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# A comparative trial of norbormide* and zinc phosphide against *Rattus norvegicus* on farms†

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## INTRODUCTION

The occurrence and spread of rats resistant to warfarin and related anticoagulant poisons in two counties of England and Wales since 1959 have stimulated interest in possible alternative rodenticides. One such alternative, norbormide first described by Roszkowski, Poos & Mohrbacher (1964) has already been compared with warfarin against small urban infestations (Drummond & Taylor, personal communication). It proved to be less effective, even at its lowest and most successful concentration, 0·5 %, and eradicated only about 50 % of the infestations treated. Nevertheless, norbormide could still play a useful role against warfarin-resistant rats if its effectiveness could be shown to compare favourably with that of currently recommended acute poisons such as zinc phosphide and arsenious oxide (Davis, 1967).

Norbormide has already been compared with zinc phosphide under laboratory conditions against normal and warfarin-resistant strains of wild rats by Greaves (1966). He found no significant difference in the response of the two strains to either poison and suggested that 0·5 % or higher concentrations of norbormide might give results in the field as good as those normally obtained with 2·5 or 5·0 % zinc phosphide, but refrained from drawing any firm conclusions until the two rodenticides had been tested under field conditions.

The field trial, now described, was planned with the dual purpose of comparing norbormide and zinc phosphide and of finding out to what degree of accuracy the laboratory results had predicted the effectiveness of the rodenticides in practice. Some of the methods, therefore, replicated those used in laboratory tests, while others were dictated by the inferences drawn from the results of those tests.

The fact that normal and warfarin-resistant rats had responded similarly to the two poisons in the laboratory meant that there could be no objection to siting the trial in an area where warfarin-resistant rat populations occurred and where, perhaps for that reason, a large number of infested farms were available. An added advantage was that acute poisons were commonly used in this area, and farmers understood and accepted the risks involved.

* 5-(α-hydroxy-α-2-pyridylbenzyl)-7-(α-2-pyridylbenzylidene) norborn-5-ene-2,3-dicarboximide.

## METHODS

### *Choice of infested properties*

The search for infested farms was started by visiting holdings up to 50 acres in size, on which pigs or poultry were kept, in the Montgomeryshire parishes of Meifod and Guilsfield Without. Pig and poultry farms were chosen as not only the most likely to be infested, but also because they comprised a high proportion (85 %) of the smaller-sized holdings that could be treated by the staff available and with the amount of norbormide that could, at first, be budgeted for. Twenty-nine of the forty-eight farms treated in the trial were so found: the remaining nineteen, which came to our attention as the search progressed, were just inside the neighbouring parishes of Llanfair Caereinion, Llangyniew, Llandrinio and Guilsfield Within. It was possible in the second half of the trial to treat infestations on properties of any size because a free supply of norbormide was made available by the manufacturers; but with 50–60 % of all the registered holdings under 50 acres, most of the farms treated remained within the original limits.

### *Poisons and baits*

Treatments were done with 0·5 and 1·0 % norbormide, the two most promising concentrations in the laboratory tests (Greaves, 1966), and with 2·5 and 5·0 % zinc phosphide, the concentrations recommended against *Rattus norvegicus* (Davis, 1967) that had also been used in the laboratory tests. Each concentration of poison was applied in four cereal baits; dry sausage rusk, Scomro,* medium grade oatmeal, and damp coarse oatmeal† with 5·0 % sugar. The first three baits had been used in the laboratory tests, and under those conditions the sausage rusk had been significantly less palatable and, when containing poison, less lethal than the other two (Greaves, 1966). Damp coarse oatmeal was included in the field trial because it was potentially a better vehicle for poison (Thompson, 1954) than the other three.

All the baits used in the field were mechanically mixed in the laboratory. To maintain similarity of consistency, as much fine oatmeal was included in each as was necessary to raise the proportion of fine ingredient to that present in the baits containing 1·0 % norbormide, which were made by mixing 1 part of 'Raticate Concentrated Rat Killer'‡ with $3\frac{1}{2}$ parts of plain bait. The addition of both the fine oatmeal and the poisons was allowed for by reducing the proportion of the major cereal constituent in each formulation.

### *Methods and organization of treatments*

There was evidence in the laboratory tests to suggest that rats discriminated less against norbormide than zinc phosphide. The corollary to this was that rats might continue to take the norbormide baits more readily and for longer periods in the field, with better results, if the baits were left down for several days. Each bait

* Sugar 5%, corn oil (5%), maize meal (< 65%), rolled oats (25%).
† Two parts by weight of pinhead oatmeal: one part water.
‡ Trade mark. The concentrate contains 4·5% norbormide in a fine cereal with dye.

containing zinc phosphide or norbormide was, therefore, applied in three ways: for either 1 day or 7 days after prebaiting, and directly (i.e. not preceded by baiting with unpoisoned bait) for 10 days.

On the first day of treatment, after a survey of the infestation, plain or poison baits were distributed in numbers and in the situations calculated to be most effective. The farms were re-visited every day, except at week-ends, to replenish the baits and record the number of spoonfuls of bait eaten at each point.

When direct poisoning was practised, two dessertspoonfuls of bait were put initially at each bait point, and this was increased or topped up, if necessary, at every visit. When poisoning after prebaiting, poison bait was laid only at the bait points where prebait had been taken. At each of these, one teaspoonful of poison bait was laid for every dessertspoonful of prebait taken on the day when most had been taken, except where this meant laying less than three teaspoonfuls, in which case three teaspoonfuls were laid. This baiting system, based partly on the finding that rats usually consume only about one-tenth as much poison bait as they do plain bait in a day (Thompson, 1954), achieved the necessary aim of providing a surplus of poison bait at each point whilst being fairly economical in the use of poison. Even with this system two-thirds of the total poison bait used was uneaten by rats, but it is doubtful whether the proportion of poison bait laid to prebait taken (1:2·3) could be decreased without running the risk of leaving too many points insufficiently poison-baited.

### *Assessment of success of treatments*

Two of the authors census-baited each infestation with whole dry wheat before and after treatment. The pre-treatment census-baiting, which lasted only 2 days and started 10 days before prebaiting or 13 days before direct poisoning, was so conducted, it was hoped, as not to condition the rats to eating the treatment baits laid later. The post-treatment census, which also lasted 2 days, began 5 days after each treatment had finished.

The census baits, weighing approximately 120 g., were measured out onto wooden trays placed in and around farm buildings, and where there were associated external infestations. The bait points were marked so that they could be used again in the post-treatment census and so that the staff doing the poison treatments could avoid baiting in the same places if alternative sites could be found.

It was known from previous work (unpublished) that the total weight of bait consumed in a given period by rats is often highly correlated with the number of bait points from which it is taken. To reduce the volume of work involved in weighing baits at individual points, only the occurrence of a take (or not) was recorded daily for each point, instead of the weight of the remaining wheat. The total wheat consumption during each census was, however, calculated by measuring the baits out from pre-weighed amounts and subtracting the weight of both the unused wheat and the wheat recovered at the end of the census.

Before the results of the trial were examined, the relationship between the total weights of wheat eaten and the total numbers of bait points with rat-takes was tested. Linear regressions of the total weights on the total numbers of rat-takes

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per census, separately calculated for the pre- and post-treatment data, fitted significantly well in each case ($P < 0{\cdot}01$). The slopes and intercepts of the two regressions were compared and found to differ only insignificantly. The relationship between the weights of wheat and number of rat-takes could, therefore, be regarded as being the same in both types of census and expressable by a single equation derived from the undifferentiated data. This was calculated to be $W = 107N - 540$, when $W$ is the total weight, in grams, of wheat consumed and $N$ the total number of rat-takes recorded in a census lasting 2 days.

### *Allocation of poisons, baits and methods of treatment*

The poisons used were allocated to plots of three farms according to a $4 \times 4$ randomized latin square, as in Table 1, in which the columns and rows are the cereal baits and operating staff respectively. The operating staff comprised two to poison and two (L.E.H. and G.L.J.) to do the census baiting before and after poisoning. They worked, in effect, as four pairs, one member census baiting, and the other poisoning, all the plots in one row, and each then changing partners before working on the properties in the next row. By census baiting and treating farms plot by plot in two rows simultaneously they were able to complete the treatments in the first two rows of Table 1 between 13 April and 1 July and in the third and fourth rows between 20 July and 30 September. They treated the plots in a different order in each row to reduce the chance of using the same bait on two plots at the same time in a period of adverse weather.

The three farms constituting each plot were simultaneously treated with the same poison bait; on two the infestations were prebaited for 6 days (Friday to Thursday) before one was poison baited for 1 day and the other for 7 days. Treatment of the third farm, by direct poisoning for 10 days, began 3 days later (on a Monday) than the prebaiting of the first two. This delay was necessary to avoid putting poison down for the first time just before the week-end, during which time no one would be visiting the farm to pick up poisoned rats.

## RESULTS

The number of pre- and post-treatment takes of wheat and the differences between them, expressed as percentages of the pretreatment number (i.e. percentage success), are given for each farm in Table 1, but because percentages are binomially distributed, they were transformed to arcsin $\sqrt{}$(percentages) for analysis.

The variances for cereal baits and operating staff were, respectively, smaller and only insignificantly larger than the main error variance. The type of bait used and differences in practice between pairs of staff did not, therefore, significantly affect the outcome of treatments. The variance for the four concentrations of poisons was, on the other hand, significantly larger ($P < 0{\cdot}05$) and the breakdown into independent (orthogonal) components, to separate the variance due to rodenticides from the variance contributed by using two concentrations of each, shows that it was the rodenticides and not their concentrations that caused differential success. Zinc phosphide was more effective than norbormide ($P < 0{\cdot}01$).

Table 1. *The design and results of the farm treatments with 5·0 and 2·5 % zinc phosphide or 1·0 and 0·5 % norbormide in four cereal baits, applied for 1 or 7 days after prebaiting and as direct poisons, in which success was measured by the reduction in the number of takes of wheat baits put down before and after treatment*

| | | Cereal baits | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sausage rusk | | | Medium oatmeal | | | Scomro | | | Damp coarse oatmeal + 5 % sugar | | |
| Row 1 | Farm number | 4 | 5 | 6 | 9 | 7 | 8 | 10 | 11 | 12 | 1 | 2 | 3 |
| | Stock hazard | Hp | p | p | Hp | Hp | p | p | p | H | H | Hp | Hp |
| | Poison conc. | 5·0 % zinc phosphide | | | 2·5 % zinc phosphide | | | 1·0 % norbormide | | | 0·5 % norbormide | | |
| | Method of baiting | i | ii | iii | i | ii | iii | i | ii | iii | i | ii | iii |
| | No. precensus takes | 41 | 38 | 49 | 28 | 38 | 33 | 71 | 14 | 26 | 33 | 11 | 11 |
| | No. postcensus takes | 9 | 17 | 36 | 9 | 12 | 20 | 47 | 9 | 22 | 20 | 8 | 4 |
| | Success (%) | 78·0 | 55·3 | 26·5 | 67·8 | 68·4 | 39·3 | 33·8 | 35·7 | 15·4 | 39.4 | 27·3 | 63·6 |
| 2 | Farm number | 13 | 14 | 15 | 22 | 23 | 24 | 19 | 20 | 21 | 18 | 16 | 17 |
| | Stock hazard | Hp | Hp | Hp | Hp | Hp | Hp | Hp | Hp | Hp | Hp | Hp | Hp |
| | Poison conc. | 1·0 % norbormide | | | 0·5 % norbormide | | | 5·0 % zinc phosphide | | | 2·5 % zinc phosphide | | |
| | Method of baiting | i | ii | iii | i | ii | iii | i | ii | iii | i | ii | iii |
| | No. precensus takes | 57 | 29 | 29 | 8 | 18 | 10 | 20 | 28 | 11 | 48 | 16 | 7 |
| | No. postcensus takes | 48 | 24 | 23 | 4 | 13 | 7 | 5 | 19 | 9 | 15 | 0 | 0 |
| | Success (%) | 15·8 | 17·2 | 20·7 | 50·0 | 27·7 | 30·0 | 75·0 | 32·1 | 18·2 | 68·8 | 100·0 | 100·0 |
| 3 | Farm number | 34 | 35 | 36 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 |
| | Stock hazard | p | H | p | p | Hp | Hp | — | H | Hp | p | H | p |
| | Poison conc. | 2·5 % zinc phosphide | | | 5·0 % zinc phosphide | | | 0·5 % norbormide | | | 1·0 % norbormide | | |
| | Method of baiting | i | ii | iii | i | ii | iii | i | ii | iii | i | ii | iii |
| | No. precensus takes | 16 | 9 | 40 | 42 | 17 | 22 | 22 | 92 | 17 | 24 | 18 | 16 |
| | No. postcensus takes | 11 | 3 | 25 | 4 | 13 | 11 | 17 | 64 | 19 | 23 | 18 | 20 |
| | Success (%) | 31·2 | 66·7 | 37·5 | 90·4 | 23·5 | 50·0 | 22·7 | 30·4 | 0 | 4·2 | 0 | 0 |
| 4 | Farm number | 43 | 44 | 45 | 40 | 41 | 42 | 37 | 38 | 39 | 46 | 47 | 48 |
| | Stock hazard | p | Hp | Hp | Hp | p | p | Hp | p | p | H | H | H |
| | Poison conc. | 0·5 % norbormide | | | 1·0 % norbormide | | | 2·5 % zinc phosphide | | | 5·0 % zinc phosphide | | |
| | Method of baiting | i | ii | iii | i | ii | iii | i | ii | iii | i | ii | iii |
| | No. precensus takes | 28 | 51 | 20 | 37 | 24 | 12 | 56 | 6 | 16 | 29 | 39 | 33 |
| | No. postcensus takes | 24 | 36 | 14 | 31 | 12 | 6 | 8 | 4 | 6 | 19 | 13 | 6 |
| | Success (%) | 14·3 | 29·4 | 30·0 | 16·2 | 50·0 | 50·0 | 85·7 | 33·3 | 62·5 | 34·5 | 66·7 | 81·8 |

Analysis of the arcsin √(percentage) successes ($Z$ = zinc phosphide: $N$ = norbormide)

| Source of variation | D.F. | Variance | $F$ |
|---|---|---|---|
| Cereal baits | 3 | 234·3 | < 1·0 |
| Operating pairs (rows) | 3 | 652·3 | 1·5 |
| Poisons | 3 | 2367·7 | 5·6* |
| 2·5 % $Z$ + 5·0 % $Z$ *vs.* 0·5 % $N$ + 1·0 $N$ | 1 | 6320·4 | 15·0** |
| 2·5 % $Z$ *vs.* 5·0 % $Z$ | 1 | 463·8 | 1·1 |
| 0·5 % $N$ *vs.* 1·0 % $N$ | 1 | 319·0 | < 1·0 |
| Main plot error | 6 | 422·3 | — |
| Methods of treatment | 2 | 83·1 | < 1·0 |
| Methods × cereal baits | 6 | 288·0 | 1·4 |
| Methods × operating pairs | 6 | 146·2 | < 1·0 |
| Methods × poisons | 6 | 105·7 | < 1·0 |
| Subplot error | 12 | 201·8 | — |

* Significant at $P < 0·05$
** Significant at $P < 0·01$.

Key: i = 6 days' prebaiting and 1 days' poison baiting; ii = 6 days' prebaiting and seven days' poison baiting; iii = 10 days' direct poison baiting.
H = pigs; p = poultry.

It is also apparent from the smallness of the variance attributable to methods of treatment, compared with the subplot error, that the results achieved by poison baiting for 1 or 7 days after prebaiting were not significantly better than those obtained by direct poisoning for 10 days. The insignificant variance for the interaction between methods and poisons confirms this and also shows that zinc phosphide was consistently better than norbormide however it was applied.

## DISCUSSION

Greaves (1966) concluded, from his laboratory tests, that neither of the poisons was likely to give a complete kill in the field, having failed to do so under favourable laboratory conditions. He also suggested that, while zinc phosphide might prove better than norbormide in the field, as in the laboratory, the safety of norbormide might help to offset the not very marked difference between them by allowing better and more liberal baiting. The first of these conclusions has been verified by the results of the present trials, in that only two treatments (farms 16 and 17) ended in the eradication of all rats. In one of these (farm 17) success was largely due to the fact that the hens had been removed from the deep litter that had been the focus of the infestation at the time of the preliminary survey. The reason was less obvious on farm 16, but it was probably because the small infestation was confined to a deep litter house and did not extend to adjacent piggeries, which could not have been so efficiently and safely poisoned.

The extent to which the safeness of norbormide offset the otherwise greater effectiveness of zinc phosphide could not be measured: but generally, infestations in or close to piggeries were more difficult to poison effectively with zinc phosphide because of the risk of secondary poisoning. Piggeries were encountered, with detrimental results in some cases, on sixteen of the properties treated with zinc phosphide. The treatment on farm 26 was the worst affected because a heavy infestation in and around an old wooden shed was, unfortunately, not poisoned at all, because of the owner's fears for the safety of the young pigs housed in it.

The risk of primary poisoning of livestock also had to be considered when using zinc phosphide, particularly on farms with free-range pigs and poultry. It is unlikely, though, that this gave any advantage to norbormide in practice because, safety apart, all baits had to be protected from being eaten by livestock if they were to be available to the rats.

In spite of the advantages of safety, norbormide proved to be significantly less effective than zinc phosphide in the field, although it caused only insignificantly fewer deaths among rats under the controlled conditions of the laboratory tests referred to above. On the other hand, though the type of bait used had little effect on the outcome of the farm treatments, it resulted in significantly different mortalities among captive rats. One reason for these apparent contradictions between the laboratory and field results may be because Greaves based his conclusions about relative toxicity on the number of deaths in the choice tests that had occurred after 4 days, including, by so doing, rats that had initially discriminated against norbormide and survived the first 2 days. It may be more realistic

Table 2. *The number of dessertspoonfuls of prebait eaten by rats on the sixth day of prebaiting and the number of teaspoonfuls of poison bait eaten the following day, the first day of poison baiting, on the thirty-two farms poisoned after prebaiting*

| Poison | Sausage rusk | | Medium oatmeal | | Scomro | | Damp coarse oatmeal and sugar | | Total | | Mean take poison tsp. | Adjusted mean take poison tsp. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Prebait dsp. | Poison tsp. | Prebait dsp. | Poison tsp. | Prebait dsp. | Poison tsp. | Prebait dsp. | Poison tsp. | Prebait dsp. | Poison tsp. | | |
| Zinc phosphide (5·0 %) | 118 | 48 | 144 | 67 | 12 | 8 | 94 | 50 | 755 | 321 | 40·1 | 41·4 |
| | 205 | 102 | 33 | 9 | 47 | 19 | 102 | 18 | | | | |
| Zinc phosphide (2·5 %) | 77 | 26 | 89 | 48 | 115 | 50 | 172 | 141 | 617 | 312 | 39·0 | 51·1 |
| | 20 | 5 | 91 | 26 | 20 | 6 | 33 | 10 | | | | |
| Norbormide (1·0 %) | 80 | 36 | 78 | 42 | 301 | 130 | 64 | 31 | 846 | 333 | 41·6 | 35·9 |
| | 101 | 21 | 79 | 32 | 60 | 14 | 83 | 27 | | | | |
| Norbormide (0·5 %) | 88 | 28 | 9 | 4 | 90 | 40 | 98 | 78 | 870 | 505 | 63·1 | 55·5 |
| | 97 | 18 | 26 | 19 | 429 | 274 | 33 | 44 | | | | |
| Totals | 786 | 284 | 549 | 247 | 1074 | 541 | 679 | 399 | 3088 | 1471 | — | — |
| Mean take | — | 35·5 | — | 30·9 | — | 67·6 | — | 49·9 | 96·5 | 46·0 | — | — |
| Adjusted mean take | — | 34·4 | — | 48·2 | — | 44·1 | — | 57·1 | — | — | — | — |

*Analysis of variance of prebait and poison takes*

| Source | D.F. | Prebait M.S. | Prebait F | Poison bait M.S. | Poison bait F |
|---|---|---|---|---|---|
| Poisons | 3 | 1641 | $< 1·0$ NS | 1056 | $< 1·0$ NS |
| Baits | 3 | 6241 | $< 1·0$ NS | 2191 | $< 1·0$ NS |
| Poisons × baits | 9 | 9341 | 1·3 NS | 3346 | 1·1 NS |
| Error | 16 | 7224 | — | 3046 | — |

*Analysis of covariance of poison takes adjusted for infestation size by takes of prebait*

| Source | D.F. | M.S. | F |
|---|---|---|---|
| Poisons | 3 | 637 | 2·5 NS |
| Baits | 3 | 698 | 2·7 NS |
| Poisons × baits | 9 | 399 | 1·6 NS |
| Error | 15 | 256 | — |

NS = not significant.

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for the present purpose to compare mortalities among naïve rats after the second day, thereby allowing for the probability that the shy rats would, in practice, have survived. Thus, considering the laboratory mortalities after 2 days (Greaves, 1966, Table 4, groups 1–6), seven out of twenty-four rats were killed by 0·5 % and 1·0 % norbormide compared with thirteen out of twenty-four by 2·5 and 5 % zinc phosphide. The $\chi^2$ for this comparison, which is 2·14 ($P < 0·20$) instead of 0·08 ($P < 0·80$) for the mortalities on the fourth day, is of an order that might have become significant if more rats had been available for the tests.

Table 3. *The average weights of plain and poisoned medium oatmeal eaten per rat in free feeding tests in the laboratory, in which individually caged rats were given plain bait for one day and then poison bait for one day*

(From data supplied by J. H. Greaves)

| Poison | Number of rats in test | Grams plain bait eaten per rat | Standard error | Grams poison bait eaten per rat* | Standard error | Number of rats killed |
|---|---|---|---|---|---|---|
| Norbormide (0·5 %) | 28 | 18·3 | 1·5 | 1·2 | 0·2 | 18 |
| Norbormide (1·0 %) | 17 | 18·6 | 1·5 | 1·5 | 0·6 | 15 |
| Zinc phosphide (2·5 %) | 4 | 17·0 | 1·5 | 0·4 | 0·2 | 4 |

* The variances of the mean takes of poison bait were significantly different by Bartlett's test (Snedecor, 1956) so that the significance of the difference between their means cannot easily be tested.

However, excluding 'discriminators' from the mortalities in the laboratory data may not explain all the difference between the laboratory and field results. To examine the situation further, the takes of prebait and poison bait in the thirty-two prebaited treatments were compared to see if the intake of poison had been deficient in any of them.

The recorded numbers of dessertspoonfuls of plain bait taken on the sixth day of prebaiting and the numbers of teaspoonfuls of poison bait taken on first day of poisoning are given in Table 2. This shows that the error variances in the separate analysis of the two sets of data were of the same order as those due to poisons and baits and that this was partly due to differences in the size of the infestations. When the takes of plain bait were used to adjust the poison takes for infestation size, in an analysis of covariance, the residual variance of the poison data was considerably reduced. It did not, however, become significantly smaller than either of the reduced variances attributable to poisons or bait bases. Differences between the adjusted mean takes of the baits containing zinc phosphide or norbormide, also shown in Table 2, were not, therefore, significant although they indicated a possible inverse relationship between the amount of a poison bait eaten and the concentration of poison. Likewise the insignificantly different adjusted means of the four bait bases demonstrated, to the same limited extent, the possible advantage of a damp bait.

Zinc phosphide was superior in this field trial, in spite of the fact that the rats ate only insignificantly different quantities of each bait. This may seem surprising on considering the potential killing power, calculated from the acute toxicity tests, of equal weights of each bait. Measured in acute 50 or 95 % lethal doses, the killing power per gram of 1·0 % norbormide was nearly the same as that of 5·0 % zinc phosphide and therefore double the killing power of the same weight of 0·5 % norbormide or 2·5 % zinc phosphide.

The average weights of plain and poison bait eaten by the rats in the laboratory free feeding tests are given in Table 3. Rats in the three groups given 0·5 and 1·0 % norbormide or 2·5 % zinc phosphide ate uniformly of the plain prebait, but when given poison bait, those on norbormide ate three to four times more than did those given zinc phosphide. Differences between the proportions subsequently dying in each group were only insignificant. This result could have occurred if differences in the palatability or mode of action of the poisons was such as to allow the rats to eat three to four times more than the estimated acute lethal dose of norbormide, before the flavour or toxic symptoms produced an aversion to the bait. The result did not suggest, as it now does in the light of the result of the field trial, that in the field it may be necessary for rats to eat more 50 % or higher acute lethal doses of norbormide (as measured in the laboratory) than of zinc phosphide, to achieve the same percentage mortality. If this is so, it is a matter for further investigation, since it could be a disadvantage of norbormide that would be hard to overcome in the field.

Rats tolerant to high doses of norbormide, like some of those in the laboratory tests (Greaves, 1966) may also have influenced the field treatments. Large poison bait takes by a few tolerant individuals may have raised the average level of the norbormide takes sufficiently to mask the fact that most rats ate fewer 'acute lethal doses' than they appear to have done. Their presence in significant numbers might have accounted for most of the difference in the results with the two rodenticides.

The results of the farm treatments as a whole appear disappointing. However, direct comparisons between these and similar results recorded by Chitty & Southern (1954, Chs. 4 and 10) are not possible because the latter were assessed by census baiting, which continued until the weight of wheat consumed per day had risen to a steady level for 3 days. Furthermore, Chitty & Southern (or their collaborators) started prebaiting on the day on which they stopped census baiting, or poisoned directly only 3 days after. And even though census and treatment bait points were different, the prolonged census baiting immediately before treating may easily have conditioned the rats to taking baits as effectively as deliberate prebaiting. The standard 4–5 days' prebaiting advocated as a result of their work by these authors might not, in fact, be sufficient to obtain a maximal response except after census baiting. Our experience, supported by records of numerically increasing daily takes of bait, was that, after minimal censuses, 6 days' prebaiting was inadequate on at least fourteen farms. These treatments, eight with zinc phosphide and six with norbormide, would probably have been more succesful if prebaiting had continued until the takes had reached a peak. As it was, they

Table 4. *The number of takes of poison bait recorded on farms being treated with zinc phosphide or norbormide, used directly or for 7 days after prebaiting*

| Poison | | Day of direct poisoning | | | | | | | | | | | Day of poisoning following prebaiting | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5* | 6* | 7 | 8 | 9 | 10 | | 1 | 2* | 3* | 4 | 5 | 6 | 7 |
| 5·0 % zinc phosphide | Farm no. 6 | 25 | 12 | 6 | 11 | — | — | 9 | 5 | 0 | 0 | Farm no. 5 | 24 | — | — | 1 | 0 | 0 | 0 |
| | 21 | 3 | 0 | 0 | 0 | — | — | 0 | 2 | 0 | 0 | 20 | 18 | — | — | 1 | 0 | 0 | 0 |
| | 27 | 7 | 4 | 0 | 0 | — | — | 0 | 0 | 0 | 0 | 26 | 6 | — | — | 2 | 0 | 0 | 0 |
| | 48 | 16 | 6 | 6 | 0 | — | — | 0 | 0 | 0 | 0 | 47 | 16 | — | — | 2 | 0 | 0 | 0 |
| 2·5 % zinc phosphide | Farm no. 8 | 8 | 4 | 1 | 2 | — | — | 0 | 0 | 0 | 0 | Farm no. 7 | 21 | — | — | 3 | 0 | 0 | 0 |
| | 17 | 2 | 0 | 1 | 0 | — | — | 0 | 0 | 0 | 0 | 16 | 4 | — | — | 0 | 0 | 0 | 0 |
| | 36 | 18 | 7 | 2 | 7 | — | — | 7 | 1 | 0 | 0 | 35 | 2 | — | — | — | 0 | 0 | 0 |
| | 39 | 1 | 2 | 0 | 2 | — | — | 0 | 0 | 0 | 0 | 38 | 11 | — | — | 1 | 0 | 0 | 0 |
| 1·0 % norbormide | Farm no. 12 | 7 | 8 | 4 | 4 | — | — | 2 | 0 | 1 | 0 | Farm no. 11 | 9 | — | — | 4 | 2 | 1 | 3 |
| | 15 | 8 | 10 | 5 | 10 | — | — | 7 | 0 | 4 | 6 | 14 | 15 | — | — | 15 | 4 | 5 | 9 |
| | 33 | 8 | 4 | 2 | 2 | — | — | 0 | 0 | 0 | 0 | 32 | 13 | — | — | 6 | 6 | 2 | — |
| | 42 | 9 | 11 | 10 | 10 | — | — | 10 | 12 | 9 | 9 | 41 | 25 | — | — | 11 | 6 | 5 | 3 |
| 0·5 % norbormide | Farm no. 3 | 10 | 5 | 2 | 1 | — | — | 3 | 3 | 2 | 1 | Farm no. 2 | 12 | — | — | 12 | 7 | 8 | 6 |
| | 24 | 10 | 4 | 1 | 1 | — | — | 1 | 1 | 1 | 3 | 23 | 10 | — | — | 7 | 3 | 0 | 1 |
| | 30 | 13 | 5 | 4 | 4 | — | — | 5 | 0 | 5 | 0 | 29 | 63 | — | — | 26 | 8 | 2 | 1 |
| | 45 | 6 | 5 | 5 | 7 | — | — | 3 | 0 | 0 | 0 | 44 | 18 | — | — | 10 | 7 | 2 | 0 |

* The farms were not visited on Saturdays and Sundays.

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probably contributed to the poor average results and, to a lesser extent, to the insignificant difference between the results by prebaiting and direct poisoning. It is also possible that the restriction imposed on the siting of the bait points, by reserving what may have been the best sites for the census baits, affected the treatments detrimentally.

The lack of any significant difference between direct and prebaited treatments in this trial was probably mainly caused by direct poison baiting for 10 days, instead of for a single day as Chitty and Southern did (1954, Ch. 4). The records in Table 4 show that although the maximum number of takes of zinc phosphide occurred on the first day of direct poisoning, the total number of takes doubled before the treatments finished. When, on the other hand, prebaited infestations were poisoned for 7 days, between 75 and 100% of all the zinc phosphide takes were recorded on the first day of poisoning (Table 4). Apart from showing why nothing significant was gained by prolonging the period of poisoning after prebaiting, the rapid acceptance of poison bait suggests less shyness and a take by a higher proportion of rats than would be attracted to directly laid baits.

The records of takes in the corresponding norbormide treatments have also been shown in Table 4, although they cannot be compared with the zinc phosphide records, because with the former poison it was impossible to distinguish takes by mice, which presumably continued to feed, unaffected by the concentration of norbormide used (Roszkowski *et al.* 1964). It is, therefore, possible, in the light of Drummond's and Taylor's records of persistent takes of norbormide for 3–4 weeks in urban treatments (personal communication) and of Greaves' evidence of rats surviving prolonged feeding on norbormide, that some of the takes recorded in Table 4 may have been by rats tolerant to its effects.

Non-toxicity to man and domestic animals remains the major advantage that norbormide has over zinc phosphide. This advantage was not enough to make up for its deficiencies as a rodenticide under the conditions prevailing on the farms between April and September, but it may be in the winter, when sheep and cattle are housed. Under most conditions the standard of acute poison treatments could probably be improved by using 0·5 or 1·0% norbormide and zinc phosphide together, employing the former in situations where the less specific rodenticide would be unsafe.

## SUMMARY

Norbormide at 1·0 and 0·5% and zinc phosphide at 5·0 and 2·5% were each tested in four types of cereal bait, after prebaiting and as direct poisons, against infestations of *R. norvegicus* on forty-eight farms in Montgomeryshire.

The relative success of treatments was measured by the reduction in the number of takes from wheat baits put down for 2 days, 13 or 16 days before, and 5 days after, poisoning.

Treatments with zinc phosphide were significantly more successful than those with norbormide, irrespective of the cereal bait, concentration of poison or method of treatment used, and in spite of conditions on many farms that partially restricted the distribution of the baits containing zinc phosphide.

Differences between these results and results of laboratory tests with the same rodenticides are discussed.

Norbormide is recommended for use in situations where zinc phosphide cannot be used efficiently without risk to livestock.

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