EFFICACY OF A NUMBER OF TOXIC BAITS AND BAITING AGAINST THE VOLES, *Microtus agrestis* and *Arvicola terrestris*

ARVO MYLLYMÄKI, Agricultural Research Centre, 31600 Jokioinen, Finland

ABSTRACT: The results from two series of control experiments against the voles, Microtus agrestis and Arvicola terrestris, are reported. In a series of field experiments in the 1970s, three acute toxicants (zinc phosphide, crimidine and difluorpropanol) were tested against Microtus. Difluorpropanol (Gliftor) was found to be the most effective, but no ready-made bait containing it was available. The performance of the crimidine bait (Kastrix) was good enough to fulfill the registration requirements, while the zinc phosphide bait (Myrax) failed to give acceptable results. In the second series (early 1980s) a brodifacoum bait (Klerat) was found to be as efficacious as the crimidine bait (Kastrix) against Microtus, and sufficiently effective against Arvicola, on which the crimidine bait does not work. The experiments with bromadiolone (Arvicolon) and flupropadine (M & B 36,892) against Microtus were discouraging; against Arvicola they were promising, though not yet conclusive. In future research, special attention should be paid not only to the screening of potential toxicants and bait formulations, but also to the study of the basic differences in the reactions of even closely related species to the baits and their active ingredients, as well as to the compensatory demographic responses of the target pest populations in cases of suboptimal performance of the bait in the field.

INTRODUCTION

Voles, especially the field vole, Microtus agrestis (for brevity: "Microtus" in the subsequent text), and the water vole, Arvicola terrestris ("Arvicola"), are major pests of cultivated trees in Finland, other Scandinavian countries, and certain parts of central Europe. According to a conservative estimate (Myllymäki 1977) the economic value of vole damage in Finland, Norway and Sweden during the two decades from the mid-1950s to the mid-1970s was close to 100 million U.S. $. The means of combating vole damage have been limited since the introduction of restrictions concerning the use of endrin as a ground spray and its final withdrawal in the 1970s. Hence, the experiments reported below were planned to find effective and, if possible, safe substitutes for endrin.

Two series of trials were conducted. In the first, two ready-made baits, one with zinc phosphide, the other with crimidine as active ingredient, were tested together with a Russian compound "Gliftor" (a. i. difluorpropanol) that was applied in apple baits (Bykovsky 1975). The second series was undertaken after the invention of the "second-generation" anticoagulants, some of which were suggested to be effective against voles (Dubock and Kaukeinen 1978, Lund 1981, Byers and Merson 1982). A new non-anticoagulant rodenticide (flupropadine) was found interesting and added to the program.

The original experimental data are collated in the annual reports of the Finnish Plant Protection Regulation Unit (Myllymäki 1980, 1983a, and in prep.), and a short summary of the main results on Microtus given by Myllymäki (1983b). The following is a somewhat detailed overview of the results, with the main emphasis on the latest data and the subsequent conclusions.

MATERIALS AND METHODS

Since the experiments reported below consist of a wide array of both laboratory and field trials on two species of voles, the methods used vary accordingly. However, methods described in the EPPO Guidelines (EPPO 1975, 1982) were generally referred to; consequently, a few notes may suffice to clarify the prevailing test conditions.

Laboratory tests

The animals used were either recently caught in the wild and acclimatized under laboratory conditions for at least two weeks (Arvicola), or laboratory-bred offspring of animals caught in the wild (Microtus).

Tests done before May 1, 1983, were conducted in the former facilities of the Agricultural Research Centre in Vantaa (near Helsinki); those after that date in its new facilities in Jokioinen (about 130 km NW of Helsinki). In both places the animal rooms and equipment used were similar; e.g., the room temperature varied somewhat, but remained between 15 and 20°C. For the trials, the animals were weighed, sexed (sex ratio in each group 1:1, whenever possible), caged singly about 1 week before the treatment, and kept under regular observation for about 30 d after the treatment. A nest box and water were available throughout the trial.

The experimental baits were placed in glass (or plastic) bowls in front of the cage, normally 30 g/animal for Arvicola. Any bait remaining was collected and weighed after 24 hours, whereafter the animals were given their normal diet, consisting mainly of fresh forbs and grass in summer, and beets or potatoes, dried hay, and a standard dry-fodder mixture in winter. In the choice tests ("CH" in the tables), the normal food was available during the treatment, too; in the no-choice situation ("NO") the

1984, Proceedings Eleventh Vertebrate Pest Conference
(D.O. Clark, Ed.). Printed at Univ. of California, Davis, Calif.

normal food was removed. When repeated feeding was applied, the treatments were on days 1 and 3. A nontreated reference group of animals was always included. All deaths (excluding occasional accidental deaths) occurring during the course of the 30 d-observation period were included in the mortality figures.

Field trials

The field trials were conducted in various types of grassy habitats (old fields, afforestation areas, seed orchards, etc.) during the autumn months or in winter. Only fields with moderately high-density vole populations were used. All three types of census methods recommended in the EPPO Guidelines (EPPO 1975) were applied in the pretreatment and posttreatment assessment of the density levels of the target populations: (1) capture-marking-recapture (CMR), (2) double removal by means of the Small Quadrat Method (SQM; Myllymäki et al. 1971), and (3) counting the signs (snow holes (SH) in the case of Microtus, opened and refilled burrows in the case of Arvicola). The plot size varied according to the circumstances, the minimum being about 1 to 1.5 ha (CMR). An untreated control plot was always included in the experimental plan.

The mode of bait application varied according to the bait type and the season. Comparisons were made between various application methods, resulting in differing bait densities under similar experimental conditions (e.g., blanket broadcast over the treated surface versus placing the bait in "bait stations" at equal intervals. The treatments were usually performed immediately after the pretreatment census. Timing of the posttreatment census depended on the type of the a.i. in the bait. In the case of typical single-dose acute poisons, it was generally conducted 1 week after the treatment; in the case of anticoagulants the interval was longer.

A special case was the winter treatments where the snow holes were used both as the basis of the population estimates and for placing the bait. In this situation, the pretreatment census and the treatment itself were most practically connected and conducted during the same day on all the plots. All holes found were treated. The posttreatment was done after a snowfall that covered all the previous holes.

The results of the field experiments are generally expressed in terms of the percentage kill which, in turn, has been calculated according to the formula by Henderson and Tilton (1955) that takes into account occasional changes in the density indices of the untreated reference populations (untreated plots).

EXPERIMENTAL RESULTS

Earlier field trials with three acute poisons

A series of field trials against Microtus with difluorpropanol (Gliftor), crimidine (Kastrix) and zinc phosphide (Myrax) baits were conducted between 1971 and 1977 (Myllymäki 1980); the series involved 13 treatments during the autumn months and 8 in winter. As difluorpropanol was applied in apple baits, it could not be included in the winter trials. The overall results of these experiments are illustrated in Fig. 1, where the average percentage kill (mean ± 95% confidence limits) is presented separately for each compound and season.

With the sole exception of Gliftor, the distribution of individual efficacy indices round the mean was rather spread during the snow-free season. Despite this, the following order of performance may be justified:

$$\text{Gliftor (difluorpropanol)} \geq \text{Kastrix (crimidine)} > \text{Myrax (zinc phosphide)}.$$

During the winter months the effectiveness of Kastrix (crimidine) treatments was clearly better than that of Myrax (zinc phosphide) treatments, and the former was more precisely predictable. These two preparations were thus easily ranked in the order Kastrix > Myrax.

In autumn treatments it was found that bait density was an important parameter determining the performance of a given bait. As an example, calculated mortality indices (percentage kill) obtained in the Kastrix treatments with various distances between the bait points were as follows:

Blanket spread	5 x 5 m	7 x 7 m	14 x 14 m
91.5	81.0	57.2	52.5

Specific bait stations (covered bird feeders) were used in connection with some treatments with Myrax. Condensation and freezing of water inside the feeder clearly decreased bait availability. A similar experience was found when the "Canadian T-feeders" (Radvanyi 1974) were used in a nursery.

Repeated treatments with Myrax did not essentially improve the final outcome; in the two cases where the percentage kill in connection of consecutive treatments was monitored, it decreased from 70.0% to 37.7% and from 49.7% to 36.9%, respectively. This result can probably be interpreted as a sign of induced bait-shyness. Repeated treatments with Kastrix were not conducted, as the original performance was good enough.

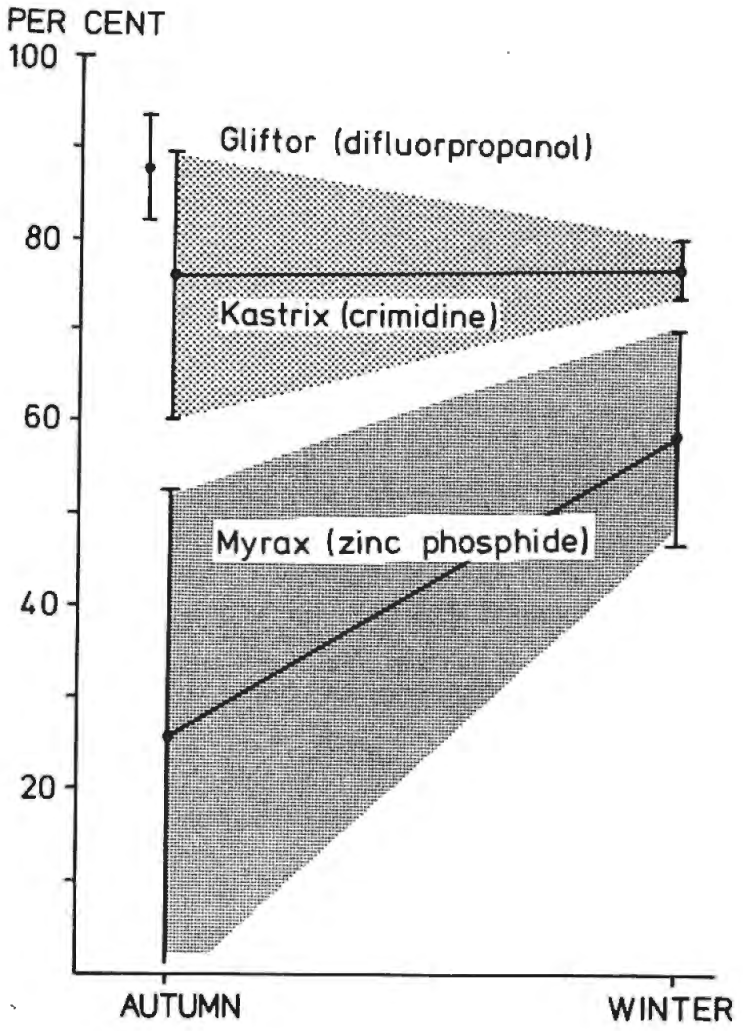

Fig. 1. Average percentage kill (mean ± 95% confidence limits) in target populations of Microtus with treatments of three acute poisons, difluorpropanol (Gliftor), crimidine (Kastrix) and zinc phosphide (Myrax).

Tentative screening of prospective new toxicants

Two series of tests were conducted using fresh apple as the carrier of the toxicant:

(1) The efficacy on Microtus of three anticoagulants with single feeding in a choice situation (normal food available) was compared; the results are given in Table 1. Not unexpectedly (cf. Lund 1981), the toxicants could be arranged in the following order of preference:

brodifacoum > diphenacoum > warfarin.

Unfortunately, there were no suitable concentrations of e.g. chlorophacinone and bromadiolone available; this may be considered a drawback, because both are widely used for controlling microtines.

(2) A gradient of three different concentrations of flupropadine (M & B 36,892) paste was tested on both Microtus and Arvicola, predominantly in a choice situation; the results are represented in Table 2. An interesting finding was that the concentration did not markedly influence bait acceptance, while, on the other hand, there was a clear-cut difference in the reactions of the two species: Microtus virtually rejected the baits throughout, while the effect on Arvicola was excellent under all conditions.

Table 1. The effectiveness of three anticoagulants on Microtus in laboratory experiments. Pieces of apple, dried overnight at room temperature, then soaked in liquid concentrations. Single treatment (24 hours) in "choice" situation, i.e., normal food simultaneously available. Animals observed for 30 d.

A.i. and its approximate concentration	No. of animals and their average weight (g)	No. of dead	Average time to death (d) and range ( )
Warfarin 0.05%	12 / 24.4	1	(4) --
Diphenacoum 0.005%	12 / 24.6	9	6.3 (4 - 21)
Brodifacoum 0.005%	12 / 27.3	11	6.9 (5 - 20)
Untreated	12 / 25.4	0	- -

Table 2. The effectiveness of three concentrations of a novel rodenticide flupropadine (M & B 36,892) on Microtus and Arvicola under laboratory conditions. A paste formulation of flupropadine applied as a thin layer on apple baits, dried overnight at room temperature. Single treatment (24 h), generally in "choice" situation, i.e., normal food simultaneously available. Animals observed for 30 d.

Concentration of a.i.	No. of animals and their average weight (g)	No. of dead	Average time to death (d) and range ( )
Trials on Microtus:			
1.0%	10 / 24.6	0	-
2.0%	10 / 33.7	0	-
3.0%	10 / 35.6	0	-
Trials on Arvicola:			
1.0%	8 / 113	8	6.4 (4 - 7)
2.0%	8 / 97	8	6.4 (2 - 8)
3.0%	7 / 111	7	6.0 (4 - 8)
3.0% (no-choice)	7 / 103	7	5.4 (4 - 7)

Testing ready-made baits in the laboratory

A whole array of anticoagulant baits and two baits with flupropadine as a.i. (two concentrations) were tested on Microtus; the results are summarized in Table 3.

In the first series of experiments it was found that only Klerat with 0.001% brodifacoum was comparable with the registered crimidine bait (Kastrix) in terms of efficacy. Its occasional failures apparently depended on total rejection of the bait by individual animals. A higher concentration of a.i., as used in the rat baits, clearly decreased the palatability and, hence, the efficacy. The apparently good performance of the diphenacoum bait (Ratak) should not be overemphasized, because it was used in one small (double) treatment only. Instead, the diphacinone bait (Ramik) can be rejected as a potential vole toxicant; the only death that occurred probably had nothing to do with the toxicant.

The second series was arranged in order to uncover the potential of the ready-made flupropadine pellets. In accordance with the findings in the apple bait trials, the pelleted form also performed poorly, while Klerat as the reference bait behaved normally.

Finally, in the third series of trials the high concentration (0.02%) bromadiolone bait (Arvicolon) was rejected as a potential bait for Microtus. In addition to the apparent palatability problems, the toxicity of a.i. itself also seemed to be unexpectedly low.

The amount of a.i. consumed by dead animals and the survivors, respectively, may give some hints about the LD 50, or LD 90, values of the toxicants tested. Thus, it seems likely that the acute LD 50 of brodifacoum for Microtus lies somewhere between 0.6 and 1.0, and the LD 90 possibly between 1 and 2. Microtus apparently survives considerably (10 - 20 times ?) higher dosages of bromadiolone than of brodifacoum. The toxicity of flupropadine to Microtus also seems to be lower than the LD 50 values (around 50) given by the manufacturer for commensal species.

In tests against Arvicola the main emphasis was on brodifacoum (Klerat) and bromadiolone (Arvicolon) baits; the results are presented in Table 4. Kastrix was used as a reference bait, although its poor acceptability by Arvicola was well known beforehand.

Table 3. The effectiveness of a number of ready-made baits on Microtus under laboratory conditions. The series consisted of both no-choice (NO) and choice (CH), as well as single (24 h = "1 x") and double (2 x 24 h = "2x") treatments; an untreated reference group always included in the experimental plan, although omitted from the table for brevity. d = dead, s = survivors.

Preparation and concentration of a.i. (%)	Type of trial	No. of animals average weight (g)	No. of dead	Average time to death (range)	Consumption of a.i. (mg/kg) ($\bar{x} \pm$ S.E.)
Series I: anticoagulant baits versus crimidine bait (Kastrix), Vantaa, 1982					
Klerat (brodifacoum 0.001)	CH 1x	17 / 30.5	14	4.5 (3 - 7)	d 1.0 ± 0.3 s 0.0
Klerat (brodifacoum 0.001)	CH 2x	17 / 29.6	15	5.1 (3 - 9)	d 2.0 ± 0.3 s 0.0
Klerat (brodifacoum 0.001)	NO 1x	16 / 32.2	10	4.6 (3 - 9)	d 0.6 ± 0.3 s 0.0
Klerat (brodifacoum 0.001)	NO 2x	16 / 28.4	15	5.9 (4 - 10)	d 2.5 ± 0.3 s 0.0
Klerat (brodifacoum 0.005)	CH 1x	10 / 31.2	5	4.6 (4 - 6)	d 1.9 ± 0.6 s 0.6 0.3
Klerat (brodifacoum 0.005)	NO 1x	10 / 32.2	6	5.8 (5 - 7)	d 3.4 ± 0.3 s 0.3 ± 0.3
Ratak (diphenacoum 0.005)	NO 2x	8 / 32.7	7	5.3 (4 -10)	d 15.3 ± 2.1 s 15/3
Ramik (diphacinone 0.005)	NO 2x	16 / 31.9	1	(3)	d 0.0 s 0.4 ± 0.1
Kastrix (crimidine 0.5)	CH 1x	9 / 30.9	7	1.0	undetectable
Kastrix (crimidine 0.5)	NO 1x	8 / 31.3	8	1.1 (1 - 2)	undetectable
Series II: flupropadine baits versus brodifacoum bait (Klerat), Vantaa 1983					
M & B 36,892 (flupropadine 0.10)	CH 1x	10 / 30.5	1	(10)	d 98.4 s 75.4 ± 36.1
M & B 36,892 (flupropadine 0.18)	CH 1x	10 / 31.6	2	9.0 (4 - 14)	d 354.4 ± 212.0 s 72.8 ± 29.5
Klerat (brodifacoum 0.001)	CH 1x	10 / 30.5	9	5.7 (2 - 10)	d 0.6 ± 0.1 s 0.3
Series III: bromadiolone (Arvicolon) versus brodifacoum (Klerat) and crimidine (Kastrix), Jokioinen, 1983					
Arvicolon (bromadiolone 0.02)	CH 1x	10 / 22.0	0	-	s 2.7 ± 0.6
Arvicolon (bromadiolone 0.02)	NO 1x	10 / 25.9	1	(3)	d 44.8 s 12.4 ± 1.5
Arvicolon (bromadiolone 0.02)	NO 2x	10 / 23.7	1	(4)	d 19.4 s 2.5 ± 0.4
Klerat (brodifacoum 0.001)	CH 1x	10 / 26.5	8	5.4 (3 - 7)	d 0.8 ± 0.4 s 0.4 ± 0.2
Kastrix (crimidine 0.5)	CH 1x	10 / 25.0	9	1.0	undetectable

Table 4. The effectiveness of ready-made baits on Arvicola under laboratory conditions. For further explanations, see the legend to Table 4.

Preparation and concentration of a.i. (%)	Type of trial	No. of animals/ average weight (g)	No. of dead	Average time to death (d) (range)	Consumption of a.i. mg/kg (x + S. E.)
Series I: Brodifacoum (Klerat) versus crimidine (Kastrix) baits, Vantaa 1982					
Klerat (brodifacoum 0.001)	CH 1x	10 / 109	8	4.6 (4 - 8)	d 0.9 ± 0.5 s 0.0
Klerat (brodifacoum 0.001)	NO 1x	8 / 109	8	6.1 (2 - 14)	d 0.6 ± 0.1
Klerat (brodifacoum 0.005)	CH 1x	10 / 121	4	4.9 (4 - 8)	d 1.2 ± 0.5 s 0.0
Klerat (brodifacoum 0.005)	NO 1x	8 / 116	3	7.9 (6 - 16)	d 1.2 ± 0.3 s 0.0
Kastrix (crimidine 0.5)	CH 1x	10 / 112	1	(1)	undetectable
Kastrix (crimidine 0.5)	NO 1x	8 / 117	1	(1)	undetectable
Series II: Bromadiolone (Arvicolon) versus brodifacoum (Klerat) baits, Jokioinen 1983					
Arvicolon (bromadiolone 0.02)	CH 1x	10 / 119	8	5.9 (3 - 9)	d 0.9 ± 0.5 s 0.1 ± 0.0
Arvicolon (bromadiolone 0.02)	CH 2x	10 / 117	6	5.3 (4 - 6)	d 0.4 ± 0.2 s 0.1 ± 0.1
Klerat (brodifacoum 0.001)	CH 1x	10 / 115	9	7.1 (4 - 10)	d 0.6 ± 0.2 s 0.3

The efficacy of Klerat on Arvicola paralleled that on Microtus. It should be noted, however, that the responses of individual voles were unambiguously positive or negative. Thus, the higher concentration (0.005%) bait was completely rejected by the majority of the test animals, while those who started to eat at all, consumed on average double the amount of bait as animals subjected to the lower concentration (0.001%) bait. On the other hand, a high concentration (0.02%) of bromadiolone in Arvicolon did not prevent the animals from consuming a lethal dose of this toxicant; nor was the rejection of the bait by the survivors as complete as it was in the case of Klerat.

In any case, the LD 50 (LD 90) values of brodifacoum for Arvicola are of the same order of magnitude as for Microtus, or by no means higher. Also the LD 50 of bromadiolone for Arvicola seems to be at the same level as that of brodifacoum, and thus completely different from that for Microtus.

Field performance of brodifacoum and bromadiolone baits

Field trials have so far been conducted with ready-made baits that proved to be somewhat promising in laboratory experiments. Hence, e.g., flupropadine that may be sufficiently effective against Arvicola was excluded, because no suitable preparation was available. The registered crimidine bait Kastrix served as reference material in trials on Microtus. Results of the field trials on Microtus are given in Tables 5 and 6, those concerning Arvicola in Table 7.

The efficacy of Klerat on Microtus was comparable with that of Kastrix. It was also demonstrated again that the performance of no bait whatsoever is dependent solely on its own properties but the bait density in the field also plays a role. Placing small amounts of bait at 2 x 2 or 3 x 3-metre intervals resulted in considerably lower kill than blanket spread over the entire surface.

The experiments with Microtus as the main target species gave some hints on the subsidiary effects of brodifacoum and crimidine baits on secondary pests (Clethrionomys) and nontarget species (Sorex) occurring on the experimental plots. When the bait was applied over a relatively sparse network of bait stations, both Kastrix and Klerat apparently affected the population of Clethrionomys glareolus more than that of Microtus (Table 6). This observation may be explained on the basis of the more explorative movement pattern and larger home range of the former species. On the other hand, neither of the baits applied apparently influenced the population of Sorex araneus (Table 5).

There is no direct indication as yet of the performance of Klerat when applied in snow holes. However, as the pellets of Klerat are similar in size and shape to those of Kastrix, a parallel could be drawn that the two baits should behave similarly in winter, as they evidently do so during the snow-free season.

Table 5. Results of a field trial against Microtus in Vahtermäki, Vihti, autumn 1982. Experimental plots, 1.5 ha each, on afforested old field. Pretreatment and posttreatment censuses based on live-trapping with Longworth traps on a central quadrat (63 traps/quadrat, 4 checks/census). Application of baits by broadcasting by hand about 10 kg/ha of each bait. About 3 weeks from treatment to post-treatment census. In addition to Microtus, the catch of a frequent nontarget species, Sorex araneus, is also indicated.

Application	Catch of Microtus		Percentage kill	Catch of Sorex	
	Precensus	Postcensus		Precensus	Postcensus
Klerat	19	4	85.2	6	4
Kastrix	28	3	92.6	6	5
Untreated	26	37	-	8	9

Table 6. Results of a series of experimental trials against Microtus in Huhtasaari/Jalassaari, Lohja, autumn 1982. Experimental plots, about 2.0 ha each, on old fields or afforestation areas. Pretreatment and posttreatment censuses by removal trapping on small quadrats (15 x 15 m, 12 traps/quadrat, 4 quadrats/treatment, and two checks/census). Application of baits by placing about 1 g-portions of bait on ground at 2 x 2 or 3 x 3-m intervals, i.e., 2.5 or 1.0 kg/ha, respectively. Posttreatment census started 2 weeks after the treatment. In addition to Microtus, the numbers of Clethrionomys glareolus were recorded at each census.

Preparation and the density of bait points	Numbers of Microtus		% kill	Numbers of Clethrionomys	
	Precensus	Postcensus		Precensus	Postcensus
Huhtasaari					
Klerat 2 x 2 m	56	38	51.5	0	0
Kastrix 2 x 2 m	59	32	61.3	0	0
Untreated	35	49	-	1	0
Jalassaari					
Klerat 3 x 3 m	29	10	43.1	12	0
Kastrix 3 x 3 m	15	7	26.1	11	2
Untreated	33	20	-	2	4

Table 7. Results of a field trial against Arvicola in Salmi, Vihti, autumn 1983. Experimental plots, 1.0 ha each, on afforested old field. Pretreatment and posttreatment censuses based on live-trapping (CMR) with large Sherman-type traps on central quadrats (48 traps/quadrat, 6 checks/census). Application by hand (blanket broadcast), about 10 kg of each bait/ha. Posttreatment census started 2 weeks after the treatment.

Preparation	Number of animals caught		Percentage kill
	Precensus	Postcensus	
Arvicolon	25	6	82.0
Klerat	23	10	67.4
Untreated	37	36	-

In treatments against Arvicola, the bromadiolone bait (Arvicolon) produced a higher percentage kill than the brodifacoum bait (Klerat); in laboratory trials the trend was slightly reversed.

It should be emphasized that timing of the treatments against Arvicola in autumn is of paramount importance. In an experiment conducted on the same plots the year before the experiment reported in Table 7, treatments with Klerat and Kastrix were complete failures, because they were done about 3 weeks later, and the animals active on ground during the pretreatment census adopted underground habits just at the time of the treatment.

DISCUSSION AND CONCLUSIONS

As the management of the vole problem became problematic after introduction of the restrictions on the use of endrin as a rodent toxicant, the search for supplementary means was first directed into screening acute rodenticides for use in baits. The series with experiments with zinc phosphide (Myrax), crimidine (Kastrix) and difluorpropanol (Gliftor) baits reported here, was an indication of this urgent action. At the same time as the experiments resulted in at least a temporary solution to the problem (registration of Kastrix to be used against Microtus), they also uncovered the most evident bottlenecks of the baiting method itself: problems of bait acceptance, bait-shyness and, hence, efficacy, availability of the bait to the target animals, and hazards to nontarget species.

Of the three compounds tested at the first stage, difluorpropanol (Gliftor) was quick-acting and effective, readily accepted by the voles and did not apparently induce bait-shyness, but no marketable formulation was available and the chemical itself was doubtless hazardous to nontarget herbivores. (In connection of the treatments with apple baits, one deer fawn and two hares probably succumbed to difluorpropanol poisoning, although this was not proven chemically.)

The zinc phosphide bait (Myrax) showed typical signs of poor palatability and bait shyness, and was thus far from being acceptable for registration. It is justified to question again (cf. Myllymäki 1979, p. 265) just how reasonable treatments with zinc phosphide against field rodents are in general because the toxicant itself is the source of the aversion reactions by the rodents, and this drawback can hardly be overcome by bait formulation only. Although it is difficult to find in the literature precise experimental data that would justify the application of zinc phosphide for vole control, this chemical is commonly used for that purpose because it is cheap and gives at least the illusion of success (dead bodies of target--and often nontarget animals) in symptomatic and uncontrolled treatments (cf., however, Byers and Merson 1982).

The crimidine bait (Kastrix) is not an ideal solution either, but is good enough as a temporary measure in emergency situations. Owing to its quick action, crimidine as such is a potential inducer of bait shyness. This has, in fact, been observed in connection with the use of lower concentration (0.1 or 0.3%) baits in mice and vole control experiments. However, the high concentration of a.i. in Kastrix (0.5%) probably ensures the intake of a lethal dose even when the animal nibbles only one piece of the pellet, and when the symptoms of poisoning appear, they are already irreversible. On the other hand, the high concentration should, at least theoretically, increase hazards to nontarget wildlife. However, during the 6 years Kastrix has been on the Finnish market, no proven, or even suspected, fatalities of wild animals have been reported. Instead, there have been a few deaths of dogs and cats, but in most instances there is no information about the conditions under which these have occurred (at least some are evidently deliberate acts rather than accidents). Moreover, from central Europe, where crimidine has been withdrawn from the market as a vole control agent, very little published data are available on the extent and type of wildlife hazards, which may make one to suspect that the withdrawal decisions were by and large political in nature.

Screening new compounds and/or preparations that could be substitutes for crimidine, or used in parallel with it for vole control, revealed only one, the brodifacoum bait Klerat (0.001% a.i.) that could be considered a finished product. Being comparable with Kastrix in terms of efficacy against Microtus, Klerat has the advantage of being useful against Arvicola, too, while the crimidine bait (Kastrix) was virtually unacceptable to this species. If Klerat will substitute for Kastrix in the future, the focus of hazards would move from primary poisoning accidents towards secondary poisoning of vole predators. Only experience can show how serious this would be in practice and, hence, the best thing to do would be to run both preparations simultaneously for a few years with an adequate follow-up of potential nontarget hazards.

As far as the other compounds tested are concerned, I would be inclined to reject the first-generation anticoagulants as potential vole control agents. A microtine-control preparation should be based on a single intake (cf. e.g., Myllymäki 1979, Lund 1981) to be effective and economical in practice, and it is generally known that the percentage kill in single treatments with first-generation anticoagulants seldom exceeds the level of 60 to 70% in controlled laboratory and field experiments (e.g., Grolleau 1971, Radvanyi 1974, Lund 1981). The results of Byers and Merson (1982) on the pine vole contradict this conclusion somewhat; it should be noted, however, that the efficacy values given by these authors are throughout 20 to 30% higher than my values, for example, which may be explainable either by different reactions of their target species or by an artifact caused by the indirect monitoring method they used. As in the case of Lund's (1981) experiments, diphenacoum seems to be a borderline case between first- and second-generation anticoagulants; however, it should be pointed out that it does not possess any advantage or probably has the same disadvantages that the brodifacoum bait has.

The experiments so far conducted on the other second-generation anticoagulant bromadiolone (Arvicolon) and the new experimental rodenticide flupropadine have not yet reached a conclusive phase. In both cases there is enough evidence to suggest that the potentials of these compounds may be limited with regard to Microtus but somewhat promising in the case of Arvicola. Even in the latter case, the development of the final formulation should be continued. The level of a.i. in Arvicolon is apparently unnecessarily high (cf. the approximations of the LD 50 values given above), and has led to controversies owing to secondary poisoning of predators, e.g., in connection with large-scale application of this bait in Switzerland (Anon. 1983). In the case of flupropadine, the information so far available on its mode of action, possible secondary hazards connected with its use, antidotes, etc., is too scanty to enable any final consideration.

The results reported here reveal at least two viewpoints that go beyond the level of considering the mere efficacy, or hazardousness, data of given compounds or preparations: the species-specific reactions of the target animals, and the influence of the baiting method (including bait density) on the performance of a control agent in the field.

The data presented above do not leave much doubt that the two species used in the trials react differently to given active ingredients or bait formulations; in fact, brodifacoum--and probably difluorpropanol--was the sole exception to this rule as far as the active ingredients used on both species were concerned. Hence, one should always be careful in drawing conclusions on the basis of experiments conducted on alien species, even if these are relatively close either taxonomically or ecophysiologically (e.g., herbivore microtines, as in this case). Without referring back to the details, I would only like to point out that basic behavioral studies on the food-selection mechanisms of the herbivorous voles are few, but they would be highly desirable from the point of view of their potential applications to vole control.

Field data on the influence of bait density on the control success may be self-explanatory as such, but the implications of the findings are more complicated than one is usually inclined to consider. First of all, I would like to refer to the compensatory demographic responses of the target population to the low percentage kill that may result from "sparing", or underdosing (does not mean supporting undue overdosing, as in the case of Arvicolon!) the bait, whether due to financial reasons or environmental concern. The prospective response may appear, depending on the season, either in terms of better life expectancy of the survivors (in winter) or increased fecundity and, hence, reproductive output (cf. Morris 1970, 1972; and Myllymäki 1974, 1979), but it is always unfavorable from the point of view of protecting the crop. In the case of controlling Microtus under Finnish conditions, there is, however, also a reasonable way to spare bait and decrease environmental hazards without losing anything of the efficacy: winter treatments in the snow holes, where the bait is placed directly in front of the nose of the pest.

LITERATURE CITED

ANON. 1983. Rapport relatif au bilan de la lutte chimique contre les campagnols terrestres. Le département de l'Agriculture de la république et canton de Neuchatel. 32 pp.

BYKOVSKY, V. A. 1975. Selective action preparations for protecting plants against field rodents. VIII Intern. Congr. Plant Protection II:80-84.

BYERS, R. E., and M. H. MERSON. 1982. Current improvements in baiting pine and meadow voles. Proc. Tenth Vert. Pest. Conf., Monterey, Calif., pp. 139-142.

DUBOCK, A. C., and D. E. KAUKEINEN. 1978. Brodifacoum (TALON™ rodenticide), a novel concept. Proc. Eighth Vert. Pest. Conf., Sacramento, Calif., pp. 127-137.

EPPO. 1975. Guidelines for the development and biological evaluation of rodenticides. EPPO Bull. 5(1):1-49.

EPPO. 1982. Guidelines for the biological evaluation of rodenticides No. 1: Laboratory tests for evaluation of the toxicity and acceptability of rodenticides and rodenticide preparation. pp. 1-32.

GROLLEAU, G. Comparison de la toxicité de divers raticides anticoagulants a l'égard du campagnol des champs, Microtus arvalis (Pallas). Ann. Zool. Ecol. Anim. 3:261-267.

HENDERSON, C. F., and E. W. TILTON. 1955. Tests with acaricides against the brown mite. J. Econ. Entomol. 48:157-161.

LUND, M. 1981. Comparative effect of the three rodenticides warfarin, difenacoum and brodifacoum on eight rodent species in short feeding periods. J. Hyg. Camb. 87:101-107.

MORRIS, R. D. 1970. The effects of endrin on Microtus and Peromyscus. I. Unenclosed field populations. Can. J. Zool. 48:695-708.

MORRIS, R. D. 1972. The effects of endrin on Microtus and Peromyscus. II. Enclosed field populations. Can. J. Zool. 50:885-896.

MYLLYMÄKI, A. 1974. Experience from an unsuccessful removal of a semi-isolated population of Arvicola terrestris. Proc. Int. Symp. Species Zoogeogr. European mammals, Nov. 22-26, Brno. pp. 376-387.

MYLLYMÄKI, A. 1977. Outbreaks and damage by the field vole, Microtus agrestis (L.), since World War II in Europe. EPPO Bull. 7(2):177-207.

MYLLYMÄKI, A. 1979. Importance of small mammals as pests in agriculture and stored products. In: Stoddart, D. M. (Ed.), Ecology of small mammals. pp. 239-279. Chapman & Hall, London.

MYLLYMÄKI, A. 1980. Eräiden akuuttien syöttimyrkkyjen teho peltomyyrään, Microtus agrestis L. Kasvinsuojelulaitoksen Tiedote N:o 24:4-35.

MYLLYMÄKI, A. 1983a. Antikoagulanttisyöttien teho peltomyyrään (Microtus agrestis) ja vesimyyrään (Arvicola terrestris). Tuhoeläinten torjuntaaineet. Koetulokset: jyrsijäkokeet 1982. pp. 1-15.

MYLLYMÄKI, A. 1983b. Baiting against the field vole (Microtus agrestis): problems and experimental results. 10th Int. Congr. Plant Protect. 1983(3):1071.

MYLLYMÄKI, A., A. PAASIKALLIO, E. PANKAKOSKI, and V. KANERVO. 1971. Removal experiments on small quadrats as a means of rapid assessment of the abundance of small mammals. Ann. Zool. Fenn. 8: 22-34.

RADVANYI, A. 1974. Small mammal census and control on a hardwood plantation. Proc. Sixth Vert. Pest. Conf., Anaheim, Calif. pp. 9-19.