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ABSTRACT: The California ground squirrel (Spermophilus beecheyi) is widely distributed throughout California. It causes serious damage to agricultural crops. Tests were conducted to evaluate the fumigant aluminum phosphide (Phostoxin®) and to compare it to the commonly used gas cartridge. Treatments consisted of applying either a single-dose (two 3-gm tablets) or double-dose (four 3-gm tablets) of aluminum phosphide, or 1 U.S. Fish and Wildlife Service gas cartridge in each burrow in the study plots. The burrow opening was then plugged with 1 sheet of newspaper and sealed with soil. Burrows in the control plot were plugged with newspaper and sealed in the same manner. All plots were retreated 4 days after the initial treatment. Overall, the aluminum phosphide treatments were more effective than the gas cartridge treatments in terms of the reduction in the number of ground squirrels seen and in reopened burrows observed after treatment. The single-dose aluminum phosphide treatment was as effective as the double-dose treatment. The gas cartridge treatment required a greater amount of time for application and did not achieve very effective control. Many aspects of this fumigation technique remain unknown and continued research is necessary.

INTRODUCTION

The California ground squirrel (Spermophilus beecheyi) is widely distributed and abundant in California. It is an important agricultural pest that damages a variety of crops and causes serious economic losses (Dana 1971). Additionally, ground squirrels cause structural damage through burrowing and gnawing and are important in transmission of several serious diseases to man (Clark 1975). Extensive ground squirrel damage occurs in perennial crops such as almonds, including: gnawing of bark; feeding on blossoms, buds, developing and mature nuts; caching large quantities of nuts; burrowing around the tree roots; and gnawing and chewing on plastic irrigation lines. In addition, harvesting and sweeping operations are hampered by burrows and mounds, and mature nuts that fall into burrows are unharvestable.

There are few, if any, economic studies of ground squirrel damage in almonds. Several growers in Kern County, California, have reported 60%+ yield reductions because of ground squirrel activity. This could translate to a $1,200 loss per acre (1980 price of almonds, Kern County, California). This does not include damages other than loss of crop yield. In several orchards, no nuts were harvested because of ground squirrel feeding, and some orchards are considered uneconomical because of ground squirrel damage.

While almond growers recognize the need for controlling ground squirrels, the methods and materials currently available are not adequate in many situations. The primary methods used in Kern County for ground squirrel control in almonds are treated grains (Compound 1080, anticoagulants), gas cartridges for fumigation, traps, and shooting.

This study was undertaken to test the effectiveness of the fumigant aluminum phosphide (Phostoxin®) for ground squirrel control in almond orchards, and to compare it with the U.S. Fish and Wildlife Service gas cartridge.

STUDY AREA

The study areas were located in Kern County, California, approximately 5 miles southeast of McFarland and 15 miles north of Bakersfield. The general area is bounded by Route 65, McFarland-Woody Road, Route 99 and Famoso-Woody Road. All plots were located in drag-line sprinkler or drip-irrigated mature almond orchards. Plot size was influenced by topography, vegetation, and features that delineate the colony boundaries such as roads, adjacent orchards, etc. The plot sizes varied from about 1 to 2 ha.

MATERIALS AND METHODS

Each plot was divided into a census area and a surrounding buffer zone (Table 1). Two separate census methods were used. The first method consisted of counting ground squirrels on the plots for a 3-day period immediately before and starting 8 days after treatment. Each squirrel seen during 5 separate scans taken at 5 minute intervals was counted. Counts were made from a vehicle using 10X binoculars and were taken from the same location at approximately the same time each day. Squirrels in the buffer zone surrounding the census area were recorded separately. Weather factors and any disturbances that may have affected the counts were noted. The second method consisted of counting the number of ground squirrel burrows on the day of treatment and again 8 days later.

Treatments were conducted in February and October, 1981. No squirrel control had been conducted on any treatment plot for at least 6 months prior to our test. Aluminum phosphide tablets (3 gm each,

Table 1. Size of census area (ha) and buffer zone (ha) and type of treatment. The numbers 1 or 2 indicate single (6 gm) or double (12 gm) dose of aluminum phosphide.

Plot Treatment	Census Area	Buffer Zone	Total
Aluminum Phosphide 1 (Feb)	.49	1.58	2.07
Aluminum Phosphide 1 (Oct)	.32	1.50	1.82
Aluminum Phosphide 2 (Feb)	.36	1.0	1.36
Aluminum Phosphide 2 (Oct)	.39	.86	1.25
Gas Cartridge (Feb)	.40	.57	.97
Gas Cartridge (Oct)	.40	1.62	2.02
Control (Feb)	.36	1.1	1.46
Control (Oct)	.90	.34	1.24

55% aluminum phosphide*) were used. The tablets function by releasing hydrogen phosphide gas (phosphine, PH_3 through reaction of aluminum phosphide with moisture in the soil and atmosphere. Phosphine is toxic to all forms of animal life. It is colorless, heavier than air with a specific gravity of 1.2, only slightly soluble in water, and has a pungent odor. It is very penetrating and will probably pass through loosely packed soil easily. The rate of decomposition of these tablets varies with temperature and moisture; higher temperature and moisture causes faster decomposition. Assuming a burrow temperature of 18-21°C and relative humidity of 90%, it is estimated that less than 2 days are required for complete liberation of the hydrogen phosphide (DEGESCH manufacturer's specifications). There are no known solvents for aluminum phosphide and the compound is extremely sensitive to hydrolysis. Translocation of the intact metal phosphide is unlikely; however, hydrogen phosphide is slightly soluble in aqueous solvent (Weston 1954), and translocation is theoretically possible. Because of hydrogen phosphide's extreme volatility, sensitivity to oxidation (Melville and Roxburghl934) and hydrolysis (Bushmakin and Frost 1933), and its rapid conversion in living tissues to orthophosphate and its precursors (Klimmer 1969), the presence of detectible residues of phosphine in plant tissue is not expected. Translocation studies in almond trees indicated no phosphine residues in the nuts (Salmon, unpublished research report).

Gas cartridges prepared by the U.S. Fish and Wildlife Service, Pocatello Supply Depot, Idaho, were also tested. These are a widely used fumigant for ground squirrel control in California. Active ingredients of the gas cartridge include sulfur, charcoal, red phosphorous, mineral oil, sodium nitrate and sawdust. When ignited, the cartridge produces a suffocating gas.

Treatments consisted of applying either a single dose (two 3-gm tablets) or a double dose (four 3-gm tablets) of aluminum phosphide, or 1 gas cartridge in each burrow in the study plots. The aluminum phosphide dose rate was recommended by the manufacturer and the gas cartridge dose was according to label directions. The burrow opening was then plugged with 1 sheet of newspaper and sealed with soil. Burrows in the control plot were plugged with newspaper and sealed in the same manner. The number of treated burrows in the census and buffer zones were recorded separately. The time required to treat each plot was also recorded. Treatment plots were treated from mid-afternoon to early evening because we felt the squirrels were more likely to remain in the burrows if darkness was approaching. All plots were retreated 4 days after the initial treatment.

Soil moisture in all plots was relatively high. In February, recent winter rains had occurred. In October, the plots had been irrigated within 3 weeks of treatment.

RESULTS AND DISCUSSION

Based on the squirrel count census, aluminum phosphide single and double treatments were 100% effective in controlling ground squirrels in the census zone (Table 2). No squirrels were seen in this area 8 days after the treatments. Gas cartridge treatment in the census zone achieved no apparent reduction in squirrel activity when compared to the control plots. In the control plots, where only a sham treatment occurred, the number of squirrels observed decreased about 60%. We do not believe filling burrows in the control plots killed or caused any squirrels to leave the area. The apparent reduction was probably related to behavioral changes due to filling in the burrows.

Based on the active burrow counts after treatment, aluminum phosphide single and double strength had the lowest percentage of holes reopened in the census zone, less than 1.2% in all cases (Table 3). The percent open burrows does not equal the percent squirrel population remaining after control; however, it can serve to compare the relative efficacy of the treatment methods. One approach to examining the data is to determine the percentage of reopened burrows on the control plots and adjust for this on the treatment plots. If the treatments were ineffective, we would expect about the same percentage of burrows reopened as in the control plots. On the control plots, 28.6% (Feb) and 17.2% (Oct) of burrows

*DEGESCH Phostoxin® New Coated Tablets-R manufactured by DEGESCH America, Inc., Weyers Cove, VA 24486.

Table 2. Maximum number of ground squirrels observed on 5 counts per day on study plots before and 8 days after treatment, Kern County, California, 1981. For plot treatments, the numbers 1 and 2 indicate single (6 gm) or double (12 gm) dose of aluminum phosphide. Numbers in parentheses represent maximum number of squirrels seen on treated buffer areas.

Plot Treatment	Number before Treatment	Number after Treatment
Aluminum Phosphide 1 (Feb)	9 (1)	0 (2)
Aluminum Phosphide 1 (Oct)	7 (2)	0 (0)
Aluminum Phosphide 2 (Feb)	7 (3)	0 (1)
Aluminum Phosphide 2 (Oct)	6 (1)	0 (0)
Gas Cartridge (Feb)	5 (0)	2 (0)
Gas Cartridge (Oct)	5 (2)	3 (2)
Control (Feb)	5 (4)	2 (2)
Control (Oct)	17 (3)	11 (3)

Table 3. Number of ground squirrel burrows treated and number of burrows open 4 and 8 days after treatment on study plots, Kern County, California, 1981. For plot treatments, the numbers 1 and 2 indicate single (6 gm) or double (12 gm) dose of aluminum phosphide. Numbers in parentheses represent burrows on treated buffer zones.

Plot Treatment	Number Treated	Number open after 4 days (retreated)	Number open after 8 days	% open 8 days after treatment	% difference between expected and reopened[a]
Aluminum Phosphide 1 (Feb)	113 (193)	3 (17)	1 (7)	0.9 (3.6)	96.9
Aluminum Phosphide 1 (Oct)	64 (167)	0 (1)	0 (1)	0.0 (0.6)	100.0
Aluminum Phosphide 2 (Feb)	86 (233)	0 (5)	1 (5)	1.2 (2.1)	95.9
Aluminum Phosphide 2 (Oct)	102 (293)	1 (1)	0 (7)	0.0 (2.4)	100.0
Gas Cartridge (Feb)	150 (167)	8 (8)	12 (7)	8.0 (4.2)	72.0
Gas Cartridge (Oct)	155 (233)	2 (4)	9 (27)	5.8 (11.6)	66.2
Control (Feb)	63 (146)	24 (28)	18 (27)	28.6 (18.5)	0
Control (Oct)	204 (50)	25 (3)	35 (7)	17.2 (14.0)	0

[a]Applies to census area only. Based on 28.6% (Feb) and 17.2% (Oct) reopened on control plots, e.g., (Al.Pl Feb) .286 x 113 = 32.3, 1 - 1/32.3 x 100% = 96.9%.

were reopened. For the gas cartridge plots, only 8% (Feb) and 5.8% (Oct) were reopened. In terms of the number of burrows reopened, this is 72% (Feb) and 66% (Oct) fewer than expected. With aluminum phosphide 1 and 2, no more than 1.2% of the burrows were reopened, which is at least 95% fewer than expected.

When data from the census and buffer zone are combined, both the single and double treatments of aluminum phosphide had significantly fewer open burrows than expected when compared to the gas cartridge (X^2 = 9.368 [Feb], X^2 = 33.4012 [Oct], d.f. = 2, $P < 0.05$). No significant differences between the single and double aluminum phosphide treatments were observed (X^2 = 0.2923 [Feb], X^2 = 2.2369 [Oct], d.f. = 1 $P > 0.05$). With the gas cartridge there were significantly fewer open burrows than expected compared to the control plots (X^2 = 29.869 [Feb], X^2 = 5.9423 [Oct], d.f. = 1, $P < 0.05$). Rain 2 nights after the February retreatment may have inflated the burrow counts on all plots by softening the soil used to close the burrows and causing some cave-ins. These may have been counted as dig-outs when in fact they were not. If so, these should have occurred randomly throughout all plots.

We feel it is necessary to use both census techniques to evaluate the efficacy of these tests. Reliance on a single method may result in misinterpretation of the data. For example, data obtained by the squirrel-observation method may be biased by disturbance, weather, vegetation growth, (tree canopy and understory) and other factors. Likewise, the burrow-count method can be biased since the number of burrow openings may have little relationship to the number of squirrels present.

Squirrels were observed after treatment in the buffer zones of all plots. These might have been squirrels that escaped treatment or invaded from adjacent areas. The treatment of relatively large buffer zones was an attempt to eliminate invasion into the census area and thus isolate that factor from the evaluation. We feel the buffer zones achieved this objective.

Application of aluminum phosphide required about 30% less time than did the U.S. Fish and Wildlife Service gas cartridge method (Table 4). While the amount of time required to treat each burrow will vary according to relative burrow density, topography, etc., aluminum phosphide treatment appears to be

Table 4. Time requirements for aluminum phosphide and gas cartridge fumigation. February and October trials combined. For plot treatments, the 1 and 2 indicate single (6 gm) or double (12 gm) dose of aluminum phosphide.

Plot Treatment	Man-hours	Minutes/burrow
Aluminum Phosphide 1	13.8	1.6
Aluminum Phosphide 2	15.6	1.4
Gas Cartridge	25.5	2.2

faster. It may not be more convenient, however. In California, aluminum phosphide is a Restricted Use Material and requires a permit issued by the County Agricultural Commissioner for purchase and use. It must be used by or under the direct supervision of a Certified Applicator. The gas cartridge has no permit requirement and is therefore less restrictive to use. Material costs for a single dose of aluminum phosphide or a gas cartridge treatment are approximately equal.

CONCLUSION

Overall, the aluminum phosphide treatments were more effective than the U.S. Fish and Wildlife Service gas cartridge treatment in terms of reduction in the number of ground squirrels seen and in reopened burrows observed after treatment. The single-dose aluminum phosphide treatment was as effective as the double-dose treatment. The gas cartridge treatments required a greater amount of time for application and did not achieve very effective control. This is consistent with reports from growers and others in Kern County who indicate 50-70% control with gas cartridge fumigation. In another test we measured the effect of not using newspaper in the burrows and found this omission to drastically reduce efficacy of aluminum phosphide (Salmon and Gorenzel, unpublished research report).

Many aspects of this fumigation technique remain unknown and continued research is necessary. Timing of fumigation and the effects of soil moisture and type are key questions that must be addressed. In a preliminary test we conducted, aluminum phosphide treatment appeared to be ineffective when soil moisture was low.

Aluminum phosphide (DEGESCH Phostoxin New Coated Tablets-R) has Federal EPA and a statewide California special local needs [24(C)] registration for ground squirrel fumigation in orchards and in noncrop areas. The current recommendation is that it be used when ground squirrels are active and when soil moisture is relatively high, as occurs in most portions of California during the spring months or after irrigation. We feel aluminum phosphide, if applied correctly, is a useful tool for ground squirrel control in orchards and noncrop areas.

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