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EVALUATION OF ZINC PHOSPHIDE BAIT FOR POCKET GOPHER CONTROL ON FOREST LAND

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ABSTRACT: Laboratory bioassays and field tests were conducted to determine if zinc phosphide baits would control pocket gophers in forest plantations. Zinc phosphide baits generally were less effective than the strychnine alkaloid-oat bait commonly used by forest managers to control gophers. However, a carrot bait with 0.75% zinc phosphide showed potential as a substitute for strychnine. Size of carrot bait and grooming activity of gophers were identified as important factors affecting efficacy of baits.

INTRODUCTION

This study originated from a need documented in a U.S. Forest Service activity review and action plan (USDA Forest Service, unpublished administrative report, "Pocket Gopher-Reforestation Activity Review, Action Plan, and Report," Washington, DC 1980) to develop an alternate toxicant to strychnine alkaloid for control of pocket gophers (Thomomys spp.) on western National Forests. Underground placement of strychnine bait is an effective means of reducing gopher populations to control their depredation of planted conifers (Barnes 1974, Crouch and Frank 1979). In fact, it is the predominant method used to control damage on Forest Service lands (Northwest Forest Pocket Gopher Committee 1976). Heavy reliance on strychnine for control, however, is a concern to forest managers because of potential hazards to wildlife and because there is no other rodenticide available for large-scale use against gophers on National Forests.

Development of a new rodenticide for federal registration is very costly and time-consuming with no assurance that it will be registered. We believed the best approach to finding an alternate toxicant would be to extend the use of a currently registered rodenticide such as zinc phosphide (ZnP). ZnP was selected as the candidate because of its low hazard potential and a large data base documenting its toxicology and biological activity (Hood 1972). ZnP is registered for use on several vertebrate species (Matheny 1980) and also for pocket gophers in eastern Oregon (Price list for "This is the Way" Rodent Baits and Supplies, Mammal Survey and Control Service, Portland, OR 1981; reference to commercial products does not imply endorsement by the U.S. Government). Unfortunately, there was little documented information on ZnP efficacy against pocket gophers.

A study on the Kaibab National Forest in Arizona (E.M. Mercer, unpublished administrative report, Denver Wildlife Research Center, Denver, CO 1952) indicated 75 to 90% gopher control from baiting with ZnP on steam-crushed oats. Other studies on pocket gopher (probably T. bottae) in southwestern United States showed that cubed carrot or sweet potato coated with ZnP produced better kills than the same root baits coated with strychnine (U.S. Fish and Wildlife Service 1952). Miller (1953), however, reported that ZnP baits of both fresh root and grain were relatively ineffective against T. bottae in California.

The objective of our study was to determine if federally registered ZnP baits were as good or better than the standard strychnine alkaloid-oat bait in reducing test populations of T. mazama, a species of gopher commonly responsible for reforestation damage. Favorable results would lead to recommendations for additional tests or recommendations to register ZnP for pocket gopher control in western United States.

The study was conducted in three parts--laboratory tests, field probe, and field evaluation. Laboratory tests and the field probe were done in western Washington near Olympia; the field evaluation was done in central Oregon near Bend. The study was conducted from spring to fall 1981.

LABORATORY TESTS

The primary objective of laboratory testing was to determine the LD_{50} of ZnP to T. mazama and to select candidate baits for field evaluation. Supplemental tests were conducted to determine toxicological relationships linked with gopher grooming behavior and size of carrot bait and to evaluate an encapsulated form of ZnP. All test animals were adult gophers conditioned to individual cages at least 3 days before tests began.

LD_{50} Determination

We completed LD_{50} tests with 12 male and 16 female pocket gophers using procedures detailed by Lindsey (1977). Briefly, test animals were fasted 4 hours before treatment, gavaged with the specified dose of ZnP (94% a.i.) suspended in propylene glycol, and fasted 2 hours after gavaging. They were observed 7 days post-treatment or until death. Rodent laboratory chow, carrots, and natural vegetation were available at all times except during pre- and post-treatment fasting.

Results indicated an LD_{50} for ZnP of 14.7 mg/kg (CL_{95} 8.3 - 26.1) for males and 14.7 mg/kg (CL_{95} 10.0 - 21.5) for females. These values differed significantly from the LD_{50} of 6.8 mg/kg reported by Hood (1972) for T. talpoides.

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Bait Bioassays

We tested five registered baits (Table 1) with ZnP concentrations ranging from 0.75 to 2.00% (a.i.). The toxicant carrier was either steam-rolled whole oats, crimped oat groats, or fresh carrot. In all tests, each of five gophers was offered 20 g of grain bait or one 2 x 2-cm piece of carrot per day until death or for 3 days. A control group of five animals was subjected to the same regime with untreated steam-rolled whole oats. All animals were observed 7 days post-treatment or until death. Supplemental feed was available to gophers at all times except the first day of exposure to bait. Carrot and natural vegetation were provided to animals tested on grain bait and natural vegetation was given to animals tested on carrot bait. We prebaited gophers with clean bait carrier in two tests of 1.00% ZnP-oat groats to determine if prebaiting increased efficacy.

Carrots treated with 0.75% ZnP were readily consumed and caused 100% mortality to gophers (Table 1). Mean mortality of animals exposed to the grain baits ranged from 70 to 100%. For the 1.00% ZnP-oat groats bait, average mortality of gophers increased from 70% without prebaiting to 90% with prebaiting. Despite high mortality in grain bait tests, direct consumption of bait was measured for only 50% of the affected animals. We theorized that gophers ingested toxicant as they groomed themselves after handling bait and that this activity was a factor in mortality.

Table 1. Summary of bioassays conducted on individually caged pocket gophers offered baits treated with zinc phosphide (ZnP); each treatment was tested twice with five pocket gophers per test.

ZnP (% conc.)	Registration information	Carrier	Adhesive (% conc.)	Mortality (%) $\bar{x}$ (range)
0.75	EPA Reg. No. 6704-52; nutria bait	Carrot	Corn oil (0.5)	100
0.92	EPA Reg. No. 6704-43; 1:100 field mouse bait	Rolled oats	Lecithin oil (1.2)	90 (80-100)
1.00	OR Reg. ACC-04488; EPA Reg. No. 9691; pocket gopher bait - eastern Oregon	Rolled oats	Petrolatum (1.0) Mineral oil (0.5)	100
1.00	OR Reg. ACC-04488; EPA Reg. No. 9691; pocket gopher bait - eastern Oregon	Crimped oat groats	Petrolatum (1.0) Mineral oil (0.5)	70 (60-80)
1.00*	OR Reg. ACC-04488; EPA Reg. No. 9691; pocket gopher bait - eastern Oregon	Crimped oat groats	Petrolatum (1.0) Mineral oil (0.5)	90 (80-100)
1.82	EPA Reg. No. 6704-6; 2:100 field mouse bait	Rolled oats	Lecithin oil (1.2)	90 (80-100)
2.00	EPA Reg. No. 6704-74; prairie dog bait	Rolled oats	Lecithin oil (1.4)	80
2.00	Experimental formulation	Rolled oats	Petrolatum (1.0)	90 (80-100)
Control		Untreated rolled oats		0

*Animals in these tests were prebaited with untreated steam-rolled oats.

Grooming Tests

To test the theory that grooming behavior affected mortality of gophers exposed to ZnP baits, we applied ZnP dry or suspended in corn oil to the feet, chest and stomach area, or in cheek pouches of individually caged gophers.

Results (Table 2) showed that ingestion of ZnP through grooming activity was a mortality factor, particularly when the toxicant was acquired by grooming the cheek pouches. This suggested that efficacy of some bait formulations might depend on whether gophers can readily transport the bait in their cheek pouches. The data also showed that corn oil enhanced efficacy of ZnP applied as a contact toxicant.

Bait Size Tests

Miller and Howard (1951) reported that any practical size of carrot bait could be used to poison gophers. They observed, however, that gophers did not use their cheek pouches to carry large pieces of bait. Our observations in grooming tests indicated that ZnP-carrot bait would be more effective if gophers used their cheek pouches to transport bait. We therefore offered various sizes of untreated carrot to caged gophers to observe food consumption and handling behavior, and then tested the effect of bait size on gophers with 0.75% ZnP-carrot bait. For the latter test, we chose a 3-cm diameter by 4-cm length of carrot and cut it into six different sizes (3 cm x 4 cm, 2 cm x 4 cm, 2 cm x 3 cm, 1 cm x 4 cm, 1 cm x 2 cm, and 1 cm x 1 cm). Equal volumes of each bait size were offered to each of two gophers.

Table 2. Effect on caged pocket gophers of technical grade (94%) zinc phosphide applied to various body parts and ingested through grooming activity.

Dosage (mg)	Type of application	Treatment site	Number of deaths/ animals tested
50	oil	cheek pouch	3/3
50	dry	cheek pouch	3/3
50	oil	chest, stomach	2/3
50	oil	feet	2/3
50	dry	chest, stomach	0/3
50	dry	feet	0/3
15	oil	cheek pouch	1/5

Caged gophers accepted all sizes of untreated and 0.75% ZnP bait. Furthermore, all bait sizes (1 x 1-cm to 3 x 4-cm) proved lethal to gophers and thereby demonstrated potential for field use. Mean consumption of treated bait was highest for the smallest size category; this resulted in an average ZnP dose of 367 mg/kg. The average ZnP dose for other bait sizes ranged from 91 mg/kg for 2 x 4-cm pieces to 166 mg/kg for 1 x 2-cm pieces. Plain and treated pieces of carrot were either transported whole or in chipped segments; there was no consistency in the size of bait that was chipped or not chipped. Transport of bait in cheek pouches and associated grooming activity was most evident in gophers exposed to 1 x 1-cm pieces of carrot.

Encapsulated ZnP

We had the opportunity to examine an experimental encapsulated form of technical grade ZnP (Hooker Chemical Corp. Research Center, Grand Island, New York) developed to improve rodent acceptance of ZnP baits. The new product was compared against standard technical grade ZnP. We followed formulating procedures of Evans (1970, pp. 38-40) to produce a 0.75% carrot bait with 0.5% corn oil adhesive on 1 x 1-cm wedges of fresh carrot, using standard or encapsulated ZnP. Each of five animals per treatment was offered eight pieces of bait.

Mean bait consumption per gopher was 6.9 g and 6.8 g, respectively, for the standard and encapsulated formulations. All animals died in less than 6 hours. Hence, we concluded there was no need to further test encapsulated ZnP in our study.

FIELD PROBE

This phase of the study was conducted to determine if acceptance of 0.75% ZnP-carrot bait in the field was affected by size of the carrot pieces. Treatment effects were evaluated with radio-telemetry (Barnes et al. 1980).

Methods

Pocket gophers were captured, fitted with radio transmitters, and immediately released at their trap sites; they were monitored before, during, and after baiting. We tested three sizes of 0.75% ZnP-carrot bait against the standard 0.5% strychnine-oat bait and a control (Table 3). Bait was

Table 3. Field efficacy of different sizes of zinc phosphide-coated carrot baits compared with the standard strychnine alkaloid bait.

Bait	Pocket gopher mortality
0.5% strychnine alkaloid-oats	100% (5/5)
0.75% zinc phosphide-carrot	
small, 1-cm wedge (about 2.5 g per piece)	80% (4/5)
large, 1-cm half-moon (about 5.5 g per piece)	40% (2/5)
large, 2-cm wedge (about 5.5 g per piece)	40% (2/5)
Control (1-cm and 2-cm wedge, untreated carrot)	0% (0/5)

dropped through probe holes into gopher burrows and probe holes then were covered with debris such as bark, soil, clods, or vegetation. Each of five gophers per treatment was baited with three bait sets placed at least 1 m apart. ZnP-carrot bait sets consisted of two large or four small carrot pieces totaling about 10 g of bait per set. Strychnine-oat bait sets contained about 4 g of grain. Gophers were excavated when their radio signals indicated no movement and probable death.

Results

High mortality (80 - 100%) occurred to gophers exposed to strychnine-oat bait and small pieces of ZnP-carrot bait (Table 3). Relatively poor kills resulted from baiting with large pieces of ZnP-treated carrot.

One of the ZnP-killed gophers was found above ground, although we suspected it died below ground and then was pushed out of its system by another animal. All other poisoned gophers, including one partially consumed by a scavenger, died in nests or burrows 51 to 160 cm underground.

We also recovered three dead deer mice (Peromyscus maniculatus) 8 cm below ground in a gopher burrow. They were within 1 m of a ZnP bait set and were presumed to be nontarget mortalities.

FIELD EVALUATION

A large-scale field test was conducted in central Oregon. This test evaluated six treatments--four registered ZnP formulations, a registered standard (0.5% strychnine alkaloid on steam-rolled oats), and a control (untreated oats). ZnP formulations were (1) 0.92% on steam-rolled oats, (2) 1.82% on steam-rolled oats, (3) 1.00% on crimped oat groats, and (4) 0.75% on fresh carrots (see Table 1 for registration data).

Methods

The experimental design consisted of five replications of the above six treatments. A replication was a series of six plots each randomly assigned to receive one of the treatments. Plot size varied from 3 to 10 ha depending on pocket gopher abundance.

Two replications were located about 4 to 5 km southwest of Bend, Oregon, and three replications were located about 5 to 6 km northwest of Sisters, Oregon. Study plots near Bend were in ponderosa pine (Pinus ponderosa)-shrub communities that had been harvested by clearcut and planted or scheduled for planting with ponderosa pine. Plots near Sisters were in mixed conifer communities dominated by ponderosa pine; study sites had been harvested by clearcut, shelterwood cut, or overstory removal and were being reforested naturally and with planted ponderosa pine seedlings.

The open-hole procedure (Richens 1967, Barnes et al. 1970) was the principal method employed to test treatment effects. Just before the treatment of each plot, we selected 30 active gopher systems based on the presence of mounds constructed within the preceding 96 hours. Duplicate sampling of individual burrow systems was avoided by using numbered, wire-stem flags to mark fresh groups of mounds spaced at least 50 m apart. Ten days after bait application we opened two burrows near each flag and examined them 24 and 48 hours later. A gopher-constructed plug at either of the opened burrows was considered evidence of a live gopher and was recorded as an active burrow system. These data were subjected to analysis of variance and Duncan's multiple range tests to determine if the number of active systems varied significantly among treatments after baiting.

Supplemental data were obtained from radio-marked gophers that occupied burrow systems separate from those used in the open-hole evaluation. Before baiting we captured and radio-marked one to three pocket gophers per plot for a total of 10 animals per treatment, excluding the control. In all, we radio-collared 50 animals. These gophers were monitored until death or at least 10 days post-treatment.

We applied bait to individual burrow systems identified by flags or occupied by radio-marked gophers. Each burrow system was baited with five bait sets spaced at least 1-m apart. A set was made by locating an underground burrow with a metal probe, dropping bait through the probe hole, and then covering the hole with nearby debris or a 6 x 6-cm piece of construction paper. Oat bait was poured from a plastic bottle (capacity of about 4 L) with a narrow (about 3 cm) spout. Carrot bait was carried in a plastic bucket (6 L) and dispensed with a tablespoon. When we experienced difficulty with dry soil collapsing around the probe hole we completely opened the burrow, placed bait into the burrow with a spoon, and then plugged the burrow opening with soil. Each carrot bait set contained three pieces of carrot (roughly 1 x 1 x 1.5-cm each) for a total of 6 to 9 g of bait. Oat bait sets each contained about 4 g of bait.

Results

Open-hole evaluation.--Open-hole analysis disclosed that 0.5% strychnine-treated oats, with an indicated mean kill of 83%, was the most effective bait (Table 4). The 0.75% ZnP-carrot bait ranked second in efficacy (43% activity reduction), although its effect was greater on the Bend plots than on the Sisters plots (72 vs 28% activity reduction). A similar disparity between study areas was apparent with the 1.82% ZnP-oat bait, which reduced activity 62% on the Bend plots compared with 11% on the Sisters plots. This variation probably was caused by habitat differences that influenced bait acceptance or gopher susceptibility to the toxicants. The 0.92% and 1.00% ZnP baits were ineffective on both study areas.

Table 4. Mean number of burrow systems plugged per replicate (30 maximum) by pocket gophers 10-12 days after bait application. Values by the same letter within columns are not significantly different ($P > 0.05$).

Bait	Number of active burrow systems ($\bar{x}$)		
	Bend replications (2)	Sisters replications (3)	Total (5)
Control (untreated oats)	19.5 A	24.0 A	22.2 A
0.92% ZnP-lecithin oil-rolled oats	18.5 A	23.7 A	21.6 A
1.00% ZnP-petrolatum + mineral oil-crimped oat groats	20.5 A	20.3 A B	20.4 A
1.82% ZnP-lecithin oil-rolled oats	7.5 B	21.3 A	15.8 A B
0.75% ZnP-corn oil-carrot	5.5 B	17.3 B	12.6 B
0.50% Strychnine alkaloid-Rhoplex-rolled oats	5.0 B	3.0 C	3.8 C

Radio-telemetry data.--Overall, mortality was high among radio-collared gophers baited with ZnP-carrot and strychnine-oat baits and low for animals exposed to ZnP-oat baits (Table 5). The ZnP-oat baits, however, were generally effective on the Bend plots but not on the Sisters plots. In comparison with the open-hole evaluation, telemetry data agreed with high efficacy of strychnine bait but indicated greater mortality associated with ZnP-carrot bait and ZnP-oat baits.

The 27 radio-marked gophers killed by bait treatment (Table 5) were recovered at a mean depth of 95 cm below ground. Eleven (41%) of the 27 carcasses were found in nests. Caches of bait were found in 15 (75%) of the 20 nests of bait-killed gophers and 3 (25%) of the 12 nests used by surviving animals.

Table 5. Fate of radio-collared pocket gophers baited with zinc phosphide (ZnP) and strychnine alkaloid baits.

Bait	Deaths/number of animals marked		Percent total mortality
	Bend area	Sisters area	
0.75% ZnP-corn oil-carrot	4/4	5/6	90
0.50% Strychnine alkaloid-Rhoplex-rolled oats	3/4	5/6	80
0.92% ZnP-lecithin oil-rolled oats	3/4	1/6	40
1.00% ZnP-petrolatum + mineral oil-crimped oat groats	3/4	0/6	30
1.82% ZnP-lecithin oil-rolled oats	2/4	1/6	30

Nontarget mortality.--We found evidence of nontarget mortality associated with ZnP and strychnine baits. The carcass of an adult male Belding ground squirrel (*Spermophilus beldingi*) was found 92 cm below ground in a nest of a radio-marked gopher. The mutilated carcass of the gopher and a cache of 0.92% ZnP-oat bait were also in the nest. We speculated that the ground squirrel mutilated the dead or dying gopher and then ingested bait.

In a plot treated with 0.5% strychnine-oat bait we excavated a gopher nest (108 cm deep) containing bait and the carcasses of a gopher and a golden-mantled ground squirrel (*S. lateralis*). Two other animals, a deer mouse and a golden-mantled ground squirrel, were found dead above ground on strychnine-baited plots and were recorded as nontarget mortalities.

CONCLUSIONS

ZnP-grain baits produced inconsistent but generally poor results for control of pocket gophers. Our data indicated that prebaiting would improve acceptance of those baits, but we do not believe prebaiting would be economically feasible for most pocket gopher control programs. The ZnP-carrot bait, in contrast, showed potential for gopher control without the need to prebait.

Laboratory tests suggested that additional bait development with ZnP could produce an effective formulation for gopher control. There is an obvious need to modify baits to exploit grooming behavior of gophers. Additional study of bait size and shape could also enhance efficacy of carrot bait.

Results of the field evaluation emphasized the need for thorough testing of candidate rodenticides over a wide range of environmental conditions. We detected differences in bait efficacy between the two study sites in central Oregon and attributed the variation to dissimilar habitat conditions. Similar variations caused by habitat diversity, species difference, and other factors can be expected elsewhere.

Our observations of nontarget mortality stressed the importance of continued investigation and operational monitoring of wildlife hazards associated with use of pesticides. Depending on the area, gopher baiting may or may not affect populations of small mammals (Fagerstone et al. 1980, Hegdal and Gatz 1976). Also, there should be consideration for animals that might feed on carcasses of nontarget kills. Our findings concur with Fagerstone et al. (1980) that at least some nontarget rodents are likely to die above ground. Fortunately, our study and previous work (Barnes et al. 1980) showed that gophers generally die below ground and their carcasses are not readily available to most scavengers.

In the field evaluation we found that radio telemetry and open-hole census data provided different estimates of bait efficacy. These differences can be explained in part by characteristics of the open-hole technique and by our study design. The open-hole method is based on the assumption that each burrow system is occupied by one animal. Because some burrow systems are likely to have more than one gopher (Hansen and Miller 1959), the method provides a conservative estimate of control. Furthermore, our baiting efforts were directed at individual burrow systems and not entire areas. This very likely resulted in the invasion of some treated systems by neighboring animals. Survival of any invading gophers would also cause the open-hole census to underestimate kills. In contrast, the telemetry evaluation involved only one animal per burrow system and was not influenced by cohabitation or invasion by other animals. Despite these inconsistencies in the data, both methods of evaluation ranked strychnine-coated oats and ZnP-coated carrots as the most effective baits.

In summary, the 0.75% ZnP-carrot bait compared favorably with the 0.5% strychnine-oat bait for control of pocket gophers. Carrot bait probably would present more problems than grain bait to formulate, store, handle, and distribute. These difficulties might restrict wide-scale use of carrot bait regardless of how effectively it controls gophers. However, these limitations should not restrict small-scale use of an effective carrot bait. We therefore recommend further development of the 0.75% ZnP-carrot bait as a substitute for strychnine-oat bait for local areas where safety to wildlife or domestic animals must be ensured.

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