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Efficacy of zinc phosphide baits to control voles in alfalfa – an enclosure study

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The efficacy of broadcasting zinc phosphide (Zn_3P_2) grain baits as an acute rodenticide to control gray-tailed voles (*Microtus canicaudus*) in alfalfa (*Medicago sativa*) was assessed. A total of 428 voles was distributed within 18, 0.2-ha enclosures having a 2+ year stand of plants. Single, pre-bait (0.0% Zn_3P_2) and test-/control-(2.0/0.0% Zn_3P_2) bait broadcasts (11.2 kg ha^{-1}) were applied within enclosures 18 and 20 days following final vole distribution. At 14 days later, a trap-out of the surviving voles was conducted. Only 5.6% of those distributed in Zn_3P_2-baited enclosures were recaptured; whereas, 70.1% of those placed in control-baited enclosures were retrapped. Analyses of variance for proportions of voles and total voles captured within enclosures yielded significant main effects for rodenticide. Program CAPTURE estimates also confirmed significant decreases in vole populations in Zn_3P_2-baited enclosures. Daily carcass searches yielded 25 and 5 vole carcasses, respectively, in the Zn_3P_2 and control enclosures during the bait-exposure period. Three non-target carcasses were found within enclosures during this period: one Savannah sparrow (*Passerculus sandwichensis*) and two vagrant shrews (*Sorex vagrans*). Results demonstrate the efficacy and low hazards to non-target passerines of a single Zn_3P_2 baiting to control vole populations in alfalfa. Published by Elsevier Science Ltd

Keywords: acute rodenticide; vole control; bait effectiveness; alfalfa pests; *Microtus canicaudus*; *Medicago sativa*

Quantitative studies of vole-caused losses to US alfalfa crops are lacking. Nevertheless, grower-survey data suggest that losses may be significant. For example, Lewis and O'Brien (1990) reported results of a questionnaire survey mailed to 500 alfalfa producers in Nevada. Of 275 respondents, 26% indicated that voles were present on their production lands, with 8% stating that voles caused moderate to severe losses in hay quality.

Interestingly, field studies have linked vole populations with economic losses to alfalfa production in Eastern Europe (Babińska-Werka, 1978, 1979; Tertil, 1977). The species was the common vole, *M. arvalis*. Although direct consumption of alfalfa biomass by voles was minor, and some compensatory growth occurred post-clipping, decreased production resulted from weed growth near colony centers (Babińska-Werka, 1979). Lost alfalfa biomass for successive spring and summer cuttings was estimated at 8.7, 35.6 and 60.2%, with densities of 145–220, 220–411 and 411–682 voles ha^{-1}, respectively. Obviously, damage increased as populations of voles grew and became more established during the growing season.

Zinc phosphide (Zn_3P_2; CAS No. 1314–84–7) is an acute rodenticide having diverse agricultural applications. For example, it is used to reduce vole populations to prevent 'girdling' of fruit trees and to reduce prairie dog populations to prevent range destruction in the Western US (Hood, 1972; Marsh, 1988). Toxicity results from release of phosphine (PH_3) gas following hydrolysis with stomach acids; death is attributable to decreased electron transport and respiratory failure (Chefurka, Kashi and Bond, 1976). Median acute lethal dose (LD_{50}) values of Zn_3P_2 are roughly equivalent for diverse North American species of voles [e.g. *M. pennsylvanicus* = 18.0 mg kg^{-1} (Hood, 1972) and *M. ochrogaster* = 16.2 mg kg^{-1} (Bell and Dimmick, 1975)].

This report describes a study to assess the effectiveness of single, pre-bait (0.0% Zn_3P_2) and test-/control-bait (2.0/0.0% Zn_3P_2) broadcasts of steam-rolled-oat (SRO) groats to control gray-tailed voles, *M. canicaudus*, in alfalfa. The gray-tailed vole inhabits river valleys and alfalfa fields in the northwestern US (Verts and Carraway, 1987). The null hypothesis (H_0) was: a single, 11.2 kg ha^{-1} broadcast of a 2% Zn_3P_2 SRO groats bait in 0.2-ha enclosures of standing alfalfa will cause <70% mortality to resident populations of gray-tailed voles [i.e. a 70% mortality criterion exists for registration of field rodenticides (EPA, 1982)]. The

The Denver Wildlife Research Center, Denver, CO is relocating to the National Wildlife Research Center, Ft Collins, CO study was conducted jointly with research of potential Zn_3P_2 hazards to non-target ring-necked pheasants (*Phasianus colchicus*) and California quail (*Callipepla californica*) (see Ramey and Sterner, 1995).

Materials and methods

Study site

The study was conducted at the Hyslop Crop Science Field Laboratory (HCSFL) operated by Oregon State University (OSU). The HCSFL is located ≈10 km north of Corvallis, Oregon. The terrain is level (elevation ≈70 m); soil is a Woodburn silty-clay loam (pH = 6.0).

During the course of the study (10 September to 2 November 1993), precipitation totaled 2.76 cm (0.17, 2.59 and 0.00 cm for the September, October and November portions of the study, respectively). Rainfall data are important because Zn_3P_2 deteriorates rapidly in the presence of moisture (see Hilton, Robison and Teshima, 1972; Sterner and Ramey, 1995).

Enclosure/trap-grid layouts

Eighteen 0.2-ha (45 × 45 m) metal-surrounded enclosures were used. Enclosures were constructed of galvanized sheet metal; the metal extended ≈1 m above ground and ≈0.6 m below ground. Adjacent panels were joined to form a continuous barrier to rodents. Alfalfa had been planted in the Spring of 1991, and an ≈1-m-wide border along the inside edge of each enclosure was cleared of plants to reduce rodent burrowing.

A 100 trap 'grid' was set up in a 10 × 10 array within each enclosure, with trap rows separated by 5 m lateral distance. A total of 75 Sherman traps (7.5 × 9.5 × 25.5 cm) was placed in commercial cardboard milk cartons and positioned at roughly equal intervals along the rows during trapping. Twenty-five pitfall traps were also used in place of Sherman traps at odd-number trap-row locations in the 10 × 10 array. Pitfall traps were ≈45-cm-long sections of polyvinylchloride 15.2-cm o.d. pipe set endwise into the ground; these were covered when not in use.

Gray-tailed voles

A total of 428 ear-tagged, gray-tailed voles was used (219 ♂, 208 ♀, and one vole of undetermined gender). Proportions of voles by weight classes were: <20 g = 0.15, 20–30 g = 0.30 and >30 g = 0.55 or 63, 129, and 236 voles, respectively.

Historical research considerations

Studies of plant/animal effects associated with periodic sprayings of the insecticide Guthion 2S® (azinphos-methyl; CAS No. 86–50–0) had been conducted in the enclosures between 1991–1993 (Edge, Carey, Wolff, Ganio and Manning, in press; Schauber, 1994). To reduce possible carryover effects, prior Guthion 2S® enclosures were balanced in the current study (see *Figure 1*). All azinphos-methyl residues found in plant or animal tissue samples were <2 ppm on 2 September 1993. Based on a <5 day half-life for azinphos-methyl, enclosure plants/soils were assumed to contain residues less than 1 ppm at the time of initial vole distributions.

Regarding alfalfa, 9 of the 18 enclosures were last

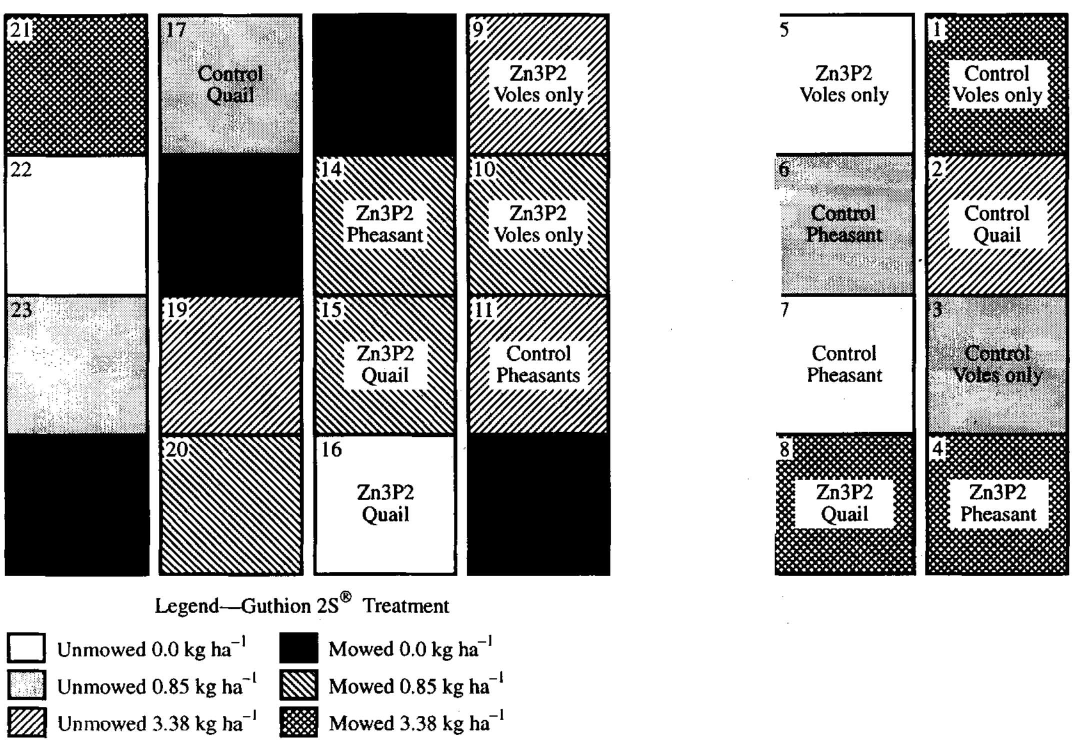

Figure 1. Schematic illustration of the 0.2-ha enclosures (n =24; only 18 used) at Hyslop Crop Science Field Laboratory, with Guthion 2S®, mowing, Zn_3P_2-/control-bait applications, plus vole-only, vole–pheasant and vole–quail assignments superimposed

mowed to a height of ≈8 cm on 22 June 1993. On 27 September, the height of alfalfa within each enclosure was determined using a modified method described by Robel, Briggs, Dayton and Hulbert (1970). Mean (± SD) alfalfa heights for the mowed and unmowed enclosures were 3.84 (± 0.56) and 3.62 (± 0.66) decimeters, respectively. Height measurements in mowed and unmowed enclosures were not significantly different ($P > 0.05$) based on an independent student's *t*-test (Winer, 1971).

Baits

The technical product used in bait formulation was Zn_3P_2 (Bell Laboratories, Inc., Madison, Wisconsin), with pigment black No. 6 and No. 7 amorphous carbon CI 7726 added to reduce ingestion by gallinaceous birds (Benbow Chemical Packaging Inc., Syracuse, New York). Pre-study assay of the technical Zn_3P_2 (Mauldin, 1991a) yielded 88.8 ± 0.27% a.i. Test bait was formulated by weight as 2.00% a.i. Zn_3P_2/0.12% pigment black/97.50% SRO groats/0.52% Alcolec-S (American Lecithin Co., Woodside, New York)/0.52% mineral oil bait. Control and pre-bait consisted of 0.12% pigment black/97.50% SRO groats/0.52% Alcolec-S/0.52% mineral oil.

Baits were accurately mixed and remained stable throughout the study. Replicate analyses of test-bait samples collected at preparation, broadcast and late in the study yielded mean (± SD) nominal values of 2.0% (± 0.36) Zn_3P_2 (Mauldin, 1991b). Control baits were free of Zn_3P_2 (<0.002% detection limit).

Design and statistical analyses

The experimental design was a two-factor, independent-groups design involving a 2 (Zn_3P_2 or control bait) × 3 (vole-only or vole–pheasant or vole–quail) factorial (Winer, 1971). Three unmowed and mowed enclosures from each of the historical 0.0, 0.85 and 3.38 kg ha^{-1} Guthion 2S® conditions were used (*Figure 1*). This approach balanced prior mowing and Guthion 2S® conditions within the Zn_3P_2- and control-bait enclosures as well as within the voles only, voles plus ring-necked pheasants, and voles plus California quail enclosures (Ramey and Sterner, 1995).

Three categories of voles were identified for statistical analyses: residents (study-released, ear-tagged voles trapped on grids), carryover/immigrant (non-study-released, ear-tagged voles trapped on grids) and non-ear-tagged-recruited voles (non-study-released, non-ear-tagged, recruited voles trapped on grids). Separate ANOVAs were computed for the proportion of resident voles recaptured and the total resident, carryover/immigrant and non-ear-tagged/recruited voles captured during final trapout (SAS Institute, 1987). Although the assumption of 'closed population' was not met (i.e. some carryover/immigrant and non-ear-tagged/recruited voles were trapped on each grid), vole populations were estimated at the completion of the study using Program CAPTURE software (White, Burnham, Otis and Anderson, 1978). Significant ANOVA effects were further analyzed using Student–Newman–Keuls *post-hoc* means comparisons (Winer, 1971). The 0.05 alpha level was used with all tests.

Procedures

Initial trap-out and distribution of voles. A 10-night trap-out to remove rodents from the 12 former Guthion 2S® grids initiated the procedures. Traps were set on the grids and pitfall traps were opened nightly. Voles captured on these grids were released outside of the enclosures. Ten successive nights of trapping has been shown to remove ≈95% of the rodents in this situation (Manning, Edge and Wolff, 1995).

Trapping of voles for use in the current study occurred between 10–21 September. Voles captured on the eight former Guthion-2S®-control grids were sorted by gender, weighed, ear-tagged, and examined (e.g. reproductive status, general health, etc.). Next, 214 of these resident voles [roughly equal mixes of ♂ and ♀ and balanced by weight classes (23 or 24 voles/enclosure)] were then placed randomly into nine of the Zn_3P_2- and control-bait enclosures each (*Figure 1*). Enclosure densities were equivalent to ≈120 voles/ha. The voles had between 6 and 18 days to acclimatize to the enclosures before pre-baiting.

Pre-bait exposure. On 28 September (≈16.00–18.00 h), pre-baiting (0.0% Zn_3P_2 control SRO groats) of the 18 enclosures occurred. Pre-baiting was used to ensure sufficient bait ingestion by rodents. That is, ingestion of small amounts of Zn_3P_2 bait causes gastrointestinal disturbance (illness) and subsequent bait shyness (i.e. sub-lethal aversion); pre-baiting decreases insufficient bait acceptance by target animals (Marsh, 1988; Sterner, 1994).

Bait was applied using two Spyker® Model-75 Spreaders (Spyker, Co., N. Manchester, Indiana) by two Certified Pesticide Applicators (CPAs). All bait was applied at a 11.2 kg ha^{-1} equivalent rate based upon area of alfalfa baited. Two or three calibrations of each spreader by each CPA were performed prior to each application.

At this time, daily searches for dead gray-tailed voles and other non-target animals were also initiated within each enclosure (≈09.30–11.00 h). Staff walked the perimeter of each grid and looked for carcasses within the cleared border strip, then walked each trap row and looked for carcasses within 1-m of each side of the row. Expected search time was 20 min/grid, but many searches took longer. These searches served to familiarize staff with the carcass-search procedures and cleared old carcasses from the enclosures.

Exposure of voles to baits. On 30 September (≈16.00–18.00 h), control (0.0% Zn_3P_2) and test (2% Zn_3P_2) SRO groats were broadcast into each of nine quasi-randomly selected enclosures each (*Figure 1*); quasi-randomly refers to the constraints on randomness imposed on our balancing of historical (i.e. Guthion-2S®, mowed/unmowed alfalfa) and current test conditions in the design. Calibration and actual broadcast applications of baits were conducted the same as during pre-baiting.

Voles were exposed to respective baits between 30 September and 14 October. Daily searches (≈09.30–11.00 h) for dead gray-tailed voles and other non-target animals within each enclosure were continued throughout this period.

Examinations of stomach contents were conducted daily on vole carcasses found during the first 9 days following test/control baiting. A laparotomy was performed on each recovered carcass, with an incision made into the oesophagus and stomach. Contents of the oesophagus/stomach were examined for partially digested seeds and other materials. Necropsy of one non-target bird was also performed. Necropsies ceased on 10 October due to lack of definitive SRO groat identifications.

Final trap-out of voles. Rodents within each enclosure were enumerated (captured/recaptured) during a final 10- to 17-night trap-out of each enclosure. Trapping was discontinued on several grids after 10 nights because no voles were trapped on ≥3 consecutive nights. All animals caught in traps were examined and identified, with eartag number, weight and reproductive status recorded for voles.

Following capture and identification, all animals trapped on Zn_3P_2-baited grids were euthanized via CO_2 inhalation. Carcasses (including necropsied carcasses) were disposed of by deep burial at a nearby landfill. All voles trapped in control-baited enclosures were released into a designated 'control' enclosure for possible future studies.

Results

Vole recaptures/captures

Only 28 voles were trapped post-baiting on Zn_3P_2-baited grids as compared with 624 voles removed from control-bait grids (*Table 1*). Of the resident voles, 12 (5.6%) and 150 (70.1%) were recaptured on the Zn_3P_2- and control-baited grids, respectively. Conversely, 202 (94.4%) and 64 (29.9%) resident voles were untrapped from these grids. Additionally, 9 and 139 previously tagged/carryover voles and 7 and 335 non-tagged/recruited/immigrant voles were captured on Zn_3P_2- and control-bait grids, respectively. Although the numbers of carryover and immigrant voles captured post-study indicates that some enclosure populations were not 'closed', the dramatic capture differences between Zn_3P_2- versus control-baited grids confirm broadcast efficacy.

Results of the ANOVA for the proportion of resident voles recaptured yielded significant main effects for both rodenticide ($F_{1,12}$ = 944.73, P = 0.0001) and vole–avian condition ($F_{2,12}$ = 3.72, P = 0.05). However, *post-hoc* Student–Newman–Keuls means tests revealed that proportion of recaptures among vole-only, vole–pheasant and vole–quail grids were insignificant. Mean proportion (± SD) resident recaptures for the Zn_3P_2- and control-bait enclosures were 0.05 (± 0.03) and 0.69 (± 0.07), respectively; whereas, proportion means (± SD) for the vole-only, vole–pheasant and vole–quail enclosures were 0.34 (± 0.35), 0.41 (± 0.38) and 0.36 (± 0.33), respectively. The rodenticide × vole–avian interaction term was not significant. Thus, H_0 was rejected; a single broadcast application of 2% Zn_3P_2 SRO groats significantly reduced the proportion of recaptured resident voles, but variances were too great across the vole–avian conditions to yield significant differences.

ANOVA for the total numbers of voles captured

Table 1. Summary of final trap-out data for each Zn_3P_2- and control-bait grid showing numbers of untrapped (missing) and trapped (resident, carryover/immigrant, and non-ear-tagged/recruited) voles

Enclosure (grid)	Released (tagged)	Untrapped (missing)	Trapped			
			Resident (released tagged)	Carryover/ immigrant (unreleased tagged)	Non-tagged recruited	Total
Zn_3P_2-bait						
4	23	21	2	0	0	2
5	23	23	0	4	0	4
8	24	22	2	0	1	3
9	24	23	1	0	0	1
10	24	23	1	1	3	5
14	24	22	2	1	0	3
15	24	22	2	2	0	4
16	24	23	1	0	3	4
18	24	23	1	1	0	2
Σ	214	202	12	9	7	28
Mean	23.8	22.4	1.3	1.0	0.8	3.1
(± SD)	(± 0.4)	(± 0.7)	(± 0.7)	(± 1.3)	(± 1.3)	(± 1.3)
Control-bait						
1	24	9	15	13	72	100
2	24	9	15	7	21	43
3	24	6	18	7	20	45
6	23	7	16	20	57	93
7	24	5	19	23	57	99
11	23	4	19	4	15	38
12	24	9	15	25	43	83
13	24	8	16	34	45	95
17	24	7	17	6	5	28
Σ	214	64	150	139	335	624
Mean	23.8	7.1	16.7	15.4	37.2	69.3
(± SD)	(± 0.4)	(± 1.8)	(± 1.7)	(± 10.5)	(± 22.8)	(± 30.0)

during trap-out also yielded a significant main effect for rodenticide ($F_{1,12} = 37.41$, $P = 0.0001$), with the vole–avian main effect and rodenticide × vole–avian interaction terms not significant. Mean (± SD) captures/recaptures for the Zn_3P_2- versus control-bait grids were 3.1 (± 1.3) and 69.3 (± 30.0), respectively. This further confirms the efficacy of the Zn_3P_2-bait broadcast. Captures of combined resident, carryover, and non-ear-tagged/recruited vole populations were very infrequent subsequent to Zn_3P_2 broadcast, with recruitment also dramatically suppressed in Zn_3P_2-baited enclosures.

Program CAPTURE estimates confirmed the post-bait reductions of vole populations on Zn_3P_2 as compared to control grids. Estimated vole populations ranged from 2 to 100 voles across all grids, with 52% (342:652; see *Table 1*) of voles being non-tagged immigrants or recruits. Population means (± SD) were 2.7 (± 1.8) and 69.0 (± 29.4) for combined Zn_3P_2- and all control-bait grids, respectively. Nightly capture data for the Zn_3P_2- and control-bait enclosures of the six vole-only, vole–pheasant and vole–quail enclosures highlight the dramatic differences in capture success between Zn_3P_2- and control-bait grids, as well as the gradual reduction in capture frequencies across successive nights of the trap-out.

Target/non-target carcasses and stomach contents

Target animals. A total of 25 and 5 dead voles were found in Zn_3P_2- and control-baited enclosures, respectively, during the test-/control-bait exposure period, with 13 (52%) discovered in Zn_3P_2-baited enclosures within 2 days after broadcast (*Figure 2*). This disproportionate number of carcass recoveries from Zn_3P_2 enclosures shortly after broadcast is further support for baiting effectiveness.

Stomach contents of 15 vole carcasses were examined. Of these, 13 were found in Zn_3P_2-bait enclosures and two were found in control-bait enclosures. The stomach contents from all carcasses contained a mass of green-pulpy material believed to be partially digested alfalfa foliage; eight stomachs contained several small yellowish spots believed to be endoderms of SRO groats. Additionally, stomach contents of three vole carcasses found in Zn_3P_2-baited enclosures contained small, ≈0.5-cm^2 portions of grayish material believed to be partially digested Zn_3P_2.

Non-target animals. Five non-target carcasses were found in enclosures (*Table 2*) including two dried deer mice, (*Peromyscus maniculatus*) carcasses collected during baseline, plus one Savannah sparrow (*P. sandwichensis*) and two vagrant shrews (*S. vagrans*) that were found during the bait exposure period. Additionally, one Brewer's blackbird (*Euphagus cyanocephalus*) and one Pacific tree frog (*Hyla regilla*) were found on the berms between enclosures. Ramey and Sterner (1995) provide pheasant/quail mortalities associated with the joint non-target hazards study.

Necropsy of the sparrow carcass yielded no identifiable bait particles in the gizzard or stomach (only small, black, hard gravel-like particles were evident). The presence of Zn_3P_2 goats in this enclosure, coupled with shorter alfalfa on the trap row, may have possibly contributed to this mortality as foraging of baits by birds was possible on trap rows. However, because no direct evidence of poisoning was found, the sparrow's death is only suspected of being bait induced.

Discussion

Although a number of studies have demonstrated efficacy of Zn_3P_2 to control rodent pests in orchards (e.g. Merson and Byers, 1985) and grasslands (e.g. Matschke, Fagerstone, Halstead, LaVoie and Otis, 1982; Teitjen, 1976), this is the first quantitative account of the use of Zn_3P_2 to control voles in alfalfa. Current data indicate that single, pre-bait and bait broadcasts of 0.0% and 2.0% Zn_3P_2 SRO groats significantly reduced vole numbers (i.e. >94%) by 14 days after application.

Olfaction, search rate, bait distribution and habitat

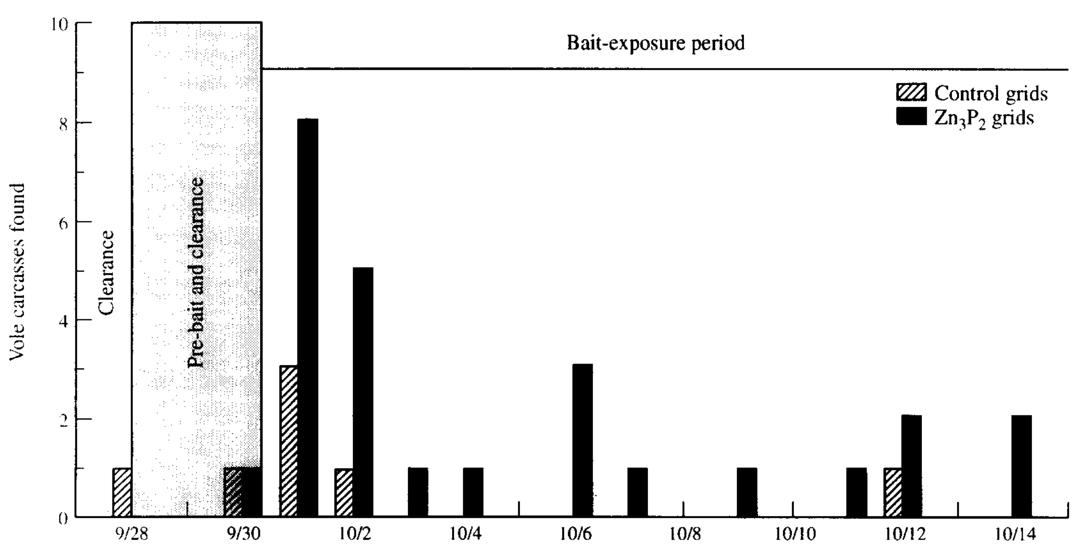

Figure 2. Histogram of the numbers of vole carcasses found daily during carcass searches in Zn_3P_2- and control-bait enclosures

Table 2. Summary of target and non-target carcass-search data for the bait exposure period; data are categorized by Zn_3P_2- and control-bait enclosures and cited as enclosure number (carcass numbers)[a]

Date	Bait-exposure day	Target species (gray-tailed vole)		Non-target species[b]	
		Zn_3P_2-bait enclosures	Control-bait enclosures	Zn_3P_2-bait enclosures	Control-bait enclosures
9/28	Baseline 1	5(1)[c]		8(1)[c] deer mouse	7(1)[c] deer mouse
9/29	Pre-bait 1				
9/30	Pre-bait 2	8(1)[c]	7(1)[c]		
10/1	Bait 1	5(1)	1(2)		
		8(2)	7(1)[c]		
		10(1)			
		14(3)			
		18(1)			
10/2	Bait 2	5(1)	7(1)[c]		17(1) shrew
		8(1)			
		14(1)			
		15(2)			
10/3	Bait 3	15(1)			
10/4	Bait 4	16(1)		4(1) Savannah sparrow	
10/5	Bait 5				shrew (1) (10/4–6: enclosure unknown)
10/6	Bait 6	5(1)			
		14(1)			
		18(1)			
10/7	Bait 7	16(1)			
10/8	Bait 8				
10/9	Bait 9	10(1)			
10/10	Bait 10				
10/11	Bait 11	16(1)			
10/12	Bait 12	9(2)	6(1)		
10/13	Bait 13				
10/14	Bait 14	5(1)			
		15(1)			

[a]Enclosures 4, 5, 8, 9, 10, 14, 15, 16 and 18 were Zn_3P_2-bait grids; enclosures 1, 2, 3, 6, 7, 11, 12, 13 and 17 were control-bait grids
[b]Only non-targets found within enclosures during carcass searches are noted. In addition, one Brewer's blackbird and one Pacific tree frog were found outside enclosures (e.g. grass berms)
[c]Carcass dried, desiccated

density can affect bait pick up by rodents (Reidinger and Mason, 1983). Our results suggest that the Alcolec-S:mineral-oil-adhered-Zn_3P_2 baits proved highly palatable to the odor-sensitive gray-tailed voles. Traditional concerns of poor acceptance and bait-shyness associated with Zn_3P_2 were not observed (Gratz, 1976; Marsh, 1988; Sterner, 1994).

Sterner (1994) examined the acceptance and particle toxicity of 2% Zn_3P_2-SRO groats to voles. He determined the mean ($\pm$ SD) weight of a SRO groat to be 23 ($\pm$ 9) mg, and developed the following particle-dose formula:

$$\text{Particles to } LD_{50} = \frac{LD_{50}\,(\text{mg/kg}) \times \text{body weight (kg)}}{\text{mean particle } Zn_3P_2\,(\text{mg})}$$

Assuming homogeneous distribution of Zn_3P_2 on these baits, mean particle Zn_3P_2 was estimated at 0.46 mg (i.e. mean particle Zn_3P_2 = 23 mg $\times$ 2.0%). Because the average weight of voles in this study was 0.032 kg, a LD_{50} of 16.2–18.0 mg/kg (i.e. prairie vole versus meadow vole) cited for voles (Hood, 1972) reveals that only $\approx$1.13–1.25 mg SRO groats [(16.2–18.0 mg/kg $\times$ 0.032 kg) $\div$ 0.46 mg] had to be ingested per rodent to lethally dose $\approx$50% of the voles.

The majority of ear-tagged/unreleased/immigrant (carryover) and non-ear-tagged/recruited voles were trapped in five control-bait enclosures (1, 6, 7, 12 and 13; *Table 1*). Partial explanation of this could be attributed to incursions beneath enclosure side panels by moles (*Scapanus* spp.) and pocket gophers (*Thomomys bulbivorous*). Between July and August 1993, staff at HCSFL observed numerous incursions by these species into enclosures 1, 2, 5, 6 and 7. Although these deep-burrowers were trapped successfully, the high number of related carryover captures may have been due to the pathways made by gophers/moles beneath these side panels.

To further decipher cases of between-enclosure movement and recruitment as factors affecting our data, we examined the distribution/capture locations of all voles not released during the current study, as well as the bodyweights of all non-tagged voles. Altogether, 148 ear-tagged voles were captured that were not distributed within enclosures in September (see Trapped: immigrant/carryover; *Table 1*). All of these were placed in enclosures during earlier research studies at HCSFL, with 120 (81%) having been placed in the same enclosure where captured, and 28 (19%) having been trapped in a different enclosure (movement). This suggests that, counter to earlier predictions, the 10-day pre-study trap-out was incomplete. Examination of the body weights of non-tagged/recruited/immigrant voles trapped out of the control-bait enclosures showed that 116 (35%), 96 (29%), and 123 (37%) weighed <20, 20–30 and >30 g, respectively. Thus, a third of these voles were juveniles that had probably been recruited into the control-bait populations after initial distribution in September 1993.

Of the current non-target deaths, only the Savannah sparrow was possibly attributable to rodenticide baits; all other non-target deaths were unlikely to have been Zn_3P_2 induced. The vagrant shrew is an insectivore (Zeveloff and Collett, 1988) and the Pacific tree frog feeds on insects and invertebrates (Breen, 1974) and are unlikely foragers of grains. Moreover, the blackbird and frog were found on the grass berms outside the enclosures. Although not necropsied, periodic occurrences of dead animals on the grass berms between enclosures/fields at HCSFL is not uncommon.

Finally, estimates of potential crop savings afforded by Zn_3P_2-broadcast procedures are dependent upon: (1) the cost of bait application(s); (2) the time(s) of baiting (i.e. prior to 1st, 2nd or 3rd cutting); (3) the loss of crop biomass expected to occur in the absence of baiting; and (4) the crop yields expected with and without baiting. Growers are advised to carefully monitor late winter vole densities and to broadcast ahead of likely population buildups. The utility of the method will depend on the economics surrounding these factors.

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