January 2003

EFFICACY OF ZINC PHOSPHIDE FOR CONTROLLING NORWAY RATS, ROOF RATS, HOUSE MICE, *PEROMYSCUS SPP.*, PRAIRIE DOGS AND GROUND SQUIRRELS: A LITERATURE REVIEW (1942-2000)

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Abstract: Zinc phosphide has been used as a control agent for commensal rodents for over 60 years. Studies utilizing zinc phosphide as a population control agent were gathered and summarized to determine its efficacy when baiting the Norway rat, roof rat, house mouse, *Peromyscus spp*., prairie dog and ground squirrel. Efficacy information was abundant for rats, squirrels, and prairie dogs. However, efficacy data for baiting mice with zinc phosphide was limited. Overall the data show that in both laboratory and field testing, control levels of greater than 70% can be achieved for commensal rodent pests. Bait acceptance appeared to be the major factor in obtaining satisfactory control. However, the field efficacy can be greatly influenced by factors such as the time of year, geographic location, habitat treated and other environmental factors. Efficacy was significantly improved for all species by pre-baiting with clean bait prior to presenting bait containing zinc phosphide. Literature pertaining to both laboratory and field testing on rats was fairly extensive. Efficacy studies with mice, prairie dogs, and ground squirrels were conducted primarily under field conditions. However, a limited number of laboratory studies were located. No laboratory studies with ground squirrels were located. In general, once acceptable bait material and zinc phosphide concentrations were identified, zinc phosphide has proven effective at reducing populations of the Norway rat, roof rat, house mouse, *Peromyscus* spp., prairie dog and ground squirrel.

Key words*:* *Cynomys spp*., efficacy, ground squirrel, house mouse, mouse, *Mus musculus,* Norway rat, *Peromyscus spp.*, prairie dog, rat, *Rattus spp*., rodenticide, roof rat, *Spermophilus spp.,* zinc phosphide

Proceedings of the 10th Wildlife Damage Management Conference. (K.A. Fagerstone, G.W. Witmer, Eds.). 2003

INTRODUCTION

Zinc phosphide is used to control populations of a variety of commensal and field rodents. It has been used as a rodenticide since the early 1940's and is presently still being used. Much of the early development work of zinc phosphide based rodenticides was conducted in the United States. However, a significant amount of work was done in

Asian countries such as India and Pakistan to customize baits for their unique rodent species.

In 1998, the U.S. Environmental Protection Agency (U.S. EPA) published the Reregistration Eligibility Decision (RED) for Zinc Phosphide. One of the requirements in the RED was the submission of laboratory and field efficacy data for public health pests conducted under U.S. EPA Guidelines 96-10 and 96-12, efficacy of commensal rodenticides and agricultural rodenticides, respectively. This data call-in required

submitting both laboratory and field efficacy data for every combination of commensal use site and commensal pest for each zinc phosphide product currently registered for commensal pest considered to pose a threat to public health. In response to this request, the Zinc Phosphide Consortium chose to compile and submit a summary of all laboratory and field efficacy information available in both the published and unpublished literature. The members of the Consortium felt that the weight of the evidence generated over the last 60 years and the proven effectiveness of zinc phosphide rodenticides should adequately meet the U.S. EPA data call-in, eliminating the need for further efficacy studies.

This manuscript attempts to compile all published and unpublished data for the period between 1942 and 2000 for the Norway and roof rat, house mouse, *Peromyscus spp.*, prairie dogs and ground squirrels. It is not an annotated bibliography. It provides simple summaries of studies in tabular form and should be used as a complete source for efficacy citations. The field and lab studies presented in this data submission show that zinc phosphide is successful in controlling populations of mice, rats, prairie dogs, and ground squirrels.

METHODS AND DATABASES

The primary source of literature cited in this data submission was a zinc phosphide literature file maintained by the USDA, National Wildlife Research Center (NWRC), Fort Collins, CO. The NWRC gathers literature from several different sources and databases which include, but are not limited to: Dialog, BIOSIS, Chemical Abstract, Agricola and unpublished information from state and federal agencies. This database, as well as additional literature queries, was used to summarize information on zinc phosphide efficacy when used for the control of the Norway Rat, roof rat, house mouse, *Peromyscus* spp., prairie dog, and ground squirrel. Literature pertaining solely to standard toxicity testing (LD_{50} and LC_{50}) were not cited or included in this literature review. Additionally, physical copies of review or summary articles and operational use manuals have not been included. However, they are cited in the list of references. This data submission does not contain any data previously submitted to the EPA in support of specific registrations which are not public information (i.e., confidential business information).

EFFICACY OF ZINC PHOSPHIDE BAITING - MOUSE CONTROL

Over the last 22 years, the efficacy of zinc phosphide under laboratory and field conditions have been conducted with three species of mice; the deer mouse (*Peromyscus maniculatus*), the Egyptian spiny mouse (*Acomys cahirinus*), and the house mouse (*Mus musculus*). The most common method of obtaining population reduction estimates in the field was live trapping during pre-treatment and post-treatment periods and comparing the differences. With the exception of one study, all studies reported efficacy rates for mouse control using zinc phosphide higher than 70% (Table1).

Field Efficacy Studies

Peromyscus maniculatus – Three articles, Uresk et al. (1987), Deisch et al. (1990) and Witmer (1999), reported the efficacy of zinc phosphide to deer mice. Uresk et al. (1987) and Diesch et al. (1990) report data from the same study. This study measured deer mice population changes resulting from use of zinc phosphide for prairie dog control. The study was conducted in rangeland by hand baiting 2% zinc phosphide/steam-rolled oats bait at a rate of 4g/burrow. A 79% reduction in deer mice in the treated plots was reported. Witmer (1999) used a rolled oat bait to control deer mice around buildings at an airport. Witmer

mechanically broadcast 2% zinc phosphide on rolled oat bait and reported a 66% (based on live trapping) to 100% (based on snap trapping) reduction in mice,

Table 1. Efficacy of Zinc Phosphide for Mouse Control

Use Site	ZP Conc. (%)	Bait Material	Application Rate	Application Method	Efficacy (% Reduction)	Citation
Peromyscus maniculatus						
Rangeland	2.0	SRO	4 g / burrow	Hand-bait	79	Uresk et al. (1987)
Rangeland	2.0	SRO	4 g / burrow	Hand-bait	79	Deisch et al. (1990)
Around buildings	2.0	SRO	8 lbs/acre	Broadcast	66-100	Witmer (1999)
Laboratory	1.8	Wheat	Ad libitum - 1 day	--	60	McCann (1998)
Laboratory	1.8	Wheat	Ad libitum - 1 day	--	60	McCann (2000)
Laboratory	2.0	Oats	Ad libitum- 1 day	–	80	McCann (1998)
Laboratory	2.0	Oats	Ad libitum - 1 day	--	80	McCann (2000)
Acomys cahirinus						
Laboratory	2.5	Corn meal	Ad libitum for 1 day	Bait station	77	Mahmoud and Rennison (1986)
Mus musculus						
Buildings	2.0	Poultry Feed	Ad libitum / 3 days	Bait Station	80	Jain and Sarkar (1984)
?	2.0	Wheat	?	?	?	Kadhim et al. (1989)
Buildings	10.0	–	?	Tracking Powder	89 - 97	Williams (1977)
Buildings	10.0	--	4 months	Tracking Powder	62-100	Advani (1992)
Buildings	10.0	--	4 months	Tracking Powder	100	Advani (1995)
Laboratory	2.0	?	Ad libitum	–	100	Kirishnakumari et al. (1980)

SRO - Steam-rolled Oats

Note: Uresk et al. (1987) and Deisch et al. (1990) report data from the same study.
Advani (1992) and Advani (1995) report data from the same study.
McCann (1999a) and McCann (1999b) report data from the same study.

Acomys cahirinus - One article cited the use of the Egyptian spiny mouse, Mahmoud and Rennison (1986). Bait stations were used with a 2.5% zinc phosphide/corn matrix. A 95.5% efficacy rate was reported.

Mus musculus- Five field efficacy studies were conducted with the house mouse: Williams (1977), Jain and Sarkar (1984), Kadhim et al. (1989), Advani (1992), and Advani (1995). Williams (1977) and Advani (1992 and 1995) tested 10% zinc phosphide tracking powder buildings and reported reductions of mouse populations by 62 -100%. Jain and Sarkar (1984) used poultry pellets in bait stations in buildings and reported an 80% reduction in house mouse numbers.

Laboratory Efficacy Studies

Two laboratory studies were conducted with *Peromyscus maniculatus*, and *Mus musculus*: Krishnakumari et al. (1980), McCann (1998), and McCann (2000). McCann (1998) and McCann (2000) report data from the same study.

Kirishnakumari et al. (1980) tested 2% zinc phosphide on the house mouse and reported 100% mortality. McCann (1998 and 2000) evaluated 1.8% zinc phosphide on wheat and 2.0% zinc phosphide on oats with deer mice and reported 60% and 80% mortality, respectively.

Reviews, Summary Papers or Use Manuals

Harnach (1942), Garlough and Spencer (1944), Bondar (1949), Fitzwater (1952), Chitty (1954a), Nagornov (1959), Oregon

State University (1959), Hatch (1966), Beasley and McKibben (1974), California Department of Agriculture (1994), and University of Nebraska Cooperative Extension (1994a and 1994b) are reviews or summary papers or use manuals and do not report results of efficacy studies.

EFFICACY OF ZINC PHOSPHIDE – RAT CONTROL

During the last 56 years the effectiveness of zinc phosphide to control commensal rats has been reported in the literature. Extensive amounts of both laboratory and field work have been conducted on the Norway rat (*Rattus norvegicus*) and the roof rat (*Rattus rattus*) (Table 2). Results of these studies are highly variable as researchers reported testing many types of bait materials both with and without pre-baiting in their efforts to control urban rat infestations. Laboratory studies were typically one or two food item challenge tests with exposure periods lasting from 12 hours to 3 days. Field studies typically utilized bait stations with a continuous supply of treated feed for a period of 1 to 3 days. The most common method of determining population reduction estimates in the field was through live trapping during pre-treatment and post-treatment periods and comparing the results.

Field Efficacy Studies

Rattus norvegicus- The Norway rat was cited in 13 field studies: Bureau of Animal Population (1943), Emlen and Stokes (1947), Rennison et al. (1968), Po-Yu (1973), Pank (1975), Pank et al. (1975), Dubock and Rennison (1977), Tongtavee (1978), Fellows et al. (1980), Karim (1983), Kadhim et al. (1989), Ahmad and Prashad (1991), and Sugihara et al. (1995). Pank et al. (1975), Fellows et al. (1980), and Sugihara et al. (1995) used aircraft to apply 1.88% and 2.0% zinc phosphide to sugarcane. Only Pank et al. (1975) reported efficacy greater than 70%. Sugihara et al. (1995) reported statistically significant reductions when oat groat baits were applied. Emlen and Stokes (1947) used bait stations and 3.0% zinc phosphide corn bait, but only reported 16% efficacy. All of the other studies were conducted in structures and used bait stations filled with various bait materials including sausage rusk, wheat, corn, barley, hog food, various oat materials, and pellets with zinc phosphide concentrations between 1.88% and 5.0%. Structural treatment with zinc phosphide appeared to present the greatest variability in control. As demonstrated by the results of Rennison et al. (1968), mortality rates were not directly related to the zinc phosphide concentration in the bait. Dubock and Rennison (1977) tested 2.5% zinc phosphide on a variety of bait materials and also showed a great deal of variation in efficacy among the grains used as the carrier. In general, early results with *Rattus norvegicus* were inconsistent. However, good control could be achieved if sufficient preparation, in terms of pre-baiting and determining species bait preferences, was done prior to the baiting program. Karim (1983) did not apply zinc phosphide in the study, but evaluated individual physiological and morphological as well as rat population characteristics.

Table 2. Efficacy of Zinc Phosphide Baits for Controlling Rats

Use Site	ZP Conc (%)	Bait Material	Application Rate	Application Method	Efficacy (% Reduction)	Citation
Rattus norvegicus						
?	2.0	Wheat	?	?	?	Kadhim et al. (1989)
Structures	1.0	Hog food	200 g / station	Bait Station	70	Tongtavee (1978)
Structures	2.5	Soaked wheat	Ad libitum - 1 day	Bait Station	64	Dubock and Rennison (1977)
Structures	2.5	Barley meal	Ad libitum - 1 day	Bait Station	77	Dubock and Rennison (1977)
Structures	2.5	Corn/barley meal	Ad libitum - 1 day	Bait Station	74	Dubock and Rennison (1977)
Structures	2.5	Wheat and corn oil	Ad libitum - 1 day	Bait Station	65	Dubock and Rennison (1977)
Structures	2.5	Med. Oatmeal	Ad libitum - 1 day	Bait Station	74	Dubock and Rennison (1977)
Structures	2.5	Wheat meal	Ad libitum - 1 day	Bait Station	67	Dubock and Rennison (1977)
Structures	2.5	Corn meal and thirds	Ad libitum - 1 day	Bait Stations	57	Dubock and Rennison (1977)
Structures	2.5	Med. Oatmeal	1 tsp / station	Bait Station	59	Rennison et al. (1968)
Structures	2.5	Course Oatmeal	1 tsp / station	Bait Station	90	Rennison et al. (1968)
Structures	2.5	Sausage Rusk	1 tsp / station	Bait Station	45	Rennison et al. (1968)
Structures	2.5	Scomro	1 tsp / station	Bait Station	61	Rennison et al. (1968)
Structures	3.0	Corn	Ad libitum - 1 day	Bait Station	12 - 16	Emlen and Stokes (1947)
Structures	5.0	Sausage rusk	200 g / site	Bait Station	SSR	BuAPOU (1943)
Structures	5.0	Med. Oatmeal	1 tsp / station	Bait Station	55	Rennison et al. (1968)
Structures	5.0	Course Oatmeal	1 tsp / station	Bait Station	61	Rennison et al. (1968)
Structures	5.0	Sausage Rusk	1 tsp / station	Bait Station	53	Rennison et al. (1968)
Structures	5.0	Scomro	1 tsp / station	Bait Station	42	Rennison et al. (1968)
Sugarcane	0	Oat Groats	2.5 lbs / acre	Aerial	?	Pank (1975)
Sugarcane	1.0	Rice	10-20 g / station	Bait Station	67 - 88	Po-Yu (1973)
Sugarcane	1.8	?	5 lbs / acre	Aerial	?	Fellows et al. (1980)
Sugarcane	1.8	Oat Groats	6.7 lbs / acre	Aerial	71	Pank et al. (1975)
Sugarcane	1.8	Oat Groats	5.7 kg / ha	Aerial	SSR	Sugihara et al. (1995)
Sugarcane	2.0	Pellets	5.7 kg / ha	Aerial	NSSR	Sugihara et al. (1995)
Sugarcane	2.4	Wheat	10 g / site	Bait Station	78	Ahmad and Prashad (1991)
Laboratory	0.05	Corn	Ad libitum - 12 hr	--	25	Dieke (1948)
Laboratory	0.1	Corn	Ad libitum - 12 hr	--	25	Dieke (1948)
Laboratory	0.2	Corn	Ad libitum - 12 hr	--	100	Dieke (1948)
Laboratory	0.94	Pellets	Ad libitum - 3 days	--	80 - 83	Matschke and Fordham (1985)
Laboratory	1.0	Corn	Ad libitum - 12 hr	--	100	Dieke (1948)
Laboratory	1.0	Corn	Ad libitum - 1 day	–	88	Emlen and Stokes (1947)
Rattus norvegicus						
Laboratory	1.0	Pafaffinized Cereal	Ad libitum - 1 day	--	70	Fellows (1977)
Laboratory	1.0	Oats	Ad libitum - 2 days	--	17	Greaves (1966)
Laboratory	1.0	Oat Groats	Ad libitum - 1 day	--	90	McCann and Matschke (1999a)
Laboratory	1.0	Rice	Ad libitum - 1 day	--	85	Po-Yu (1973)
Laboratory	1.8	Oat Groats	Ad libitum - 3 days	--	10	Sugihara et al. (1995)
Laboratory	1.8	Oat Groats	Ad libitum - 3 day	–	40	Tobin et al. (1991)
Laboratory	1.8	Pellets	Ad libitum - 3 days	--	10	Sugihara et al. (1995)
Laboratory	1.8	Pellets	Ad libitum - 3 days	--	75	Matschke and Fordham (1985)
Laboratory	1.8	Pellets	Ad libitum - 3 days	--	90	Matschke and Fordham (1985)
Laboratory	2.0	?	Ad libitum - 1 day	--	100	Kirishnakumari et al. (1980)
Laboratory	2.0	Corn	Ad libitum - 12 hr	--	80	Dieke (1948)
Laboratory	2.0	Oats	Ad libitum - 3 day	--	0 - 20	Tobin and Sugihara (1990)
Laboratory	2.0	Oats	Ad libitum - 3 day	--	0 - 20	Tobin et al. (1990)
Laboratory	2.0	Oat Groats	Ad libitum - 1 day	--	100	McCann and Matschke (1999b)
Laboratory	2.0	Oat Groats Pellets	Ad libitum - 1 day	--	16	Fellows (1977)
Laboratory	2.0	Pellets	Ad libitum - 3 days	--	70	Sugihara et al. (1995)
Laboratory	2.0	Pellets	Ad libitum - 3 days	--	5	Sugihara et al. (1995)
Laboratory	2.0	Pellets	Ad libitum - 3 day	--	20 - 80	Tobin and Sugihara (1990a)
Laboratory	2.0	Pellets	Ad libitum - 3 day	--	20 - 80	Tobin et al. (1990)
Laboratory	2.0	Wax Block	Ad libitum - 3 day	--	10	Tobin et al. (1991)

Table 2. (cont.) Efficacy of Zinc Phosphide Baits for Controlling Rats

Use Site	ZP Conc (%)	Bait Material	Application Rate	Application Method	Efficacy (% Reduction)	Citation
Laboratory	2.0	Parafinized Oat Groat	Ad libitum - 1 day	--	30	Fellows (1977)
Laboratory	2.5	Oats	Ad libitum - 2 days	--	50	Greaves (1966)
Laboratory	3.4	Oats - One-seed dose	Ad libitum - 1 day	--	20	Fellows (1977)
Laboratory	5.0	Oats	Ad libitum - 2 days	--	58	Greaves (1966)
Laboratory	5.0	Corn	Ad libitum - 1 day	--	92	Emlen and Stokes (1947)
Laboratory	5.33	Oats - One-seed dose	Ad libitum - 1 day	--	20	Fellows (1977)
Laboratory	8.0	Corn	Ad libitum - 12 hr	--	100	Dieke (1948)
Laboratory	10.84	Oats - One-seed dose	Ad libitum - 1 day	--	30	Fellows (1977)
Rattus rattus						
Macadamia	1.9	?	5 lbs / acre	Broadcast	85	Pank et al. (1976)
?	2.0	Wheat	?	?	?	Kadhim et al. (1989)
Sugarcane	0	Oat Groats	2.5 lbs / acre	Aerial	?	Pank (1975)
Sugarcane	1.8	Oat Groats	5 lbs / acre	Aerial	83	Pank et al. (1975)
Sugarcane	1.8	Oat Groats	5 lbs / acre	Aerial	76	Fellows et al. (1978)
Sugarcane	1.8	?	5 lbs / acre	Aerial	?	Fellows et al. (1980)
Sugarcane	2.0	Pellet	3.2 g / ha	Aerial	18-61	Lefebvre et al. (1985)
Structures	1.0	Wheat	Ad libitum - 1 day	Bait Station	?	Rennison (1976)
Structures	2.5	Wheat	Ad libitum - 1 day	Bait Station	?	Rennison (1976)
Structures	5.0	Pakoras	Ad libitum - 2 days	Bait station	96	Kapoor and Khare (1965)
Rice	0.8	Rice	5-10 g piles / 5 m	Hand-bait	53 - 92	West and Libay (nd)
Rice	1.0	Rice	6 g piles / 5 m	Hand-bait	25	West et al. (1972)
Laboratory	1.5	?	Ad libitum	--	100	Pachori et al. (1995)
Laboratory	1.8	Oat Groats	Ad libitum - 3 days	--	90	Sugihara et al. (1995)
Laboratory	1.8	Oat Groats	Ad libitum - 3 day	--	70	Tobin et al. (1991)
Laboratory	1.8	Cracked corn	Ad libitum - 1 day	--	20	Lefebvre et al. (1978)
Laboratory	1.8	Oat Groats	Ad libitum - 1 day	--	38	Lefebvre, et al. (1978)
Laboratory	1.8	Oat Groats	Ad libitum - 1 day	--	21	Lefebvre et al. (1978)
Laboratory	1.8	Pellets	Ad libitum - 3 days	--	60	Sugihara et al. (1995)
Laboratory	1.8	?	Ad libitum	--	100	Pachori et al. (1995)
Laboratory	2.0	Pellets	Ad libitum - 3 days	--	55	Sugihara et al. (1995)
Laboratory	2.0	Pellets	Ad libitum - 3 days	--	80	Sugihara et al. (1995)
Laboratory	2.0	Wax Block	Ad libitum - 3 day	--	80	Tobin et al. (1991)
Laboratory	2.0	Pellets	Ad libitum - 3 day	--	70 - 80	Tobin and Sugihara (1990)
Laboratory	2.0	Oats	Ad libitum - 3 day	--	30 - 60	Tobin and Sugihara (1990)
Laboratory	2.0	Pellets	Ad libitum - 3 day	--	70 - 80	Tobin et al. (1990)
Laboratory	2.0	Oats	Ad libitum - 3 day	--	30 - 60	Tobin et al. (1990)
Laboratory	2.0	Oat Groat Pellets	Ad libitum - 1 day	--	32	Fellows (1977)
Laboratory	2.0	?	Ad libitum - 1 day	--	100	Kirishnakumari et al. (1980)
Laboratory	2.0	Paste on millet	Ad libitum	–	20	Malhi and Prashad (1991)
Laboratory	2.0	Waxed Oat Groat	Ad libitum - 1 day	--	60	Fellows (1977)
Rattus rattus						
Laboratory	2.0	?	Ad libitum	--	100	Pachori et al. (1995)
Laboratory	2.3	?	Ad libitum	--	100	Pachori et al. (1995)
Laboratory	3.4	Oats - One-seed	Ad libitum - 1 day	--	50	Fellows (1977)
Laboratory	5.3	Oats - One-seed	Ad libitum - 1 day	--	60	Fellows (1977)
Laboratory	10.8	Oats - One-seed	Ad libitum - 1 day	--	60	Fellows (1977)

SSR - Statistically Significant Reduction NSSR - No Statistically Significant Reduction

Note: Pank (1975a) was not conducted to determine efficacy. It was designed to determine the most appropriate aerial baiting technique to reduce reinvasion effects. Baits were treated with declomycin which imparts a yellow fluorescence under UV light.
Tobin and Sugihara (1990) and Tobin et al. (1990) report data from the same study.

Rattus rattus - The roof rat was cited in 10 field studies: Kapoor and Kharer (1965), West et al. (1972), West and Libay (no date), Pank (1975), Pank et al. (1975), Pank et al. (1976), Rennison (1976), Fellows et al. (1978), Fellows et al. (1980),

Lefebvre et al. (1985), and Kadhim et al. (1989). Aerial baiting of sugarcane fields was tested by Pank et al. (1975), Fellows et al. (1978), Fellows et al. (1980), and Lefebvre et al. (1985). Pank et al. (1975) and Fellows et al. (1980) utilized 1.88% zinc phosphide/oat bait at a rate of 5lbs/acre. Lefebvre et al. (1985) baited with a 2% zinc phosphide pellet at 3.2g/ha, and was the only study reporting less than 70% control. All of the other studies employed bait stations. West et al. (1972) and West and Libay (no date) used 1.0% and 0.75% zinc phosphide on rice for controlling black rat damage in rice fields. They reported 25% and 52-91% efficacy, respectively. Rennison (1976) reported adequate control with 2.5% zinc phosphide bait, but 1.0% zinc phosphide did not provide sufficient reduction in rat populations. Rat populations were reduced 95% when 2.0% zinc phosphide baits were applied in Macadamia nut orchards by Pank et al. (1976).

Laboratory Efficacy Studies

Rattus norvegicus - The Norway rat was cited in 10 laboratory studies: Emlen and Stokes (1947), Dieke (1948), Greaves (1966), Po-Yu (1973), Fellows (1977), Kirishnakumari et al. (1980), Matschke and Fordham (1985), Tobin and Sugihara (1990), Tobin et al. (1990), Tobin et al. (1991), Suighara et al. (1995), McCann and Matschke (1999a) and McCann and Matschke (1999b). Emlen and Stokes (1947) and Dieke (1948) used corn as the bait material and found 80-100% mortality could be achieved at concentrations above 0.2% zinc phosphide. Po-Yo (1973), Matschke and Fordham (1985), and McCann and Matschke (1999a and 1999b) tested pellets, oat groats and rice with 1.0%, 1.8% and 2.0% zinc phosphide and found efficacy to be consistently above 75%. Greaves (1966), Fellows (1977), Tobin and Sugihara (1990), and Sugihara et al. (1995) all performed laboratory experiments where a wide variety of zinc phosphide concentrations were tested with various oat and pellet material under single and two choice exposures scenarios. Results of these exploratory tests were consistently less than 70% efficacious. Wax block baits were shown to be ineffective by Tobin et al. (1990).

Rattus rattus - The efficacy of zinc phosphide with the roof rat was evaluated in 7 laboratory studies: Fellows (1977), Lefebvre et al. (1978), Krishnakumari et al. (1980), Tobin and Sugihara (1990), Tobin et al, (1990), Tobin et al. (1991), Mahli and Prashad (1991), Pachori et al. (1995), and Sugihara et al. (1995). Fellows (1977) reported efficacy rates less than 70% in exploratory studies conducted using various bait encapsulation techniques and efforts to develop one-seed lethal baits. Lefebvre et al. (1977 and 1978) also reported efficacy rates lower than 70% with 1.88% zinc phosphide on cracked corn and oat groats. Krishnakumari et al. (1980) and Pachori et al. (1995) showed that in multiple food choice tests, zinc phosphide baits at concentrations between 1.5% and 2.25% resulted in 100% mortality. Sugihara et al. (1995) tested pellet and oat groats baits at concentrations at 1.88% and 2.0% zinc phosphide and reported mortality rates up to 90%. Tobin and Sugihara (1990) tested multiple 1.88% and 2.0% zinc phosphide products and found acceptable mortality using oat based baits.

Reviews, Summary Papers or Use Manuals

Doty (1945), Chitty (1954b), Brooks (1962), Hood (1968), Hood et al. (1970), Teshima (1970), California Department of Agriculture (1994), and University of Nebraska Cooperative Extension (1994a and 1994b) are reviews, summary papers or use manuals and do not report results of efficacy studies.

EFFICACY OF ZINC PHOSPHIDE – GROUND SQUIRREL CONTROL

Over the last 20 years, 14 studies have evaluated the efficacy of zinc phosphide in controlling three species of ground squirrels: the California ground squirrel (*Spermophilus beecheyii*), the Columbian ground squirrel (*Spermophilus columbianus*), and the Richardson ground squirrel *(Spermophilus richardsoni*) (Table 3). Results of most tests were obtained by comparing the pre-baiting burrow activity level to the post-baiting burrow activity level. No laboratory studies were conducted with ground squirrels.

Table 3. Efficacy of Zinc Phosphide Grain Baits for Ground Squirrel Control

Use Site	ZP Conc. (%)	Bait Material	Application Rate	Application Method	Efficacy (% Reduction)	Citation
Spermophilus beecheyi						
Rangeland	1.0	Oat Groats	6 lbs / acre	Broadcast	88 - 100	Matschke et al. (1995)
Rangeland	1.0	Oat Groats	11g / burrow	Hand-bait	96 - 100	Matschke et al. (1995)
Rangeland	2.0	Oat Groats	6 lbs / acre	Aerial	76	Marsh and Record (1985)
Rangeland	2.0	Oat Groats	6lbs / acre	Broadcast	73 - 100	Matschke et al. (1995)
Rangeland	2.0	Oat Groats	11g / burrow	Hand-bait	89 – 99	Matschke et al. (1995)
Spermophilus columbianus						
Alfalfa	0.8	Cabbage	8-10 pcs / burrow	Hand-bait	62	Albert and Record (1979a)
Alfalfa	0.8	Oats	0.22 oz / burrow	Hand-bait	42	Albert and Record (1979b)
Alfalfa	2.0	Cabbage	8-10pcs / burrow	Hand-bait	62	Albert and Record (1979b)
Alfalfa	2.0	Oats	0.22 oz / burrow	Hand-bait	42	Albert and Record (1979a)
Alfalfa	2.0	Pellets	0.22oz / burrow	Hand-bait	55	Baril (1980)
Pasture	2.0	Oats	1tsp / burrow	Hand-bait	93	Sullivan and Baril (1981)
Hayfield	2.0	Oats	1 tsp / burrow	Hand-bait	53	Sullins and Sullivan (1995)
Spermophilus richardsoni						
Rangeland	0.8	Cabbage	10 lbs / acre	Hand-bait	39	O'Brien (1978)
Rangeland	2.0	SRO	1 tsp / burrow	Hand-bait	69	Matschke et al. (1978)
Rangeland	2.0	SRO	1 tsp / burrow	Hand-bait	70 - 79	Matschke et al. (1979)
Rangeland	2.0	Oats	0.22oz / burrow	Hand-bait	69	Swick (1980)
Rangeland	2.0	SRO	6 lbs / swath acre	Broadcast	85	Matschke et al. (1980)
Rangeland	2.0	SRO	1 tsp / burrow	Hand-bait	69	Matschke et al. (1982)
Rangeland	2.0	SRO	6 lbs / swath acre	Broadcast	85	Matschke et al. (1983)
Hayfield	2.0	Oats	1 tsp / burrow	Hand-bait	96	Sullins and Sullivan (1995)

SRO - Steam Rolled Oats

Note: Matschke et al. (1980) and Matschke et al. (1983) report data from the same study.
Matschke et al. (1978) and Matschke et al. (1982) report data from the same study.
Albert and Record (1979a) and Albert and Record (1979b) report data from the same study.

Field Efficacy Studies

Spermophilus beecheyii - Two studies reported the efficacy of rangeland applications of zinc phosphide oat-groat bait for controlling the California ground squirrel: Marsh and Record (1985a), Marsh and Record (1985b), and Matschke et al. (1995). Marsh and Record (1985b) is a report the results of a 1-year follow-up survey to the 1985a efficacy trial. Marsh and Record (1985a) aerially applied 2% zinc phosphide oat-groat bait at a rate of 6 lbs/acre and reported a 76% reduction in ground squirrel activity. One year later Marsh and Record (1985b) surveyed ground squirrel activity again and found levels similar to that found during pre-treatment surveys. Matschke et al. (1995) tested both 1.0% and 2.0 zinc phosphide on oat-groat using both hand baiting (11g/burrow) and broadcast (6lbs/acre). All four methods resulted in greater than a 73% reduction in ground squirrel activity.

Spermophilus columbianus - Three studies reported the efficacy of hand baiting zinc phosphide for controlling Columbian ground squirrel: Albert and Record (1979a), Albert and Record (1979b), Baril (1980), Sullivan and Baril (1981), and Sullins and Sullivan (1995). Both publications by Albert and Record report data from the same study (Albert and Record 1979a, 1979b). Albert and Record (1979a and 1979b) conducted two tests in alfalfa using 2.0% zinc phosphide/oat matrix bait at a rate of 0.22oz/burrow and 0.8% zinc phosphide/cabbage matrix bait at the rate of 8 - 10 pieces/burrow and reported 42% and 62% control. Baril (1980) achieved only 55% control when 2.0% zinc phosphide pellets were applied at 0.22oz/burrow. Sullivan and Baril (1981) reported 93% control using 2% zinc phosphide on oats at a rate of 1 teaspoon/burrow. Sullins and Sullivan (1995) used 2.0% zinc phosphide/oat bait at a rate of 1tsp/burrow and achieved only 53% control.

Spermophilus richardsoni - Seven studies were found in the literature reporting the efficacy of zinc phosphide with the Richardson's ground squirrel: Matschke et al. (1978), O'Brien (1978), Matschke et al. (1979), Matschke et al. (1980), Swick (1980), Matschke et al. (1982), Matschke et al. (1983), and Sullins and Sullivan (1995). However, Matschke et al. (1978 and 1982) and Matschke et al. (1980 and 1983) report data from the same two studies.

With the exception of O'Brien (1978) all studies used a 2.0% concentration of zinc phosphide/oat bait formula. O'Brien (1978) used 0.8% zinc phosphide on cabbage at a rate of 10 lbs / acre and achieved only a 39% reduction in ground squirrel activity. Matschke et al. (1978, 1979, and 1982) and Swick (1980) hand baited with 1 teaspoon/burrow and achieved 69% to 79% control. Using the same application rate Sullins and Sullivan (1995) were able to reduce ground squirrel activity by 96%. Matschke et al. (1980 and 1983) broadcast zinc phosphide at a rate of 6 lbs/acre swath and reported 85% control.

Laboratory Efficacy Studies

No laboratory efficacy studies were reported for ground squirrels.

Reviews, Summary Papers or Use Manuals

Hagen (1972), USFWS (1975), Schilling (1976), Marsh (1987), Montana Department of Agriculture (1993), California Department of Agriculture (1994), University of Nebraska, Cooperative Extension (1994a and 1994b), and Storer (no date) are reviews, summary papers or use manuals and do not report results of efficacy studies.

EFFICACY OF ZINC PHOSPHIDE – PRAIRIE DOG CONTROL

As many as 14 separate studies have evaluated the efficacy of zinc phosphide on oats as a control technique for prairie dogs in rangeland (Table 4). Most of the studies were conducted on the black-tailed prairie dog (*Cynomys ludovicianus*). Only one report studied the Gunnison prairie dog *(Cynomys gunnisoni gunnisoni)*. In most studies, estimates of control were generated by monitoring pre- and post-treatment burrow activity. All but one study was performed with hand baiting 2.00% concentration zinc phosphide/oat bait at rates of approximately 4g/burrow. Only one study evaluated efficacy under laboratory conditions.

Field Efficacy Studies

Cynomys ludovicianus - The efficacy of zinc phosphide with the black-tailed prairie dog was reported in 15 studies: Tietjen (1976), Swick (1976), Sullins (1980), Tietjen and Matschke (1981), Knowles (1982), Record and Swick (1983), Apa (1985), Holbrook and Timm (1985), Knowles (1986),

Uresk et al. (1986), Cincotta et al. (1987), Uresk et al. (1987), Uresk and Schenbeck (1987), Hygnstrom and McDonald (1989), Apa et al. (1990), Sullins and Sullivan (1995) and Hygnstrom et al. (1998). Apa (1985) and Apa et al. (1990), and possibly Uresk et al. (1986 and 1987) report data from the same study. Knowles (1982 and 1986) also report data from the same study. Most studies reported prairie dog activity decreased by more than 80% following spot treatments with 2% zinc phosphide on oats. However, two studies reported efficacy lower that 70%. Swick (1976) reported only 33% and 30% efficacy. Pre-baiting was not used in these trials. Tietjen and Matschke (1981) encapsulated

Table 4. Efficacy of Zinc Phosphide Grain Baits for Prairie Dog Control

Species	ZP Conc. (%)	Bait Material	Application Rate	Application Method	Efficacy (% Reduction)	Citation
Cynomys ludovicianus						
Rangeland	1.0	Oat Groats	0.22 oz / burrow	Hand-bait	33	Swick (1976)
Rangeland	2.0	Oat Groats	4 g / burrow	Hand-bait	85	Tietjen (1976)
Rangeland	2.0	Oat Groats	4 g / burrow	Hand-bait	88	Tietjen (1976)
Rangeland	2.0	Oats	4 g / burrow	Hand-bait	96	Tietjen (1976)
Rangeland	2.0	SRO	0.22 oz / burrow	Hand-bait	30	Swick (1976)
Rangeland	2.0	Oats	1 tbl / burrow	Hand-bait	95	Sullins (1980)
Rangeland	2.0	SRO	4 g / burrow	Hand-bait	83	Tietjen and Matschke (1981)
Rangeland	2.0	Pellets	4 g / burrow	Hand-bait	71	Hygnstrom et al. (1998)
Rangeland	2.0	Encap. SRO	4 g / burrow	Hand-bait	27	Tietjen and Matschke (1981)
Rangeland	2.0	Oats	1 tsp / burrow	Hand-bait	85	Knowles (1982)
Rangeland	2.0	Oats	?	?	92	Record and Swick (1983)
Rangeland	2.0	SRO	4 g / burrow	Hand-bait	66	Holbrook and Timm (1985)
Rangeland	2.0	SRO	4 g / burrow	Hand-bait	86	Apa (1985)
Rangeland	2.0	SRO	?	?	95	Uresk et al. (1986)
Rangeland	2.0	Oats	1 tsp / burrow	Hand-bait	85	Knowles (1986)
Rangeland	2.0	Grain	4 g / burrow	Hand-bait	99	Cincotta et al. (1987)
Rangeland	2.0	SRO	?	?	95	Uresk et al. (1987)
Rangeland	2.0	SRO	4 g / burrow	Broadcast	93	Uresk and Schenbeck (1987)
Rangeland	2.0	SRO	4 g / burrow	Hand-bait	95	Apa et al. (1990)
Rangeland	2.0	Oats	4 g / burrow	Hand-bait	80	Hygnstrom et al. (1998)
Rangeland	2.0	Oats	4 g / burrow	Hand-bait	78	Hygnstrom et al. (1998)
Hayfield	2.0	Oats	5 g / burrow	Hand-bait	93	Sullins and Sullivan (1995)
Laboratory	2.0	Oat Groat	Ad libitum	3-day exposure	80 – 100	Schitoskey et al. (1971)
Laboratory	2.0	Oat Groat	Ad libitum	?	90	Tietjen (1976)
Cynomys gunnisoni						
Rangeland	2.0	SRO	4 g / burrow	Hand-bait	81	Tietjen (1979)
Pasture	2.0	SRO	4 g / burrow	Hand-bait	96	Tietjen (1979)

SRO - Steam Rolled Oats

Note: Apa (1985) and Apa et al. (1990) and possibly Uresk et al. (1986) and Uresk et al. (1987) report data from the same study. Knowles (1882) and Knowles (1986) report data from the same study.

steam-rolled oats and found that encapsulated bait reduced prairie dog activity by only 27%. Tietjen (1976) is the most complete reference for providing information on bait development and field methodology.

Cynomys gunnisoni gunnisoni - The Gunnison prairie dog was the subject of one study. Tietjen (1979) used 2.0% zinc phosphide on oats at an application rate of 4g/burrow in two habitat types. The trial conducted in rangeland reported efficacy of 81%. The other trial, conducted in pasture, reported efficacy of 95%.

Laboratory Efficacy Studies

Two laboratory efficacy studies were conducted with black-tailed prairie dogs. Schitoskey et at. (1971) tested 2.0% zinc phosphide oat-groat bait with the black-tailed prairie dog and reported 80% to 100% mortality. Tietjen (1979) tested five zinc phosphide concentrations (0.75 ppm – 3.0 ppm) on oat groats and reported 2% zinc phosphide was the most satisfactory concentration.

Reviews, Summary Papers or Use Manuals

Ludemann (1962), USFWS (1972), Sandall (1975), Painter (1976), Henderson and Boggess (1979), Montana Department of Agriculture (1993), California Department of Agriculture (1994), and University of Nebraska Cooperative Extension (1994a and 1994b) are reviews, summary papers or use manuals and do not report results of efficacy studies.

CONCLUSIONS

Zinc phosphide has been used as a control agent for commensal rodents for over 60 years. More than 125 published and unpublished reports and review papers were compiled for this paper. The results reported in the cited manuscripts show that control results can be variable, but overall they demonstrate that rodenticide products containing zinc phosphide can be used to successfully control commensal rodents, or pests considered to pose a threat to public health (Norway rat, roof rat, house mouse, *Peromyscus spp.*, prairie dog and ground squirrel) under both laboratory and field conditions. In general, bait acceptance appeared to be the major factor in obtaining satisfactory control therefore, prebaiting can increase efficacy. However, the field efficacy can be greatly influenced by factors such as the time of year, geographic location, habitat treated and other environmental factors.

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