USE OF ZINC PHOSPHIDE FOR CALIFORNIA GROUND SQUIRREL CONTROL

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ABSTRACT: Zinc phosphide (ZnP) is the only acute rodenticide currently registered for control of the California ground squirrel (*Spermophilus beecheyi*). Research has shown ZnP to give excellent control of sciurid rodents, but operational control programs in California have reported poor and inconsistent control. We examined the literature and conducted 34 field trials between 1996 and 1999 in order to identify factors affecting the field efficacy of ZnP. Important factors identified from the literature include bait acceptance, prebaiting, and timing of control operations in relation to ground squirrel and vegetation phenology. We used ground squirrel counts or active burrow counts to assess the efficacy of ZnP in the field trials. Treatments were either mechanical broadcast or spot baiting of 2% ZnP-treated oat groats. The first field trials in 1996 and 1997 were conducted without bait acceptance tests and prebaiting, and control was inconsistent, ranging from none on one plot, poor on three plots (45% to 63%), to good on two plots (84% to 87%). Field trials in 1998 and 1999 were conducted with bait acceptance tests and pre-baiting. In 1998 control was excellent (88% to 100%) on all plots. However, control was variable in 1999 trials with good control (80% to 90%) on five plots, but poor control (60% to 79%) on two plots, and no control on one plot. In our studies, pre-baiting had little effect on the efficacy of the ZnP for controlling California ground squirrels.

KEY WORDS: broadcast baiting, California ground squirrel, control, efficacy, bait acceptance, best management guidelines, prebaiting, *Spermophilus beecheyi*, spot baiting, zinc phosphide

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INTRODUCTION

Zinc phosphide (ZnP) is an acute rodenticide that has been used for many years for rodent control (USDA APHIS 1994). It is a fast acting material that produces visible toxicosis within an hour of consumption. Investigators have reported that zinc phosphide rodenticide baits have a distinct odor and taste and this is believed important in the overall effectiveness of this material. In California, ZnP is the only acute rodenticide registered for California ground squirrel (*Spermophilus beecheyi*) control. Marsh (1987) provides a historical account of ZnP and discusses its general characteristics and uses. He reports inconsistent effectiveness varying from 25% to 75% for the California ground squirrel. In many operational control programs in California, growers report poor results. However, recent studies conducted under strict research conditions reported population reductions of up to 96% for the California ground squirrel (Matschke et al. 1995).

Various factors could influence ZnP efficacy (Bruggers et al. 1995; Koehler et al. 1995; Sterner and Ramey 1995). ZnP is relatively stable under normal storage conditions (Lund 1988; Elmore and Roth 1943; Anonymous 1967; and Guerrant and Miles 1969), but ZnP-grain bait concentration may be reduced in crop situations due to application method, precipitation, and soil acidity (Sterner and Ramey 1995; Hilton et al. 1972; Hilton and Robison 1972).

Researchers have documented the efficacy of ZnP for the control of voles, rats, or various species of ground squirrels (Table 1). Factors that appear to relate to efficacy in these studies include: prebaiting, bait acceptance, species differences in bait acceptance, bait quality, bait type (grain vs. pellet), moisture resistance, weather factors, timing of application with regard to species and vegetation phenology, and frequency of baiting.

Most of the published ZnP field trials involving ground squirrels or prairie dogs have used spot or hand baiting application methods. Tietjen and Matschke (1982) compared spot vs. aerial prebaiting, but then spot baited on all plots for prairie dog control. They achieved excellent control (88% to 96%) with both prebaiting methods. Matschke et al. (1995) directly compared the two baiting methods and 1% vs 2% ZnP. They achieved excellent control (>90%) of California ground squirrels and found no difference between the baiting methods or the different strengths of ZnP. They did not test the effect of prebaiting.

Sterner (1994) examined animal foraging behavior and particle-dose analysis (predicting the specific number of treated grains needed to achieve a LD_{50} for a target or nontarget species) to comment on broadcast vs. spot baiting. He predicted aerial or mechanical broadcast should prove effective for voles and mice, which need to ingest only one to four grains to get an LD_{50}. On the other hand, localized dense applications (i.e., spot baiting) should be more effective with prairie dogs that require $\geq$39 grains for an LD_{50}. Sterner also predicted that bait shyness in prairie dogs would more likely result from broadcast baiting than spot baiting since foraging for widely dispersed, broadcast bait would require more time, with an increased likelihood for interruptions during the search. The increased foraging time could allow sufficient time for the onset of ZnP hydrolysis in the gastro-intestinal tract before a fatal dose had been ingested, causing a cessation of feeding and subsequent bait shyness.

Our objective was to evaluate the effectiveness of ZnP in operational-type ground squirrel control programs and

Table 1. Information on published and unpublished field trials or efficacy studies using zinc phosphide.

Authors	Target Species[a]	Prebait?	Baiting Method[b]	Control	Comments
Apa et al. 1990	Black-tailed prairie dog	Yes	B,S	95%	Level of reduction maintained at least through the following year. Prebait increased bait consumption.
Cincotta et al. 1987	Black-tailed prairie dog	Yes	U	≥99%	Excellent control. Subsequent immigration resulted in more yearlings than expected.
Knowles 1986	Black-tailed prairie dog	Yes	S	65%-95%	Best control on plots with total bait coverage, lowest control on plots with perimeter treatment only. Took 3 to 5 years for population to rebound on plots with total coverage.
Lefebvre et al. 1978	Roof rat	Yes	NA	18%	Lab study; prebaiting with raw oat groats enhanced consumption by roof rats only, but species differences in acceptance and mortality. Bait not effective for roof rat.
	Cotton rat	Yes	NA	67%	
Lefebvre et al. 1985	Roof rat	No	AB	18%	Pelleted bait not moisture resistant; rain fell second night after application. Prebaiting with non-toxic pellet not possible.
Marsh and Record 1985	California ground squirrel	No	AB	76%	Authors considered results good, but might have been better if not for rapid onset of high temperatures that induced estivation.
Matschke et al. 1982	Richardson's ground squirrel	Yes	S	60% for May-Jun, 95% for Jul-Aug	Vegetation phenology affected bait acceptance. Green vegetation preferred in May-June trial, but vegetation dried by second trial, increasing attractiveness of bait vs. the vegetation. Annual retreatment may be needed for this species.
Matschke et al. 1983	Richardson's ground squirrel	Yes	B	85%	Good results; authors offer no specific reasons to suggest why.
Matschke et al. 1995	California ground squirrel	Yes	B, S	>90%	Vegetation phenology optimum with grasses dried, but some estivation probably occurred. No difference between 1% vs. 2% ZnP or in spot baiting vs. broadcast baiting.
Proulx 1997	Richardson's ground squirrel	?	U	<40%	Abstract only. Implied timing was important; ZnP was more efficient in late April than in late July.

Table 1. continued.

Authors	Target Species[a]	Prebait?	Baiting Method[b]	Control	Comments
Sterner et al. 1996	Gray-tailed vole	Yes	B	>94%	Authors suggest bait formulation used was highly palatable and well accepted.
Sugihara et al. 1995	Roof rat, Norway rat, Polynesian rat	Yes	AB	~30% for Norway rat	Low efficacy due to absorption of moisture and physical degradation that reduced acceptance. Breakdown of ZnP not suspected. Repeated ZnP treatments (≥2/yr) over 20 years may have created bait aversion. Bait formulation may also be a factor. Prebaiting enhanced effectiveness, but overall, ZnP not effective.
Sullins and Sullivan 1991	Richardson's ground squirrel	Yes	S	97%-early spring	Timing important. Best applied when squirrels emerge, prior to spring green-up. Prebaiting necessary. Oat bait best. Pelleted bait not well accepted, not possible to prebait with non-toxic pellet.
		Yes	S	56%-mid spring	
		No	S	32%-mid spring	
		Yes	S	78%-summer	
	Columbian ground squirrel	No	S	24%-May	Timing also a factor, but squirrels emerge later, after green-up, hindering bait acceptance. Best results in summer when seeds more prevalent in diet.
		Yes	S	48%-May	
		Yes	S	71%-July	
Sullins and Sullivan 1995	Richardson's ground squirrel	Yes	S	96%	Prebaiting gave better results for all species. Species differences exist; control not good for Columbian ground squirrels. Timing of application is important in relation to vegetation phenology and ground squirrel cycle, e.g., emergence, diet.
		No	S	62%	
	Columbian ground squirrel	Yes	S	53%	
		No	S	13%	
	Black-tailed prairie dog	Yes	S	92%	
		No	S	77%	
Tietjen and Matschke 1982	Black-tailed prairie dog	Yes	S	88%-96%	Tested spot vs. aerial prebaiting, but all plots were spot baited during treatment. Good results with either prebaiting method.

Table 1. continued.

Authors	Target Species[a]	Prebait?	Baiting Method[b]	Control	Comments
Uresk et al. 1986	Black-tailed prairie dog	Yes	U	95%	Prebaiting considered essential.
Uresk and Schenbeck 1987	Black-tailed prairie dog	Yes	S	93%	Good control; treatment once every three years sufficient to control colony expansion.

[a]Scientific names for species, in the order as presented in the table: black-tailed prairie dog (*Cynomys ludovicianus*); roof rat (*Rattus rattus*); cotton rat (*Sigmodon hispidus*); California ground squirrel (*Spermophilus beecheyi*); Richardson's ground squirrel (*Spermophilus richardsonii*); gray-tailed vole (*Microtus canicaudus*); Norway rat (*Rattus norvegicus*); Polynesian rat (*Rattus exulans*); Columbian ground squirrel (*Spermophilus columbianus*).
[b]Baiting method: AB=aerial broadcast; B=broadcast from ground-based seed spreader; NA=not applicable, laboratory study; S=spot baiting by hand; U=unknown, method not described in text.

to identify potential areas where baiting techniques or other operations could be changed to improve the efficacy of ZnP bait.

METHODS

Field Trials

We conducted 34 field trials at seven different locations to measure the efficacy of ZnP for California ground squirrel control (Table 2). Using counts of ground squirrels or their burrows as indices, we evaluated population changes related to our treatments. Treatments included ZnP bait with and without bait acceptance tests and prebaiting.

Ground squirrel counts. Visual census was the primary method for assessing ground squirrel population activity. We counted ground squirrels on the study plots during a three-day period before treatment and for a three-day period after treatment. On the count days we arrived at a fixed viewing point for each plot between 0800 and 0930 h (period of most squirrel activity). After a 15-minute period, we counted every squirrel seen in a scan of the plot. We completed five separate scans across the plot (at 5-minute intervals) using 10X binoculars or a 20X spotting scope. We varied the order in which the plots were counted every day.

Burrow counts. At AR we used burrow counts as the index of ground squirrel populations. The burrow count method involved filling all burrows openings with soil on the first day of the pre-treatment squirrel counts. We then counted reopened burrows after the last pre-treatment squirrel count (three days later). The same procedure was followed during the post-treatment period. We counted and filled burrows within the study plots and in a buffer zone of up to 61 m around each plot.

Bait acceptance tests. We conducted bait acceptance tests during the pretreatment ground squirrel counts on plots at five of the seven study sites (Table 2). In the morning, we placed a tablespoon of clean oat groats on bare ground at ten points near active burrows that appeared to be from different systems. We visually estimated the amount of grain consumed around mid-day and again in the late afternoon. We initiated prebaiting if consumption of the bait piles averaged ≥90%. These tests were used primarily to determine if the squirrels had switched from a diet of green vegetation to seeds. Secondly, since the grain used in the tests is the same as that to be used during the prebaiting and treatment, the tests determine if the squirrel will accept that particular type of grain.

Prebaiting. Prebaiting is the application of nontoxic, or "clean" bait, on the area that will be treated later with a toxic bait. Prebaiting introduces the bait material to the target animals and conditions them to eat the particular toxic bait carrier (e.g., oat groats). We prebaited on five of the seven study sites or 26 of 34 plots (Table 2). We used the spot-baiting technique for the three trials in 1998, spreading 1 tablespoon of clean oat groats near to all open burrows and at other locations of ground squirrel activity. In 1999, at the MD and S-99 sites we prebaited using a "Herd Sure-Feed" seed broadcaster mounted on a 4wd ATV. We calibrated the broadcaster during tests at the University of California Davis prior to arrival at the study sites. Prebait was broadcast at a rate of 6.7 kg/ha (6 lb/ac). At each of the 1999 sites, we prebaited only two of the four treatment plots. In addition to the prebaited plots, we also prebaited a minimum 30.5 m buffer zone around each prebaited plot.

Treatment. At the S-96 and CTR sites, 2% ZnP on oat groats was broadcast at a rate of 11.2 kg/ha (10 lb/ac) from a custom-built seed spreader mounted on a 4wd ATV. An estimated area of 65 to 81 ha were treated at S-96, which included large buffer areas around the study plots. Likewise, the 111 ha treated at CTR included large buffer areas judged sufficient to prevent squirrels from outside the plots from invading the plots during the post-treatment period.

We spot baited ZnP, as described above for prebaiting, at the three study sites in 1998. In 1999, we used the "Herd Sure-Feed" spreader on the MD and S-99 sites to broadcast the ZnP at a rate of 6.7 kg/ha. Approximately 24 ha were treated at MD and 10 ha at S-99. One or two plots were left as untreated control plots at each site.

Efficacy calculations. We used the maximum number of ground squirrels seen during the five scans on each count day as an index of population level on each plot. We calculated the average maximum number of ground squirrels for each three-day count period for each

Table 2. Name, location, and other characteristics of seven study sites treated with ZnP for ground squirrel control.

Name	Location: Town	Location: County	Bait Acceptance Tests	Prebaited	Habitat Description
S-96	King City	Monterey	No	No	Annual grassland; cattle present; heavily grazed; west side of one treated plot bordered irrigated broccoli fields and had a seep with green vegetation running along the east side. Excellent sight lines with colonies located on hillsides; herbaceous plant height 0 to 15 cm. Plot size from 0.6 to 2.4 ha.
CTR	Long Valley	Monterey	No	No	Old barley field, recently harvested; two of four plots also disced; cattle present; heavily grazed; grass 0 to 15 cm high where not disced, but mostly trampled; sparse to moderate stand of mustard (*Brassica* sp.) in one plot; ground very dry with many deep cracks and fissures. Excellent sight lines for viewing. Plot size from 1 to 4 ac.
CL	Tracy	San Joaquin	Yes	Yes	Annual grassland; cattle present; moderately grazed; annual grass height 0 to 3 cm; mostly dried up, some doveweed (*Eremocarpus setigerus*) present. Good to excellent sight lines. Plot size from 0.4 to 2.1 ha.
AR	Pozo	San Luis Obispo	Yes	Yes	Oak/digger pine/chaparral habitat with annual grasses; green grasses and sedges in seeps running through two plots; grass height 15 to 30 cm; cattle present; lightly grazed. Poor to excellent sight lines, unfavorable topography a factor. Plot size from 0.1 to 0.3 ha.
PR	Greenfield	Monterey	Yes	Yes	Annual grasslands with scattered oak trees; cattle present, plots lightly to heavily grazed. In 10/98, herbaceous vegetation dried except for a few green forbs; vegetation height 0 to 61 cm. Sight lines fair to excellent. Plot size from 0.6 to 1.8 ha. In 3/99, excellent sight lines with vegetation 2.5 to 15 cm high, but one plot uncountable with grass 30 to 61 cm high.
MD	Approx. 19 km east of Madera	Madera	Yes	Yes	Annual grasslands intermixed with oak and pine trees; numerous rock outcroppings on each of the four plots; light cover of green grasses and forbs along the shorelines and in the swales draining into stock ponds on all four plots; dense but dried out grass cover on the higher upland portios of the plots, grass height 15 to 91 cm; cattle present; plots lightly grazed. Poor to good sight lines. Plot size from 1.6 to 5.3 ha.
S-99	King City	Monterey	Yes	Yes	Annual grassland; cattle present; heavily grazed; irrigation runoff from nearby croplands resulted in green herbaceous vegetation on or adjacent to the four treated plots. Excellent sight lines. Plot size from 0.8 to 3.0 ha.

plot. We used Kolmogorov-Smirnov nonparametric test to compare the number of ground squirrels seen in the pre-treatment vs. post-treatment periods. We used a one-way ANOVA and Duncan's multiple range test to compare results from the pre-treatment and two post-treatment counts at PR.

Statistical tests were not undertaken for the AR data. The squirrel colonies on this ranch were small and isolated. Thus, we used only descriptive data from squirrel and burrow counts to assess control efforts on this site.

RESULTS

Our results indicate varied efficacy of ZnP bait to control California ground squirrels (Tables 3, 4, and 5).

S-96

There was no difference in squirrel numbers on the control plot between the pre- and post-treatment periods. There were significant decreases in squirrel numbers on all three treated plots (Table 3). Good control (>80%) was achieved on plots 1 and 2, but control was poor (45%) on plot 3. Unlike the other two plots, plot 3 had green grass and herbs due to irrigation runoff from the adjacent broccoli fields. We observed squirrels foraging in these areas.

CTR

There was a significant decrease in the number of squirrels on the control plot after the treatment period (Table 3). We did not consider estivation as the cause because high temperatures, thought to trigger estivation, did not occur during the trial. The 35% decrease accents the poor control on the treated plots, suggesting the decreases in squirrel numbers on the treated plots were not all due to ZnP. The change in squirrel numbers was significant on plots 2 (63%) and 3 (55%), but were unsatisfactory in terms of squirrel management. There was no statistical change in squirrel numbers on plot 1, suggesting a total failure of ZnP on this plot. Plot 1 had the most green vegetation of all the plots, mostly comprised of mustard (*Brassica* sp.). We observed squirrels foraging on the mustard.

CL

Bait acceptance tests showed acceptable consumption of the clean oat groats. There was no significant change in squirrel numbers on the control plot (Table 3). Excellent control was achieved on the three treated plots, with reductions ranging from 90% to 93%.

AR

During the pre-treatment period, consumption of the clean oat groats was acceptable on all plots except plot 3. Consumption on plot 3 never exceeded 60%, but we considered overall consumption from the other plots adequate to proceed with prebaiting. At the end of the pretreatment period 14% to 96% of the filled-in burrows were reopened (Table 4). Pre-treatment ground squirrel counts showed very low numbers of squirrels on the plots, averaging 3.0 squirrels on the control and plots 1 and 2, and 0.7 squirrels on plot 3.

Squirrel numbers increased slightly during the post-treatment period on the control plot, averaging 3.3 squirrels. Post-treatment counts revealed no squirrels on plots 1 to 3. There also were no reopened burrows on plots 1 to 3, suggesting 100% control. On the burrow count-only plots, there were no reopened burrows on plot 4, but one reopened burrow on plot 5, suggesting close to 100% control. Combining all the burrows from the five treated plots, there was only one reopened burrow after treatment.

PR

Bait consumption tests ended after one day as a result of acceptable consumption of the clean oat groats on the plots. There were no significant changes in the squirrel numbers on the two control plots during the pre-treatment and the first post-treatment periods (Table 5). There were significant decreases in squirrel numbers on all four treated plots after treatment, ranging from 88% to 100%. However, five months after treatment, squirrel numbers equaled or surpassed numbers recorded during the pre-treatment period on two of the three treated plots where counts were conducted.

MD

Bait consumption tests ended after one day with acceptable consumption of the clean oat groats on the plots. Squirrel numbers on the control plot did not change from the pre-treatment to the post-treatment period (Table 3). Significant decreases in squirrels numbers occurred on three of four plots after treatment. Good control (85% to 89%) occurred plots 1 to 3. A reduction in squirrels of 73% occurred on plot 4, but it was not significant. All of the plots had green vegetation, but there was no obvious relationship to efficacy, with only one of the four treated plots having <80% control. Prebaiting appeared to have no impact on efficacy. Plots 1 and 2, the non-prebaited plots, had control similar levels of control (in the 85% to 89% range) as the best prebaited plot, plot 3.

S-99

Bait acceptance reached an acceptable level (>90%) after the morning of Day 2. There was no significant change in squirrel numbers on the control plot during the pre- and post-treatment periods (Table 3). Control was good (80% to 84%) on the two non-prebaited plots. Control on one prebaited plot was poor (66%) and was a total failure on the second prebaited plot (4% increase in squirrels). Prebaiting appeared to have no positive effect on efficacy of ZnP.

DISCUSSION

Many California growers believe that ZnP is not cost effective for ground squirrel control and, therefore, do not use this material. The California Department of Food and Agriculture annual Report 3-A compiles data on the amount of pesticides used by each county to control vertebrate pests seems to confirm ZnPs low status as a squirrel control option. During the seven-year period from 1991 to 1997, only 135,941 kg of 1% and 2% ZnP bait was sold by 24 counties (Table 6) for the purpose of ground squirrel control compared to the 2.5 million kg of

Table 3. Maximum number of ground squirrels seen on control and treated plots during pre-treatment and post-treatment periods at five study sites, 1996 to 1999.

		Pre-treatment		Post-treatment		
Location	Plot	$\bar{x}$	SE	$\bar{x}$	SE	Percent Change
S-96	Control	33.3	5.8	33.0	1.4	- 0.1
	1	31.3	2.5	4.0	0.6	-87.2[a]
	2	51.0	4.0	8.0	1.0	-84.3[a]
	3	28.7	0.7	15.7	4.2	-45.3[a]
CTR	Control	53.3	0.9	34.7	5.9	-35.0[a]
	1	62.0	10.4	45.0	12.2	-27.4
	2	191.7	19.7	70.7	4.4	-63.3[a]
	3	38.0	2.9	17.0	2.5	-55.3[a]
CL	Control	6.3	0.6	5.7	1.5	-10.5
	1	20.0	4.6	1.3	0.3	-93.3[a]
	2	10.0	2.5	1.0	0.6	-90.0[a]
	3	20.3	3.5	2.0	0.6	-90.7[a]
MD	Control	5.5	0.5	7.0	1.0	+27.3
	1	6.0	1.5	0.7	0.6	-88.9[a]
	2	11.0	2.1	1.7	0.7	-84.8[a]
	3[b]	13.7	3.5	1.7	0.3	-87.8[a]
	4[b]	7.3	2.9	2.0	0.6	-72.7
S-99	Control	14.3	1.7	10.3	0.9	-28.0
	1[b]	25.0	6.4	26.0	4.0	+4.0
	2	6.3	1.8	1.0	0.6	-84.2[a]
	3[b]	47.3	2.0	16.0	4.6	-66.2[a]
	4	6.7	1.2	1.3	0.9	-80.0[a]

[a]Number of ground squirrels in post-treatment period significantly different than number observed in pre-treatment period (Kolmogorov-Smirnov nonparametric test).
[b]Plots prebaited with clean oat groats two or three days prior to treatment with ZnP.

Table 4. Number of ground squirrel burrows filled and reopened on control and treated plots (1 to 5) during pre-treatment and post-treatment periods at the AR near Pozo, San Luis Obispo County, July 1998. All plots were prebaited with clean oat groats prior to treatment with ZnP.

	Pre-treatment Burrows			Post-treatment Burrows		
Plot	Filled in on 7 July	Reopened by 9 July	Percent Reopened	Filled in on 16 July	Reopened by 18 July	Percent Reopened
Control	33	18	54.5	18	16	88.9
1	48	31	64.6	46	0	0
2	87	50	57.5	79	0	0
3	43	6	14.0	8	0	0
4	27	26	96.3	26	0	0
5	47	23	48.9	48	1	2.1
Total	285	154	54.0	225	17	7.6

Table 5. Maximum number of ground squirrels seen on control and treated plots (1 to 4) during pre-treatment and two post-treatment periods at PR near Greenfield, Monterey County, October 1998 and March 1999. All plots were prebaited with clean oat groats prior to treatment with ZnP.

	Pre-treatment (A)		Post-treatment (B)		% Change	Post-treatment (C)		F		Relation Between
Plot	$\bar{x}$	SE	$\bar{x}$	SE	A vs. B	$\bar{x}$	SE	Value	P	Counts
Control 1	7.7	2.0	5.3	0.9	-30.4	15.7	1.2	13.9	0.006	A=B,B<C,C>A
Control 2	9.0	3.2	6.7	2.0	-25.9	6.3	0.9	0.4	0.677	A=B=C
1	22.3	4.8	2.7	0.3	-88.1	13.3	1.8	10.9	0.010	A>B,B<C,C=A
2	8.7	2.7	0	0	-100	9.0	1.5	8.3	0.019	A>B,B<C,C=A
3	17.0	4.4	1.3	1.3	-92.2	7.0	2.0	7.6	0.022	A>B,B=C,C<A
4	17.0	3.5	0	0	-100	-	-	-	-	A>B

Table 6. Kilograms of 1% and 2% zinc phosphide grain bait sold for ground-based, California ground squirrel control by California counties by year. Data from California Department of Food and Agriculture Report 3-A from 1991 to 1997.

County	1991	1992	1993	1994	1995	1996	1997	Total
Alameda	23	26	0	125	111	36	74	395
Alpine	0	0	0	0	0	0	8	8
Colusa	186	91	0	129	9	0	0	415
El Dorado	92	90	71	129	318	45	53	798
Fresno	5,252	5,550	1,898	1,462	767	1,481	1,435	17,845
Glenn	112	230	144	587	206	556	420	2,255
Kern	132	113	181	0	0	0	0	426
Kings	0	0	0	0	0	0	27	27
Lassen	0	0	0	34	0	9	0	43
Merced	4,082	3,130	3,386	7,979	5,872	4,277	3,016	31,742
Monterey	1,299	4,323	2,548	6,295	1,788	817	9,088	26,158
Orange	1,882	458	0	0	0	0	0	2,340
Plumas-Sierra	4	0	0	0	0	0	0	4
Riverside	1,358	694	261	315	29	0	0	2,657
Sacramento	515	552	810	318	200	152	211	2,758
San Benito	120	413	485	1,894	966	989	499	5,366
San Bernardino	3,688	1,955	1,177	1,522	973	1,020	1,463	11,798
San Joaquin	417	308	1,442	435	3,200	2,948	1,461	10,211
Santa Clara	0	0	0	0	0	0	159	159
Siskiyou	0	45	0	0	0	0	0	45
Stanislaus	703	1,973	181	0	0	0	0	2,857
Sutter	322	1,353	623	1,175	1,125	197	0	4,795
Tulare	0	159	68	839	168	435	181	1,850
Yolo	679	624	3,588	5,976	122	0	0	10,989
Total	20,866	22,087	16,863	29,214	15,854	12,962	18,095	135,941

anticoagulants sold or used by the counties from 1991 to 1997 (Figure 1). There is no obvious trend in 2% ZnP use, rather the amount used fluctuated from year to year. In any given year, the amount of anticoagulants used was 14 to 27 times the amount of ZnP.

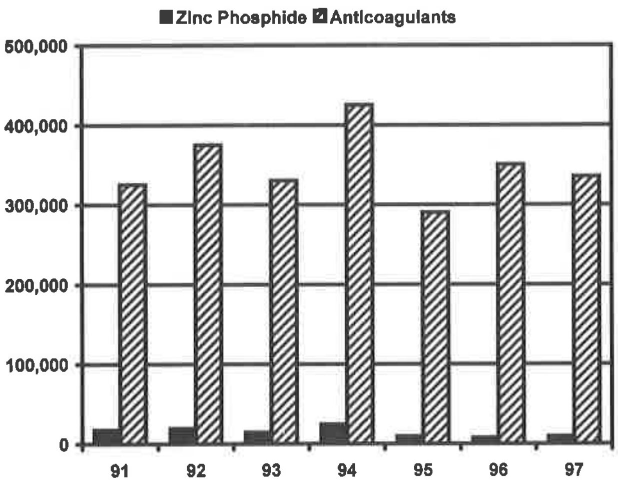

Figure 1. Kilograms of anticoagulant grain baits (chlorophacinone and diphacinone) and zinc phosphide grain bait (1% and 2%) sold or used by California Agriculture Commissioners by year for ground-based California ground squirrel control. Data from California Department of Food and Agriculture Report 3-A from 1991 to 1997.

ZnP has never been the preferred ground squirrel bait in California. During the seven-year period from 1981 to 1990 the counties sold or used over 1.5 million kg of compound 1080, 4.1 million kg of anticoagulants, and ~250,000 kg of ZnP (Figure 2). Compound 1080 became unavailable in 1991, however, there was no substantial increase in either ZnP or anticoagulant use for ground squirrel control after that time. Since the costs of using ZnP for ground squirrel control are similar to anticoagulants, the relative low use suggests a problem with efficacy of this material.

The literature indicates a number of factors contribute to successful ground squirrel control. Vegetation phenology influences bait acceptance (e.g., Matschke et al. 1982; Matschke et al. 1995; Sullins and Sullivan 1991, 1995). For some squirrel species, including California ground squirrels, the best bait acceptance and control is achieved after the vegetation has dried, at which time seeds become more prevalent in the diet. For the Richardson's ground squirrel, on the other hand, grain bait is most effective when the squirrels emerge from winter hibernation, prior to spring green-up. In either case, the timing of the bait application is critical. Timing of control is also important as it relates to ground squirrel behavior, especially estivation. Marsh and Record (1985) achieved 76% control of California ground squirrels, but indicated control could have been better if conducted before the rapid onset of high temperatures that triggered estivation. We believe that the timing of control and vegetation phenology were not primary factors influencing our tests.

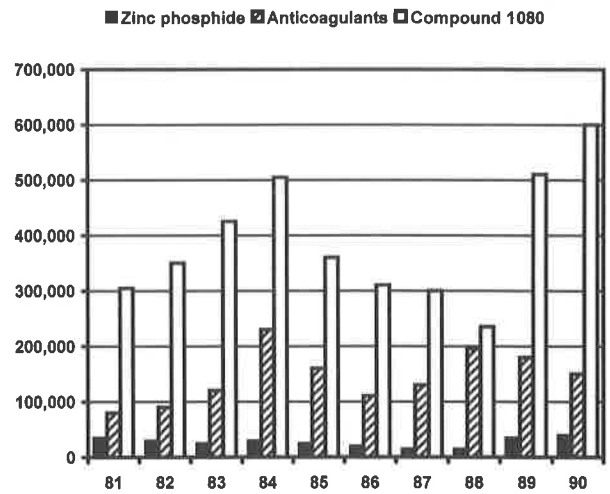

Figure 2. Kilograms of compound 1080, anticoagulant grain baits (chlorophacinone and diphacinone), and zinc phosphide grain bait (1% and 2%) sold or used by California Agriculture Commissioners for ground squirrel control by year. Data from California Department of Food and Agriculture Report 3-A from 1981 to 1990. Data for compound 1080 include amounts used for Belding's ground squirrels as well as for California ground squirrels.

The literature also shows that prebaiting improves efficacy of ZnP for some species. Sullins and Sullivan (1991, 1995) showed increases in control ranging from 15% to 40% when prebait was applied. Uresk et al. (1986) considered prebaiting essential for Black-tailed prairie dog control. Pre-baiting is recommended but not required by the 1% or 2% ZnP labels registered in California for ground squirrel control. The labels only state that prebaiting "may enhance bait acceptance by target species, indicate their degree of readiness to accept bait and identify potential problems of non-target exposure."

The results of our field trials varied and support the contention of many growers and others, mainly that ZnP is inconsistent in its effectiveness. The first two trials in Monterey County were undertaken in late May when the rangeland vegetation had dried, the young were above ground, but estivation, in our opinion, had not yet occurred. Several plots had green grass and forbs, in part due to irrigation runoff. Of the six plots treated, two had good control (84% to 87% reduction), three had poor control (45% to 63% reduction), and one had no control at all. Neither bait acceptance tests nor prebaiting were undertaken at these trials.

The three trials in 1998 achieved excellent control on all 12 treated plots (88% to 100% reduction). Conditions at all three sites were similar: grazed rangelands, vegetation dried out, no or few alternate green food sources, young squirrels above ground, and no onset of estivation during the trial (except possibly at PR). Bait acceptance tests, prebaiting, and spot baiting were employed at all the sites. These results are similar to those of Matschke et al. (1995) who obtained excellent control (>90%) using both 1% and 2% ZnP by spot or broadcast baiting.

The last trials in 1998 at PR were conducted in the fall and achieved excellent control (88% to 100%). However, late fall treatments are generally discouraged due to concern that many adult squirrels may have already gone into hibernation, leaving only a portion of the population active above ground (e.g., mainly juvenile squirrels). Despite the high mortality in the squirrels still active above ground at the time of our treatment, follow up counts showed repopulation of the plots five months later. These results point to the need for additional testing of fall treatments.

The two 1999 trials gave inconsistent results with the broadcast bait giving excellent control (88%) on two plots, but poor control (60% to 79%) on two plots and no control on one plot. These results were especially disappointing at S-99, with no significant control on two of the four plots. In addition, prebaiting had no effect on efficacy. Obvious differences between the trials in 1998 (with excellent results) and those in 1999 were the method of baiting (spot baiting in 1998, broadcast baiting in 1999) and the presence of green food sources (none or very little in 1998, abundant in 1999 on S-99).

Sterner (1994) discusses potential problems with ZnP and, although he provides no data on California ground squirrels, his predictions may have application to S-99. The LD_{50} of ZnP for the California ground squirrel (33.1 mg/kg) is nearly twice the LD_{50} of the black-tailed prairie dog (Clark 1994). Following Sterner's formulas, a 0.75 kg California ground squirrel would require about 54 grains for a lethal dose compared to $\geq$39 grains for a prairie dog. Although the California ground squirrel is a good forager capable of finding broadcast bait, there may be some conditions that could hinder foraging and increase the time span to find and consume a lethal dose of bait. If ZnP hydrolysis begins in the gastro-intestinal tract before consumption of a lethal dose, then bait shyness and poor control could result. Dense cover or cracks and fissures in dried-out soil may prevent squirrels from foraging efficiently in a given area. The presence of green forage (such as at S-99) in combination with broadcast baiting could represent another situation that hinders bait consumption since squirrels might feed on the green forage as well as the grain bait, potentially slowing down bait consumption to the point where onset of symptoms, and subsequent bait shyness, occur before a lethal dose is consumed.

In contrast to broadcast baiting, spot baiting scatters a tablespoon of ZnP bait in a relatively small area, usually near a burrow. The bait placement is probably more easily found by squirrels and contains more than a lethal dose of bait. Spot baiting likely decreases the foraging time required to find a lethal dose by placing the required amount in one location. However, broadcast baiting was very effective for Matschke et al. (1995) and in our MD tests, demonstrating that this application method can work.

Research has shown that prebaiting may increase control by 20% or more (e.g., Sullins and Sullivan 1995). Prebaiting did not appear to improve efficacy of ZnP for California ground squirrel control, although the effect of other factors may have masked the effect of prebaiting in our trials.

We conducted this study to identify how ZnP should be used to improve its effectiveness as a bait for California ground squirrel control. We believed that proper timing of baiting, bait acceptance tests, prebaiting, and accurate bait placement would make ZnP a consistently good material for California ground squirrel control. Although we achieved excellent control in many of our tests, we could not get consistent results regardless of the methods used.

Our recommendation to California growers is to use ZnP in places where quick population knockdown is required. If necessary, a follow-up with anticoagulant baiting should be very effective. This combination approach has the potential advantage of reducing the overall secondary hazard of the control program since the squirrels killed with ZnP should not present a secondary hazard to other wildlife or domestic animals. Prebaiting is probably a good practice but may not be cost effective.

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