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Field tests with a molluscicide containing iron phosphate

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Abstract

The effect of slug pellets containing iron phosphate was evaluated in field trials. In comparison with untreated controls, iron phosphate reduced leaf loss of lettuce, increased the number of marketable lettuce heads and reduced numbers of the slug *Arion lusitanicus*. The reference treatment metaldehyde was more effective in preventing slug damage and reduced numbers of all slug species present (*A. lusitanicus*, *A. hortensis* and *Deroceras reticulatum*). In rape, iron phosphate reduced the percentage of seedlings with slug damage, but did not affect the total number of seedlings per unit area. Iron phosphate seems promising for organic agriculture, where other chemical molluscicides cannot be used.

Keywords: *Arion lusitanicus*; *Arion hortensis*; *Deroceras reticulatum*; Iron phosphate; Molluscicide; Organic farming; Slug

1. Introduction

Slugs occur in temperate and humid habitats all over the world and are important pests in a wide range of agricultural and horticultural crops (reviews in Godan, 1979; Port and Port, 1986; South, 1992). Their importance as pest organisms has drastically increased in the past few decades, as illustrated by the 70-fold increase of molluscicide usage in the UK over the last 30 years (Garthwaite and Thomas, 1996). In Central Europe, arable crops (particularly rape, but also sugar beet, maize, potato, soybean and winter cereals), vegetables (particularly lettuce and many Brassicaceae), strawberries and ornamentals are especially susceptible to slug damage, but a large array of other crops is also damaged occasionally (Godan, 1979; South, 1992).

The economically most important species of pest slugs in Central Europe are *Deroceras reticulatum* Müller (Agriolimacidae), *Arion lusitanicus* Mabille (Arionidae) and the *A. hortensis* aggregate. *D. reticulatum* is the most widespread slug species worldwide, occurring in temperate regions of Europe, Asia, North and South America, Australia and New Zealand (Godan, 1979; South, 1992). In economic terms, this species is responsible for most of the slug damage worldwide. The slug species *A. lusitanicus* was originally endemic to the Iberian peninsula, but has become a serious pest throughout Central Europe in recent years (Fechter and Falkner, 1990; Turner et al., 1998). The *A. hortensis* aggregate is divided into three species, which can only be identified safely by internal anatomy: *A. hortensis* (sensu stricto, s.s.), *A. distinctus* and *A. owenii* (Davies, 1977, 1979). *A. hortensis* s.s. and *A. distinctus* occur in Central Europe, and both were found at the study site (Iglesias and Speiser, 2001). Species of the *A. hortensis* aggregate are among the most important slug pests of field crops in the United Kingdom (Port and Port, 1986) and France (Chabert et al., 1997), but are probably less important in Switzerland. The individual species forming the *A. hortensis* aggregate are rarely separated in the agronomic literature.

Slugs are mainly controlled with bait pellets which usually contain either metaldehyde or a carbamate as active ingredients (Garthwaite and Thomas, 1996; Speiser, in press). In organic agriculture, the use of such slug pellets is not allowed or severely restricted: the EU regulations for organic farming still allow the use of molluscicides containing metaldehyde, with the restriction that they must contain repellents for higher animals, and that they must be used in traps (Schmidt and Haccius, 1992). The requirement to apply the molluscicide in traps prevents any large-scale application because it is very laborious. In addition, many national or regional organic farmers' associations

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completely prohibit the use of molluscicides containing metaldehyde. This is also the case for Switzerland (FiBL-Dokumentation, 2000). Recently, a biocontrol method for slugs based on the nematode *Phasmarhabditis hermaphrodita* has been developed (Glen et al., 1996). This method can be used in organic farming, but its practical application is limited by the high price, the short shelf life, temperature sensitivity and low efficacy against large Arionids. Thus, practicable solutions for slug problems in organic agriculture are almost lacking. Organic vegetable growers in Great Britain and Switzerland named slugs as the most important pests (Peacock and Norton, 1990; Kesper and Imhof, 1998).

A number of iron, aluminium and copper compounds show molluscicidal properties (Henderson et al., 1989, 1990; Henderson and Martin, 1990; Bullock et al., 1992; Davis et al., 1996; Young, 1996). Iron (III) phosphate is among the least toxic for mammals (EPA, 1998). Iron (III) phosphate occurs in nature in the form of the minerals strengite and metastrengite, and also as a component of several other minerals (Roberts et al., 1990; Clark, 1993). It might therefore potentially be used in organic agriculture (although none of the organic label organizations worldwide allows its use to date). Therefore, we tested the effect of a commercially available slug pellet containing 1% iron phosphate in a series of small-scale field trials. The trials were carried out in lettuce and rape because they are among the most slug sensitive vegetable and arable crops, respectively.

2. Materials and methods

2.1. Lettuce miniplot trials

Lettuce miniplot trials were established in Frick (Northwestern Switzerland) in spring 1999 and 2000. Plots, measuring $4.5\,m \times 4.5\,m$ each, were arranged in a grass-clover meadow. The centre of each plot ($1\,m \times 1\,m$) was mechanically cleared, and nine plantlets of lettuce with four true leaves were planted (on May 12, 1999 and on April 27, 2000). The plots were left untreated, or treated either with metaldehyde or iron phosphate. There were nine replicates in 1999 and six replicates in 2000, arranged in a completely randomized design. On one side, the meadow with the experimental plots bordered on a wildflower strip.

The timing and dosage of molluscicides were adjusted to the weather conditions, which were extremely wet at the beginning of the experiment in 1999, and drier in 2000. Metaldehyde (Metarex R.G.®; Siegfried, Switzerland; 5% active ingredient) was applied by hand at $1.5\,g/m^2$ in 1999 and at $0.75\,g/m^2$ in 2000, as recommended by the manufacturer for different intensities of slug pressure. Iron phosphate (Ferramol®; Neudorff, Germany; 1% active ingredient) was applied by hand at $5\,g/m^2$ in both years (= recommended rate; no adaptation to slug pressure recommended). Molluscicides were applied on May 12, 14 and 17 in 1999, and on April 27, May 3, 15 and June 6 in 2000.

For each lettuce plant, percentage leaf loss was assessed three times during the first week, and then once every week until harvest. Lettuces were harvested on June 16, 1999 and on June 14, 2000. At harvest, each head of lettuce was scored for the presence or absence of slug damage and weighed.

In 2000, the slug populations of each plot were estimated on May 19, 30 and 31 with traps. Flowerpot saucers (diameter 11 cm) covered with aluminium foil to reflect the sunlight were placed upside down, baited with two slices of cucumber (thickness 5 mm) underneath. Two traps were placed in each plot, on a flat spot in the meadow vegetation approximately 50 cm away from the cleared area. Traps were laid out in the evening and checked on the next morning between 7 and 9.30 a.m. All slugs inside traps were recorded, distinguishing three categories: *D. reticulatum*, *A. lusitanicus* and the *A. hortensis* aggregate. A few specimens of other slug species were also seen, but these were too rare to determine their reactions towards the experimental treatments.

2.2. Rape on-farm trial

The rape trial was installed in autumn 2000 in a commercial rape field in Oberwil-Lieli (Northwestern Switzerland). Twelve plots, measuring $6\,m \times 8\,m$ each, were arranged along one edge of the field, bordering on a grass-clover meadow with their long edge. There were six untreated plots and six plots treated with iron phosphate, grouped in six blocks. A metaldehyde treatment could not be included in this experiment because the farm is managed organically. The rape was sown on August 29. Iron phosphate (Ferramol, applied at $5\,g/m^2$) was applied on September 1 and 12. Assessments were made on September 12, 19 and October 13. A frame measuring $40 \times 60\,cm^2$ was randomly placed on the field. All rape plants within the frame were assessed for the presence or absence of slug damage. This assessment was done twice in each plot and averaged.

Three more trials with the same design were established on other organically managed farms in Wegenstetten, Oftringen and Reuenthal (Northwestern Switzerland). Because the rape suffered little slug damage in these trials, they are only briefly mentioned in the text.

2.3. Data analysis

Leaf loss in lettuce was integrated over time and standardized for the duration of the experiment (Speiser, 1997). Heads weighing at least 200 g and lacking severe slug damage were considered marketable, while heads weighing less than 200 g or showing severe slug damage were considered non-marketable. Statistical analyses were made with JMP (SAS Institute, USA). Leaf loss data were not distributed normally, and were therefore log-transformed. The treatment effects on leaf loss and on the number of marketable heads were determined with analysis of covariance, treating the distance from each plot to the wildflower strip as covariable; treatments were compared with the Tukey test.

The number of slugs of each species found under both traps in the same plot were added, and data for all three assessments were averaged. The treatment effects on the number of slugs of each species were determined as described above.

The number of rape plants counted in the frames was converted to numbers of intact and damaged plants/m^2. The total number of plants (intact and damaged) and the percentage of damaged plants were then determined. Because these variables were not distributed normally, they were log-transformed before being analysed with two-way analysis of variance.

3. Results

3.1. Slug damage to lettuce

In both years, leaf loss of untreated lettuce increased rapidly within the first 14 days, but remained almost constant thereafter (Fig. 1). Casual observations revealed that *A. lusitanicus* was the most important slug species causing damage to the lettuce. In both years, there were highly significant ($p<0.001$) differences among treatments in leaf loss and in the number of marketable lettuce heads harvested per plot (Table 1). In the untreated plots, leaf loss was highest and the fewest marketable heads were harvested. In the metaldehyde treated plots, leaf loss was lowest and the highest number of marketable heads was harvested. The iron phosphate treatment was intermediate with respect to leaf loss and the number of marketable heads. The two molluscicides metaldehyde and iron phosphate were not significantly different from each other except for the number of marketable heads in 1999. Metaldehyde was always significantly different from untreated. Iron phosphate was significantly different from untreated except for the number of marketable heads in 1999.

In 1999, lettuces close to the wildflower strip were damaged more ($p<0.001$), and there were fewer marketable lettuce heads ($p<0.05$) than towards the centre of the field. In 2000, distance to the wildflower strip affected neither slug damage nor the number of marketable heads ($p > 0.5$).

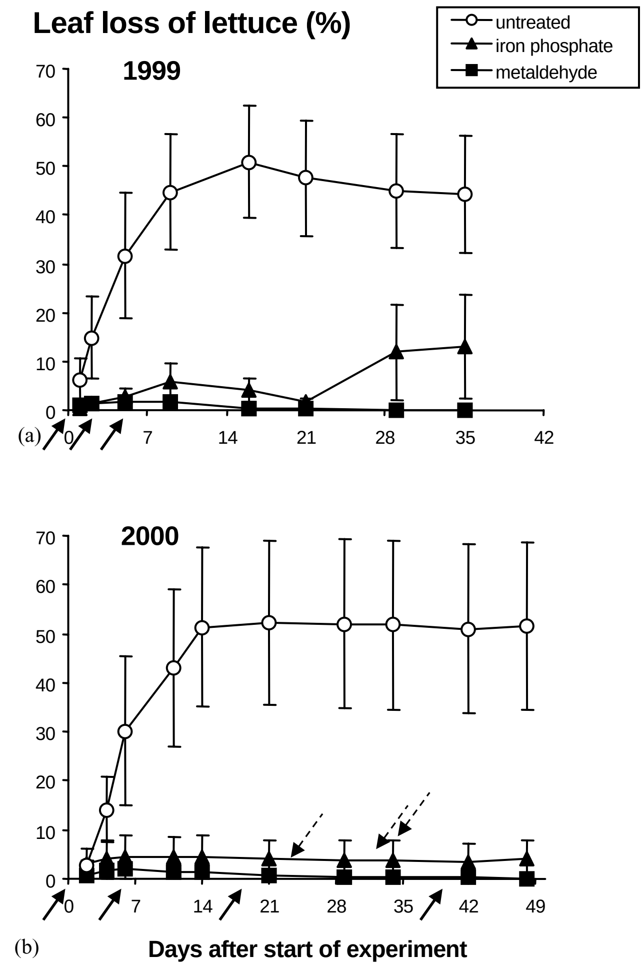

Fig. 1. Time course of leaf loss of lettuce in miniplot field trials. Error bars indicate one standard error; full line arrows indicate molluscicide applications; dashed arrows indicate assessments of slug populations (only in 2000).

Table 1
Mean leaf loss (A) and number of marketable heads of lettuce (B) in miniplot field trials in 1999 and 2000[a]

Treatment	1999	2000
(A) *Leaf loss*		
Untreated	42.7±11.2a	46.5±15.6a
Iron phosphate	5.8±4.1b***	4.0±3.9b***
Metaldehyde	0.7±0.3b***	0.7±0.6b***
(B) *Marketable heads*		
Untreated	1.6±0.5a***	2.2±1.2a
Iron phosphate	3.2±1.0a**	6.2±0.8b*
Metaldehyde	7.2±0.5b	8.8±0.2b***

[a] *Note*: Leaf loss is expressed as standardized integral over time, ranging from 0% to 100% (see Section 2.3); the number of marketable heads per plot can range from 0 to 9. Figures are means ± standard error. Means sharing the same letter are not significantly different ($p>0.05$). For different means, asterisks indicate the level of significance (***$p<0.001$; **$p<0.01$; *$p<0.05$).

3.2. Slugs in miniplots

The number of *D. reticulatum* was significantly lower in the metaldehyde treated plots than in the iron phosphate treated plots ($p<0.01$; Fig. 2). The number in the untreated plots was not significantly different from either the metaldehyde or the iron phosphate treated plots ($p>0.05$). The distance to the wildflower strip did not affect the number of *D. reticulatum* ($p>0.5$).

The number of *A. lusitanicus* in plots treated with metaldehyde ($p<0.01$) and iron phosphate ($p<0.05$) was significantly lower than in the untreated plots, while metaldehyde and iron phosphate were not significantly different from each other. *A. lusitanicus* was more frequent close to the wildflower strip than further away ($p<0.05$).

The number of *A. hortensis* in the metaldehyde treated plots was significantly lower than in the untreated plots ($p<0.05$), while the other treatments were not significantly different from each other. The distance to the wildflower strip did not affect the number of *A. hortensis* ($p>0.5$).

3.3. Rape trial

For the trial in Oberwil-Lieli, numbers of intact and damaged rape plants are shown in Fig. 3. The total number of rape plants (intact and damaged) was similar in the untreated and in the iron phosphate treated plots at all three assessments ($p>0.1$). The percentage of damaged rape plants was lower in the iron phosphate treated plots than in the untreated plots. However, the difference between treatments was only significant in the first two assessments (Table 2). Slug damage was distributed heterogeneously among the blocks.

At the other three sites, slug damage was generally lower than at Oberwil-Lieli, but the same pattern was observed at the first assessment: in the untreated plots, a higher percentage of plants was damaged than in the iron phosphate treated plots. However, the treatment effect was not significant in these trials. In Wegenstetten, 18% of the untreated and 11% of the treated plants were damaged ($p>0.1$). In Oftringen, 3.3% of the untreated and 0.7% of the treated plants were damaged ($p>0.5$) and in Reuenthal, 21% of the untreated and 19% of the treated plants were damaged ($p>0.5$).

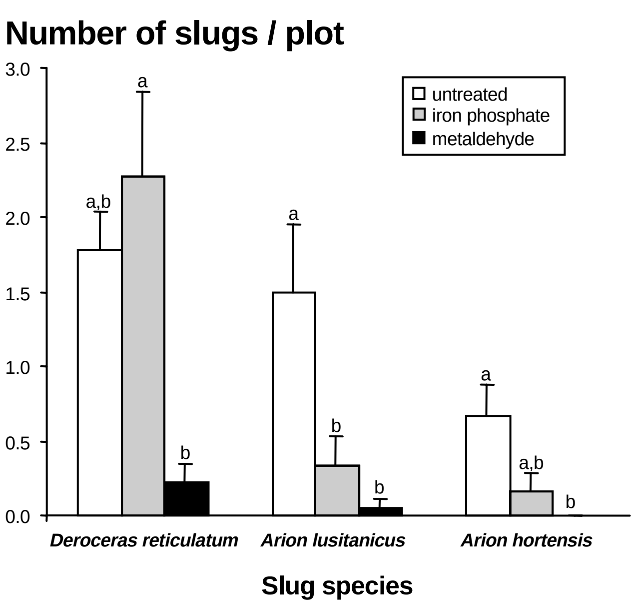

Fig. 2. Mean number of slugs of three different species trapped in the miniplots at three dates in 2000. Error bars indicate one standard error. Means sharing the same letter are not significantly different ($p>0.05$). Statistical comparisons were calculated with log-transformed data, while graph shows untransformed data.

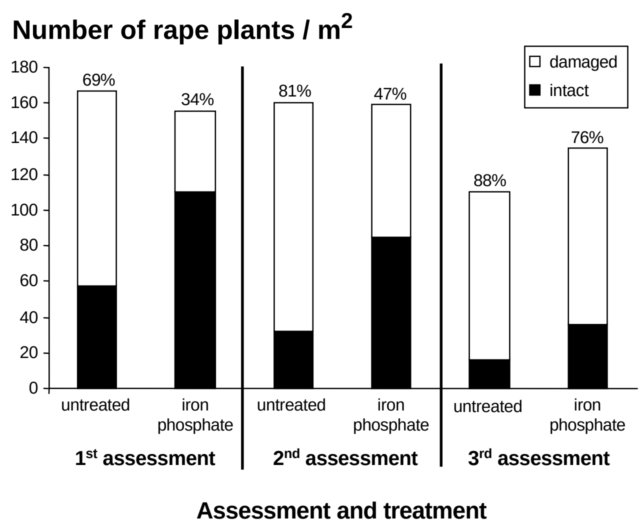

Fig. 3. Average numbers of intact and damaged rape plants (black and white bars), and percentage of damaged plants (percentages above bars), assessed three times in an on-farm field trial in Oberwil-Lieli. For significance of differences see Table 2.

Table 2
Significance of treatment, block and treatment × block interaction effect on the percentage of damaged rape plants, determined with analysis of variance. Data are shown in Fig. 3

Factors	1st assessment	2nd assessment	3rd assessment
Treatment	$p<0.001$	$p<0.01$	$p>0.1$
Block	$p<0.001$	$p<0.001$	$p<0.05$
Treatment × block interaction	$p<0.05$	$p>0.1$	$p>0.1$

4. Discussion

In the present experiments, iron phosphate clearly reduced slug damage in lettuce, although it was less effective than metaldehyde. In rape, it caused a clear reduction of slug damage in one field, and non-significant reductions in three other fields. Reduction of slug damage by iron phosphate has been observed under laboratory and glasshouse conditions (Jäckel, 1999; Koch et al., 2000; Iglesias and Speiser, in press). Other molluscicidal iron compounds have been shown to be equally effective as metaldehyde or methiocarb (Henderson et al., 1989; Henderson and Martin, 1990; Young, 1996). However, none of these compounds is commercially available as molluscicides in Central Europe, and none is likely to be permitted in organic agriculture because of their synthetic nature. All pest slug species of major importance for open fields in Central Europe, *D. reticulatum*, *A. lusitanicus* and *A. hortensis*, were affected by iron phosphate in one of the studies mentioned or in the present investigation. By contrast, the formulation of iron phosphate used here was ineffective against the glasshouse slug *Lehmannia valentiana* Müller (Koch et al., 2000).

The lettuce experiment was carried out under conditions of extreme slug pressure by the large, voracious species *A. lusitanicus*. These conditions are untypical for most of the commercial vegetable growing areas but they reflect the situation at field margins and in home gardens. Under these extreme conditions, iron phosphate reduced leaf loss of lettuce by a factor of 7 in 1999 and by a factor of 11 in 2000. In contrast, the number of marketable heads was only increased by a factor of 2 in 1999 and by a factor of 2.8 in 2000. Most of the leaf loss (often total defoliation) occurred within the first two weeks after planting of lettuce, showing that lettuce is particularly susceptible shortly after planting (see Fig. 1). Later, entire heads were occasionally devoured by slugs, but more frequently, slugs only caused feeding holes in the outer leaves. These feeding holes were negligible in terms of percentage leaf loss, but they rendered a head of lettuce unmarketable. Apparently, iron phosphate was more effective at reducing early slug damage (responsible for most of the leaf loss) than late slug damage (which mainly affects the number of marketable heads). This may be partially explained by the timing of molluscicide applications, which was biased towards the early stages of the lettuce, especially in 1999. Our observations suggest that Ferramol pellets decayed more quickly than the Metarex pellets. In the neighbourhood of the wildflower strip, slug damage was elevated in 1999, but not in 2000, Probably, the wet weather in 1999 favoured extensive emigration of slugs from the wildflower strip into the study area. As evident from the trapping results, this was mainly the case for *A. lusitanicus*, which is consistent with the literature (Frank, 1998a, c).

Rape is among the most sensitive arable crops grown in Central Europe and can be completely destroyed by slugs (Godan, 1979; Chabert and Maurin, 1994; Chabert et al., 1997; Frank, 1998b, c). In Switzerland, only a minority of the fields are generally affected in any given year, and only if several unfavourable factors coincide, such as high slug populations, unfavourable soil conditions, high moisture and humidity. In this study, slug damage was negligible in economic terms, as hardly any plants were killed. Nevertheless, slug damage was substantially reduced by iron phosphate. The spatial heterogeneity observed in this trial is typical for slugs (Bohan et al., 2000).

Iron phosphate is known to cause both feeding inhibition and mortality in slugs (Koch et al., 2000; Iglesias and Speiser, in press). In the lettuce trial in 2000, iron phosphate did not reduce the number of *D. reticulatum*, but strongly reduced *A. lusitanicus* and *A. hortensis*. Whether slugs were killed, immobilized or their behaviour altered in such a way that they were found less in the traps cannot be determined from these data. A large proportion of the trapped *D. reticulatum* were freshly hatched individuals. These may have hatched after molluscicide application, and therefore escaped contact with the molluscicides. By contrast, all specimens of *A. lusitanicus* and *A. hortensis* were larger and must have been present in the field at the time of molluscicide application. Slug populations were estimated approximately two weeks after most of the slug damage occurred. Therefore, slug numbers cannot be related directly to slug damage.

In comparison to metaldehyde, iron phosphate was less effective and had to be applied at higher rates. Because of the higher recommended rate, application of iron phosphate is more expensive than application of metaldehyde. Nevertheless, iron phosphate might be competitive to conventional molluscicides in certain niche markets. In organic farming, iron phosphate would facilitate production of a number of crops considerably, and it could protect organic farmers from severe losses through slug damage. However, the use of iron phosphate as a molluscicide is not allowed in organic agriculture at present. Secondly, home gardeners might appreciate that iron phosphate is less toxic to mammals than metaldehyde or carbamates. In home gardens, slug pellets are often applied according to personal preferences rather than recommended rates (Hörler, 1992), and costs for molluscicides are less important than in commercial agriculture or horticulture. In such niche markets, iron phosphate may be an agronomically and commercially successful molluscicide.

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