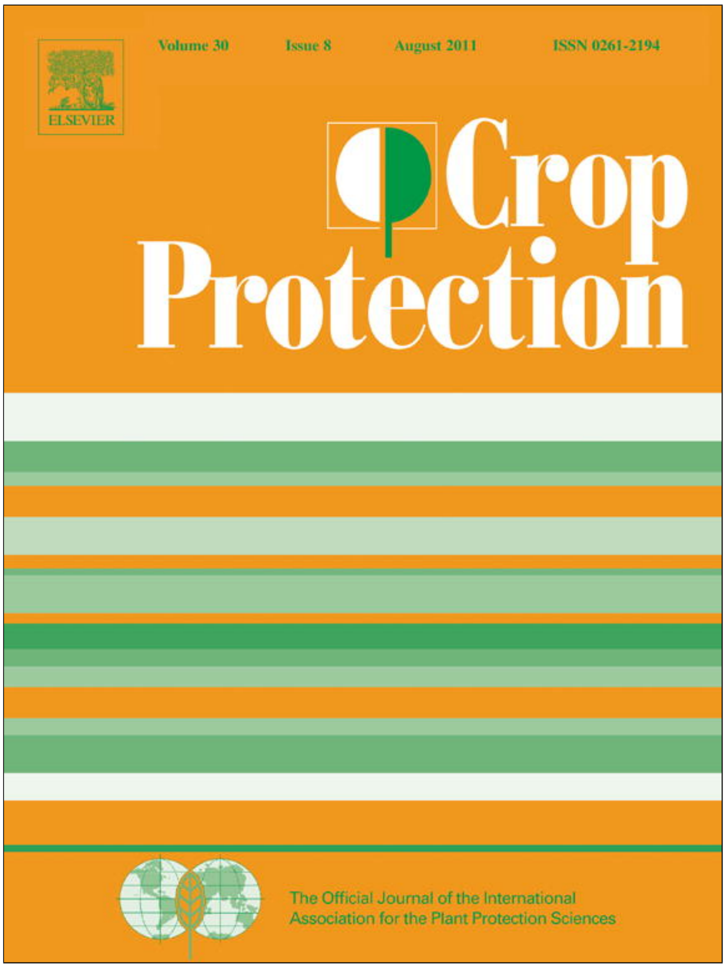
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Efficacy of aluminum phosphide tablets to control Richardson's ground squirrel (*Spermophilus richardsonii*) populations in southern Saskatchewan, Canada

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ABSTRACT

The objective of this study was to assess, using a capture-recapture program, the effectiveness of aluminum phosphide tablets for control of Richardson's ground squirrels (*Spermophilus richardsonii*) in southern Saskatchewan grasslands, from April to July 2007–2009. Aluminum phosphide tablets were tested in study plots in moist or dry soil conditions, where burrow openings had either been marked with a flag (to ensure that all openings would be found and treated) before treatment or left unmarked. In five study plots with moist soil conditions and flagged burrow openings, the mean control level was 80.9 (SD = 6.3) %. In two study plots with dry soil conditions and flagged burrow openings, and one study with moist soil conditions and unflagged burrow openings, control levels were < 60%. It is recommended that aluminum phosphide tablets be used to control Richardson's ground squirrels in relatively small areas (i.e., < 5 ha) with moist soil conditions and flagged burrow openings, or in specific sites where there are still high concentrations of ground squirrels after an initial treatment with poison food baits.

1. Introduction

During the last decade, in western Canada, Richardson's ground squirrel (*Spermophilus richardsonii*) populations reached high densities (often exceeding 40 adults/ha in spring, Proulx et al., 2010) due to an extensive drought (Liu et al., 2004), poor grassland management and a lack of effective control methods (Proulx, 2010). Richardson's ground squirrels have caused extensive damage to crop and pasture land, and received the status of pest under the Saskatchewan Pest Control Act (Hopson, 2010).

In Canada, aluminum phosphide was registered in 2003 for the control of Richardson's ground squirrels. Salmon et al. (1982) found that aluminum phosphide reacted with moisture in the soil and produced phosphine gas that was 100% effective for controlling *S. beecheyi*. In Montana, Sullins and Sullivan (1992) estimated that, on the basis of percent reduction in activity, aluminum phosphide controlled 87.3% of the population of Richardson's ground squirrels.

In Canada, the ability of aluminum phosphide to control ground squirrel populations is unknown. The objective of this study was to assess, using a capture-recapture program, the effectiveness of aluminum phosphide tablets to control Richardson's ground squirrels in southern Saskatchewan grasslands.

2. Material and methods

The study was carried in the rural municipalities of Mankota, Glen McPherson and Pinto Creek near the towns of Mankota, Hazenmore, and Ponteix (Fig. 1). Study plots corresponded to mixed grasslands of crested wheat (*Agropyron crustatum*), brome (*Bromus* spp.), slender wheat grass (*Elymus trachycaulus*) and alfalfa (*Medicago* spp.). The soil of most study plots was judged to be moist on the basis of dampness at touch, color and aggregation. Two study plots had dry soil that was cracked on the surface, did not exhibit signs of moisture and was without apparent cohesion (USDL, 2007). These study plots had sparse or drought-stressed vegetation.

Live-trapping was conducted in spring (14 April –1 June) and summer (14 June–2 July) using 15 × 15 × 48 cm Tomahawk (Tomahawk Live Trap, Tomahawk, WI) live-traps baited with peanut butter on bread. Traps were set and checked early in the morning and in mid-afternoon. All ground squirrels inhabiting study plots were tagged (Monel # 1 tag, Newport, KY) in both ears. Their sex, weight and general body condition were recorded before releasing them at their capture site. In spring, captured populations consisted of adult Richardson's ground squirrels. In summer, because some adults may hibernate in June (Michener and Koeppl, 1985), only juveniles were included in the populations. Each season, the average natural mortality rate was estimated in 2–3 control study plots where no treatment occurred. They were located away from study plots treated with aluminum phosphide

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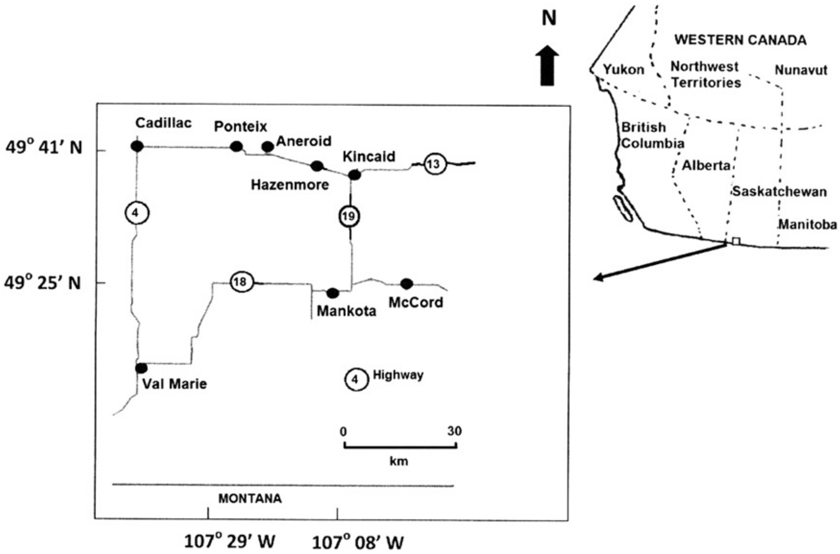

Fig. 1. Location of the study area in southern Saskatchewan, 2007–2009.

tablets, but in the same quarter sections. Live-trapping followed the highest standards of humaneness (Powell and Proulx, 2003).

The exact size of study plots was determined on the basis of capture-recapture locations. The efficacy of aluminum phosphide tablets (Phostoxin®, Degesch America Inc., Weyers Cave, VA; a 3-g tablet liberated 1 g of hydrogen phosphide gas) was tested in 1) four study plots with moist soil in spring, from 2007 to 2009, and one study plot in summer 2009; and 2) two study plots with dry soil conditions, i.e., one in spring 2007 and one in summer 2009. Approximately 12 h before treatment, all ground squirrel burrow openings within study plots were flagged to ensure that they would all be treated. Because flagging is time consuming, Phostoxin® tablets were also tested in spring 2009 in one study plot with moist soil conditions where ground squirrels holes had not been flagged. In all study plots, particular attention was paid to the identification of burrow systems that may be inhabited by carnivores and particularly species at risk such as the swift fox (*Vulpes velox*) and the burrowing owl (*Athene cunicularia*). Burrows with fresh signs of badger (*Taxidea taxus*) and long-tailed weasels (*Mustela frenata*) were not treated with toxicants.

Phostoxin® tablets were thrown approximately 22 cm deep into Richardson's ground squirrel holes late in the evening near sunset, or early in the morning before sunrise, when animals were underground. All burrow openings were counted and filled with soil immediately after treatment. In each study plot, live-trapping was initiated the day following treatment, and lasted up to 15 d to capture all animals present. Open hole counts were conducted 1 day after treatment only in spring 2007 and 2008. The number of holes not reopened was used as an index of reduced activity.

Estimates of the control efficacy of Phostoxin® tablets took into consideration natural mortality, and was calculated with Abbott's formula, $M = 100 \times [1 - (t2 \times c1)/(t1 \times c2)]$, where M (%) is Richardson's ground squirrel mortality, t is the treated population, c is the control population, 1 is the population before treatment, and 2 is the population after treatment (Henderson and Tilton, 1955). Aluminum phosphide was found acceptable if it controlled at least 70% of ground squirrel populations (Matschke and Fagerstone, 1984; Proulx, 1998). Chi-square statistics (Siegel, 1956) were used to determine if the sex ratio of populations differed from a 1:1 ratio. Student t-test was used to compare mean population densities (Zar, 1999). A 0.05 level of significance was used for all tests.

3. Results

3.1. Richardson's ground squirrel populations

Population densities varied considerably among seasons and study plots, ranging from 5.9 to 62.5 animals/ha. Populations had an even sex ratio ($P > 0.05$), except in a spring 2008 population with a male-biased sex ratio, and a spring 2009 population favoring females (Table 1). Natural mortality markedly varied among seasons, being only 12.5% in spring 2007, but exceeding 28% in 2009 (Table 1).

3.2. Study plots with moist soil conditions

All aluminum phosphide treatments achieved > 70% control of Richardson's ground squirrel populations (Table 1). Mean control level for 5 populations was 80.9 (SD = 6.3) %. On average, the post-treatment population density/ha (4.3 ground squirrels; SD = 2.1) was 9 times lower than the pre-treatment population density (39 ground squirrels; SD = 18.7). There was a significant difference between means ($t = 4.123$, $P < 0.005$).

3.3. Study plots with dry soil conditions

Aluminum phosphide treatments controlled < 60% of ground squirrel populations (Table 1). Mean control level for 2 populations was 47.4%. The average post-treatment population density/ha (14 ground squirrels) was 2 times lower than the pre-treatment density (28 ground squirrels).

3.4. Study plot with moist soil conditions and unmarked burrow openings

The aluminum phosphide controlled only 55.7% of the ground squirrel population in the unmarked burrow opening plot (Table 1). The post-treatment population density was 3 times lower than the pre-treatment density.

3.5. Burrow hole counts

In spring 2007, the percentage of holes not reopened 1 day after treatment was 64.4% in the study plot with moist soil conditions,

Table 1
Characteristics of Richardson's ground squirrel populations before and after treatment with aluminum phosphide tablets, 2007–2009, southern Saskatchewan, Canada.

Plot no.	Plot size (ha)	Pre-treatment marked populations				Natural mortality (%)	Post-treatment marked populations				Control efficacy (%)	Number of burrow holes	
		Male	Female	Total	Density/ha		Male	Female	Total	Density/ha		Treated	Not reopened (%) after treatment
Study plots with moist soil conditions (flagged holes)													
Spring 2007													
1	2.4	11	14	25	10.4	12.5	1	4	5	2.1	71.4	371	239 (64.4)
Spring 2008													
1	0.6	14	10	24	40.0	19.2	2	2	4	3.3	78.5	305	236 (77.4)
2	0.4	18	7[a]	25	62.5	19.2	2	1	3	7.5	85.1	426	341 (80.1)
Spring 2009													
1	1.3	11	46[a]	57	43.8	29.4	2	3	5	3.8	87.6	–	–
Summer 2009													
1	0.6	7	16	23	38.3	28.1	0	3	3	5	81.9	–	–
Study plots with dry soil conditions (flagged holes)													
Spring 2007													
2	0.6	12	12	24	40	12.5	5	9	14	23.3	36.0	140	71 (50.7)
Summer 2009													
2	1.7	14	13	27	15.9	28.1	6	2	8	4.7	58.8	–	–
Study plots with moist soil conditions (unflagged holes)													
Spring 2009													
2	5.4	18	14	32	5.9	29.4	6	4	10	1.9	55.7	–	–

[a] Uneven sex ratio, $P < 0.05$.

compared to 50.7% in the plot with dry soil conditions (Table 1). In spring 2008, > 77% of holes in study plots with moist soil conditions were not reopened following treatment with aluminum phosphide (Table 1).

4. Discussion

This study showed that in grasslands with well established Richardson's ground squirrel populations, independently of the season or year, aluminum phosphide must be applied in fields with moist soil conditions, and all burrow openings must be flagged before treatment, in order to effectively control ≥ 70% of Richardson's ground squirrels. Then, a marked decrease in ground squirrel activity may be expected, as suggested by the low percentage of reopened burrow holes.

The capture-recapture program used in this study allowed us to determine with confidence natural mortality levels, which varied considerably from year to year, and to better estimate the efficacy of aluminum phosphide tablets to control ground squirrel populations. In 2007 and spring 2008, tests were conducted in landscapes where most fields had been poisoned in previous years with various rodenticides, and populations of natural predators were low due to secondary poisoning (Proulx et al, 2010; Proulx 2011). During other test periods, studies were conducted in landscapes with little or no poison food bait use. Also, avian and terrestrial predators were numerous, thus explaining higher natural mortality rates.

When soil conditions were dry, aluminum phosphide controlled < 60% of populations. This result was in agreement with previous studies where the efficacy of aluminum phosphide to control ground squirrels was affected by soil porosity and moisture, i.e., dry porous soil allowed a greater diffusion of gas (Salmon et al., 1982; Moline and Demarais, 1987). Reproduction alone would likely compensate for losses due to the application of aluminum phosphide tablets when soils are dry.

Farmers using aluminum phosphide do not generally flag burrow openings. Yet, on the basis of only one treated field, applying aluminum phosphide in fields where burrow openings have not been flagged, appeared to be a waste of time and money. The search for unmarked burrow openings delayed the application of aluminum phosphide tablets, and some holes were overseen. Animals escaping from improperly treated multi-entrance burrow systems traveled on surface, reopened other treated burrow systems, whistled, and caused awareness among other ground squirrels. The end result was poor control performance compared to fields where burrow openings had been flagged before treatment.

Under optimum conditions, applying aluminum phosphide tablets is time-consuming and labor-intensive. Using 1 applicator and 2–3 technicians to fill holes with soil, 2–4 holes/min could be treated. Therefore, treating sections with thousands of ground squirrel holes before sunrise or at sunset would require several people and consecutive crepuscular periods. Aluminum phosphide tablets should therefore be used to control Richardson's ground squirrels in relatively small areas, i.e., < 5 ha, or in areas where there are still high concentrations of ground squirrels after an initial treatment with poison food bait.

Finally, Baker (1992) considered that aluminum phosphide tablets could be safely applied by hand or with a mechanical applicator. It was noticed that, even when recommended safety measures were taken, researchers and producers showed signs of discomfort and nausea. There is a need for the development of a mechanical applicator that would speed up the delivery of tablets, increase safety, and decrease user discomfort.

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