method for controlling California ground squirrel populations, although few studies have corroborated their effectiveness. Additionally, utilizing aluminum phosphide in combination with gas cartridges could increase effectiveness of both fumigants by indicating additional burrow openings through escaping smoke from gas cartridges and allowing for treatment of these additional openings with aluminum phosphide, which is a cheaper and potentially more effective material. Therefore, we compared the efficacy of gas cartridges, aluminum phosphide, and a combined treatment on ground squirrel populations from mid-April through early May 2009 to determine which was most effective. We established 4 plots (3 treatments plus control) at each of 2 treatment sites in Madera County, California. All plots were between 1 and 2 ha in size with survey areas of 0.3 - 0.5 ha centrally located within the plot. Ground squirrels were visually counted within survey areas for 3 consecutive days prior to treatment. Following counting, treatments were applied. Forty-eight hours post-treatment, squirrels were again counted within survey areas to determine percent control. These counts were repeated the following 2 days. All treatments were then reapplied for the same plots, with similar surveys again following 48 hours post-treatment. We found that all fumigation methods resulted in marginal to exceptional control of ground squirrels (percent control: gas cartridges = 62 - 86%, aluminum phosphide = 97 - 100%, gas cartridges + aluminum phosphide = 59 - 71%). We suggest aluminum phosphide use could be expanded to increase ground squirrel control in California, given its high efficacy combined with its relatively cheap material cost.

**KEY WORDS:** aluminum phosphide, California ground squirrel, fumigant, gas cartridge, rodent control, *Spermophilus beecheyi*

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## INTRODUCTION

The California ground squirrel (*Spermophilus beecheyi*) is one of the most damaging pests in California, causing extensive damage to agricultural crops and infrastructure, structural damage to levees and dikes, and is an important reservoir for several diseases including bubonic plague (Marsh 1994, 1998). Many management options are available for controlling this pest, including habitat modification, poison baiting, trapping, and fumigation. Habitat modification provides an option for reducing ground squirrel populations, although habitat manipulations are rarely enough to eliminate ground squirrel populations (Marsh 1994). Poison baiting through the use of rodenticides (e.g., chlorophacinone, diphacinone, zinc phosphide) can be an effective method for controlling large populations of ground squirrels (Marsh 1994). However, ground squirrels will not always consume these rodenticides (O'Connell 1994), and poisoned animals pose a potential hazard to secondary consumers (i.e., predators and scavengers; Littrell 1990, McMillin et al. 2008). Trapping is a control option that allows the user to target specific animals and is effective any time when ground squirrels are active. However, trapping can be very labor intensive and is often not as effective as baiting at controlling ground squirrel populations (Salmon and Schmidt 1984). Fumigation provides an alternative approach for targeting specific members in the population, and limited studies have shown that it can be effective (Salmon et al. 1982). However, additional research is warranted to further address the utility of fumigation for controlling ground squirrels.

Currently, two fumigants are used to control the California ground squirrel: 1) gas cartridges, and 2) aluminum phosphide. Gas cartridges are cylindrical cartridges that, when ignited, emit smoke containing toxic gases including carbon monoxide and carbon dioxide. When found in high enough concentrations, these gases will asphyxiate target animals. Aluminum phosphide comes in tablet or pellet formulations. These tablets or pellets are placed into burrow systems, and when they come in contact with soil moisture, will evolve phosphine gas, which is toxic to all animals. Because of this high toxicity, aluminum phosphide is a Restricted Use Pesticide; however, the gas cartridge is not restricted, making it a more readily available fumigant. Both fumigants require relatively moist soils to be effective, as the toxic gases tend to diffuse into surrounding soils when dry, thereby lowering gas concentrations within dry burrows to non-toxic levels.

In addition to its non-restricted status, gas cartridges have another positive attribute. Because they release smoke when ignited, it is easy to discern burrow openings that are connected to the treated opening. This is not possible with aluminum phosphide, as phosphine gas is not visible. Therefore, gas cartridges allow for identification of burrow openings that might be missed when applying aluminum phosphide; missing these

openings would likely reduce the efficacy of control efforts. However, aluminum phosphide is reportedly cheaper to apply and more effective (Salmon et al. 1982). Ostensibly, a combination of these approaches could yield even better ground squirrel control, given the ability to locate undetected burrow openings through the application of gas cartridges, while treating additional openings with aluminum phosphide tablets, given its cheaper cost and potentially higher efficacy. Therefore, we decided to test the efficacy of gas cartridges, aluminum phosphide, and gas cartridges + aluminum phosphide for controlling California ground squirrels to determine which was most effective.

## METHODS

We identified 2 sites with abundant ground squirrel populations in pistachio orchards in Madera County, CA (hereafter referred to as Block 1 and Block 2). These sites were located 13 km apart. Within each block, 4 circular treatment plots were established ranging from 1 - 2 ha in size. We randomly assigned 1 of 4 treatment types (gas cartridge, aluminum phosphide, gas cartridge + aluminum phosphide, and control) to each plot in each block

To assess efficacy of fumigants, we needed to establish estimates of ground squirrel population size before and after treatments. Therefore, we established circular census plots of 0.3 - 0.5 ha, centrally located within each of the survey plots defined previously, to index ground squirrel numbers. Following Salmon et al. (1982), we counted the number of ground squirrels observed through binoculars in each census plot on 5 separate occasions at 5-minute intervals; locations for these counts occurred outside the census area from a location where ground squirrels could not detect our presence. Squirrel counts occurred between 07:00 and 12:30 to coincide with periods of relatively high activity for ground squirrels. All individual squirrels within census areas were counted during each survey period; no squirrels observed outside the census area were included in these counts. Squirrel counts were repeated for 3 consecutive days for a total of 15 counts per census area. All squirrel counts were conducted by the first author, to eliminate the potential for surveyor bias. These counts were averaged to provide a mean estimate of the number of squirrels present in each census plot. Mean estimates were calculated before the first treatment and approximately 48 hours after the first and second treatments.

After initial population estimates were established, we covered all ground squirrel burrows within the treatment areas with loose soil. We considered all burrows that were opened 48 hours later as active. We followed this approach to reduce the number of burrows that needed to be treated, as well as to clearly define which burrows were active. Tiger salamanders (*Ambystoma californiense*) are considered threatened species in California and were potentially present in treatment areas. This species utilizes abandoned ground squirrel burrows. To eliminate the potential of killing any tiger salamanders, only active ground squirrel burrows were fumigated.

Gas cartridge and aluminum phosphide treatments were applied per label specifications. The gas cartridges used in this study, which are provided by the U. S. Department of Agriculture, Pocatello Supply Depot, ID, were purchased from the Madera County Agricultural Commissioner's office. For application, we inserted fuses into the cartridges, lit them, and placed them deep into the ground squirrel burrows; the opening was then covered with soil. If smoke was observed emanating out of an attached opening, we covered the additional burrow opening with soil as well. For aluminum phosphide applications, we used Degesch Phostoxin® (D&D Holdings, Inc., Weyers Cave, VA), which contains 55% aluminum phosphide and 45% inert ingredients (ammonium carbonate). For application, we placed 2 - 4 tablets far back into all ground squirrel burrow openings. We covered these openings with newspaper or dry grass to prevent burying the tablets, and then sealed them with soil.

For combined treatments, we first treated burrow systems with gas cartridges and sealed the opening. If no smoke was observed emanating from any other burrow opening, we moved on to the next burrow. If smoke was leaking out of a separate burrow opening, we waited approximately 3 minutes before applying aluminum phosphide tablets into that burrow opening. The 3-minute waiting period was to provide enough time for the gas cartridge to burn out, because we were concerned about the potential for igniting phosphine gas from the aluminum phosphide applications. Once the aluminum phosphide tablets were placed into these additional burrow openings, we sealed them with newspaper/grass and soil. For control plots, we did not apply any fumigants to the burrow systems, but did cover all burrow entrances to eliminate any potential effect of burrow closure on ground squirrel populations. We repeated this process after ground squirrel populations were counted following the first treatment, resulting in a total of 2 treatments per plot. The difference in the mean number of ground squirrels observed after each treatment and the initial mean population count was divided by the initial mean population count to provide an estimate on percent control for each treatment method. This entire study was conducted from 17 April to 7 May 2009.

## RESULTS

We observed a range in mean numbers of ground squirrels of 3.2 - 11.8 pretreatment for Block 1 and 3.9 - 13.9 for Block 2; a range of 0.1 - 2.5 for Block 1 and 0.3 - 6.1 for Block 2 following treatment 1; and a range of 0.0 - 3.3 for Block 1 and 0.3 - 5.7 for Block 2 following treatment 2 (Figure 1). Collectively, we observed a 100%, 86%, 71%, and 8% reduction in mean squirrel observations following aluminum phosphide, gas cartridge, combined, and control treatments, respectively, for Block 1, and a 97%, 62%, 59%, and 5% reduction in mean squirrel observations following aluminum phosphide, gas cartridge, combined, and control treatments, respectively, for Block 2 (Figure 1).

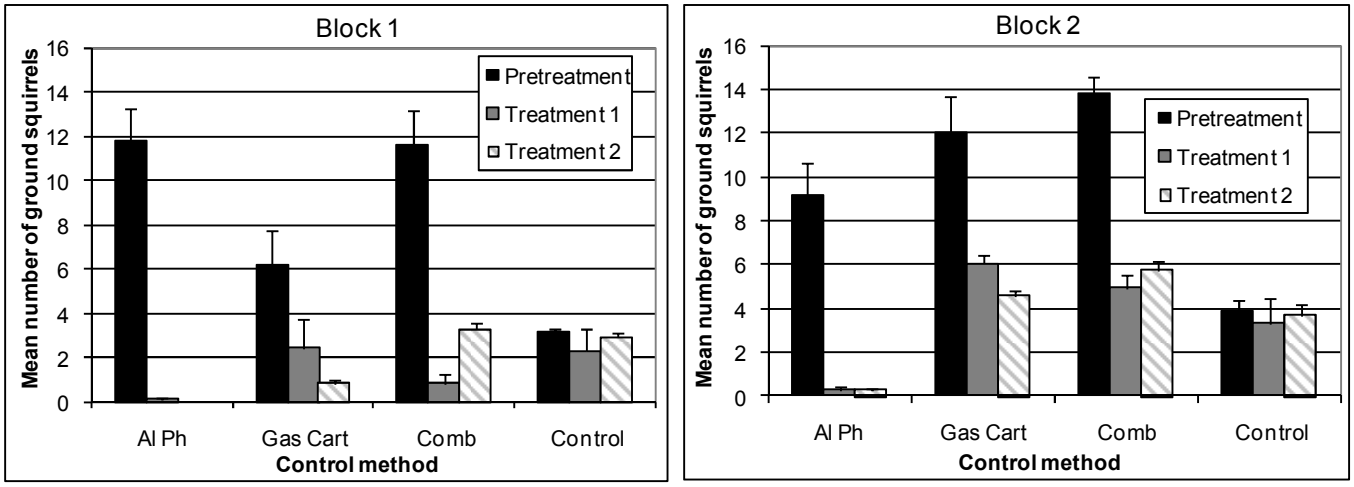


**Figure 1. Mean number of California ground squirrels observed within aluminum phosphide (Al Ph), gas cartridge (Gas Cart), gas cartridge + aluminum phosphide (Comb), and control plots for Block 1 and Block 2 in Madera County, CA; standard error bars are also provided. Counts were made pretreatment, after the first treatment (Treatment 1), and after the second treatment (Treatment 2).**

## DISCUSSION

Our results corroborate those of Salmon et al. (1982), which indicated that aluminum phosphide was an excellent material for controlling the California ground squirrel. Efficacy levels above 70% are considered to be effective by the EPA; we approached or reached 100% efficacy in our study (Figure 1). Gas cartridges were moderately to marginally effective at ground squirrel control with efficacy values of 62% and 86% in our study. Reasons for this difference in efficacy between aluminum phosphide and gas cartridges are not known, but they could be due to the greater toxicity of phosphine gas versus carbon monoxide, or could be due to a greater perceived threat of gas cartridges by ground squirrels than from aluminum phosphide tablets. For example, gas cartridges flare up, are noisy, and emit much smoke which could frighten ground squirrels and cause some of them to rapidly wall themselves off from these gases in their burrows. Enough of these squirrels may engage in this activity to reduce efficacy by 20 - 35%. With aluminum phosphide, the only noticeable characteristic would be a slow build-up of ammonia and $CO_2$ from the ammonium carbonate, which reduces the fire hazard and acts as a warning agent (Baker and Krieger 2002). However, this odor does not appear to frighten ground squirrels and may reduce the probability that they would seal themselves off from the aluminum phosphide tablets. Phosphine gas is odorless and colorless.

We are unsure why the combined gas cartridge-aluminum phosphide treatments were less effective than either of these materials singularly (Figure 1). Because of our concern for the potential ignition of phosphine gas from flames associated with the gas cartridges, we did not seal off the burrow systems until 4 - 5 minutes after the initial application of the gas cartridges. This led to the escape of much carbon monoxide and may have resulted in concentrations too low to kill many ground squirrels. The addition of aluminum phosphide tablets in these burrows may have also been rendered less effective if the gas cartridges served to dry out the soil within the burrow system, resulting in less evolution of phosphine gas, thereby leading to a less toxic burrow system than might have been present when either material was used singularly. Alternatively, our presence at smoking burrow entrances while waiting for the cartridges to burn out may have frightened the squirrels more than normal, potentially leading to a higher incidence of ground squirrels sealing themselves off from the fumigants and us. Whatever the reason, the combined method was not as efficacious as either of the fumigants singularly, and as such, is not recommended for use.

In addition to a difference in efficacy between treatments, there also appeared to be a difference in efficacy between Blocks 1 and 2 (Figure 1). This difference may have been related to soil moisture, as Block 1 received more consistent irrigation over the duration of this study than did Block 2; Block 2 appeared to be noticeably drier than Block 1, particularly after the first treatment. Relatively moist soil conditions are required for these fumigants to be effective; if the soil is not moist, the gases may generate slower and can diffuse out through the spaces in dry soil resulting in a non-fatal concentration of gases within burrow systems. This seemed to be the case in our study and illustrates the need for sufficient soil moisture when using burrow fumigants.

Costs associated with applications are always an important consideration as well. For our study, material costs were substantially lower for aluminum phosphide ($0.16 - $0.32/burrow) than for gas cartridges ($1.67/burrow). Additionally, a previous study indicated a mean time of application per burrow system of 1.6 minutes and 2.2 minutes for aluminum phosphide and gas cartridges, respectively (Salmon et al. 1982). These values will vary depending on user experience, but they suggest that aluminum phosphide treatments require less time to apply than do gas cartridge treatments. Collectively, these results indicate that aluminum phosphide applications are more cost effective than fumigation with gas cartridges.

These results clearly illustrate the positive attributes of aluminum phosphide fumigation for controlling ground

squirrels. However, it should be noted that aluminum phosphide is a Restricted Use Pesticide and can be dangerous to use when applied inappropriately. It is imperative that all applicators be properly trained in the application of aluminum phosphide before use. Baker and Krieger (2002) provide an excellent review on safety procedures when using this material.

Additionally, aluminum phosphide has further label restrictions that are likely responsible for its limited use for ground squirrel control in California, as the appropriate steps required to use aluminum phosphide often appear overwhelming to the average grower or PCA. These steps include: 1) filing a fumigation management plan, 2) filing a Notice of Intent with the County Agricultural Commissioner's office, 3) ensuring the physical presence of a Certified Applicator at the treatment site during aluminum phosphide applications, 4) filing a Pesticide Use Report with the County Agricultural Commissioner's office, and 5) ensuring that all transportation procedures are followed when transporting aluminum phosphide (see Baldwin 2009 for greater detail on these steps). Although the procedures required to use aluminum phosphide may seem daunting initially, once the protocol is understood and the procedures mastered, it becomes a very effective tool for controlling California ground squirrels.

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