Project Title:	Hardy nursery stock: Integrated control of slugs and snails
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Key workers:	Jude Bennison, ADAS Boxworth (Project Leader) Heather Maher, ADAS Boxworth (Site Manager)
Location of Project:	R.A. Meredith & Son (Blooms) Ltd., Bressingham, Norfolk
Project Co-ordinators:	Paul Sopp, Fargro Ltd. John Hedger, New Place Nurseries Ltd.
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DISCLAIMERS

The results and conclusions in this report are based on an investigation conducted over one year. The conditions under which the experiment was carried out and the results obtained have been reported with detail and accuracy. However because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results especially if they are used as the basis for commercial product recommendations.

PRINCIPAL WORKERS

J A Bennison, Senior Research Entomologist, ADAS Boxworth (Project Leader and author of report)

H M Maher, Senior Scientific Officer, ADAS Boxworth

AUTHENTICATION

I declare that this work was done under my supervision according to the procedures described herein and that this report represents a true and accurate record of the results obtained.

.... JUDE BENNISON
Project Leader

Date.............................

Report authorised by: ....

DR W E PARKER
Crop Protection Research Manager

Date......................

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GROWER SUMMARY

Headline

- Both Draza and Ferramol as single applications reduced numbers of slugs and slug damage, on potted Delphiniums in a replicated trial in polythene tunnels on a commercial nursery. Neither product reduced numbers of snails.

- Draza was used in the trial as the standard molluscicide, under Specific Off-label approval for use on protected crops (SOLA 3215/02). The approval for Draza and thus for this SOLA has now expired. However, 'New Draza' and certain other approved methiocarb products can be used on protected HNS under the current Long-Term Arrangements for Extension of Use, as they are approved for use on protected lettuce.

- Ferramol and certain metaldehyde products are approved for use on both outdoor and protected HNS. The efficacy of metaldehyde has not been compared with that of Ferramol against slugs and snails on HNS.

- Ferramol is specific to slugs and snails and has low toxicity to ground and rove beetles, birds and mammals such as hedgehogs, all of which are natural slug and snail predators. Thus Ferramol may be preferred by growers using IPM or those wishing to use a more environmentally-acceptable alternative to other molluscicides (methiocarb is toxic to beetle predators and both methiocarb and metaldehyde pose risks for birds and mammals).

- Garlic as a single foliar spray did not reduce numbers of slugs, snails or plant damage.

- Nemaslug applied at various rates and timings did not reduce numbers of slugs, snails or plant damage. This may have been due to high compost temperatures after the experiment was set up, which will have reduced nematode survival.

- Tex-R matting did not prevent migration of slugs and snails from adjacent plants when used as a border of 31 cm.

Background and expected deliverables

UK growers of hardy nursery stock are experiencing difficulties in controlling slugs and snails on container-grown plants with conventional molluscicide pellets, and growers would prefer to use non-chemical, environmentally-acceptable methods of pest control wherever possible. Slug and snail populations have become established on many nurseries, both under protection and outdoors, and are damaging plants in plugs, liners and containers. Plants affected include high value shrub and herbaceous subjects, alpines, grasses and herbs. As feeding damage to foliage and flowers is very obvious and can be severe, considerable losses and downgrading of marketable plants can occur in susceptible species. The current project aimed to build on the knowledge and experience gained in HNS 105 and in other related research, to further evaluate 'Nemaslug', a garlic treatment, ferric phosphate pellets and Tex-R matting in a trial on a commercial nursery, in order to develop an effective environmentally-acceptable integrated control strategy for slugs and snails on HNS.

Expected deliverables include:

- Evaluation of selected curative and preventive treatments against slugs and snails, in a replicated trial on a commercial nursery.
- Guidelines for growers on environmentally-acceptable integrated control strategies for slugs and snails on HNS.

Summary of the project and main conclusions

- It was originally intended to do two experiments on commercial nurseries, one in autumn 2004, probably on slugs, and one in spring 2005, probably on snails. However, no suitably infested site could be found in autumn 2004. Therefore it was agreed with HDC to do only one experiment in spring 2005, on a nursery with both slug and snail problems.
- The experiment was done on potted Delphiniums in two adjacent polythene tunnels. The plants were naturally heavily infested with the slug and snail species identified in HNS 105 as the most common species on UK HNS, i.e. the slug, *Deroceras panormitanum* and the small semi-aquatic 'water' snail, *Oxyloma pfeifferi*. Each experimental plot contained both badly damaged plants and undamaged plants, the latter were added as a food source for the slugs and snails and to evaluate further plant damage during the 6-week experimental period.
- Draza was used as the standard molluscicide in the trial as until recently it was the main product used on HNS. Draza as a single application at the recommended rate (SOLA 3215/02) gave a significant reduction in numbers of slugs, but not of snails, over the 6-week trial period (Figure 1). Further damage to both the original severely damaged plants and to the original undamaged plants was significantly reduced six weeks after treatment (Figure 2). The approval for Draza has now

expired, thus use under protection using SOLA 3215/02 is no longer permitted. However, 'New Draza' and certain other approved methiocarb products can be used on protected HNS under the current Long-Term Arrangements for Extension of Use, as they are approved for use on protected lettuce.

- Ferric phosphate (applied as the home/garden product 'Advanced Slug Killer') as a single application of 5g per m^2 gave significant reduction in numbers of slugs, but not of snails, for a 6-week period and significantly reduced plant damage to the original undamaged plants three and six weeks after treatment. Further damage to the original severely damaged plants was not reduced.
- Ferric phosphate (as the commercial product 'Ferramol') was released after the project had started and at the Panel's request some additional plots were added to the trial one week after the experiment had started to test this product. A single application at 2.5g per m^2 gave significant reduction of numbers of slugs for a 2-week period but not for a 5-week period. Damage to the original undamaged plants was reduced five weeks after treatment, possibly due to the reduction in numbers of slugs two weeks after treatment. No reduction in damage to the original damaged plants was given. It is likely that more persistent control of a heavy slug infestation could be achieved by higher rates or repeated applications, which are optional recommended treatments on the product label.

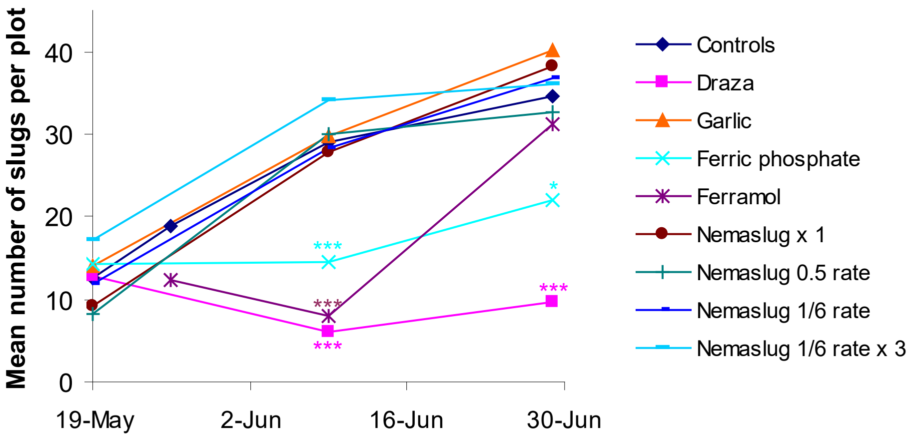

Fig. 1. Mean numbers of slugs per plot, treated with curative treatments.
(* significantly less than the controls, $P<0.05$, *** significantly less than the controls, $P<0.001$)

- Ferric phosphate and certain metaldehyde products are approved for use on both outdoor and protected HNS. Ferramol has low toxicity to non-target organisms such as ground and rove beetles, birds and mammals such as hedgehogs, all of which are natural slug and snail predators. Thus Ferramol may be preferred by growers using IPM or those wishing to use a more environmentally-acceptable alternative to other molluscicides (methiocarb is toxic to beetle predators and both methiocarb and metaldehyde pose risks for birds and mammals).

- The efficacy of metaldehyde has not been compared with that of Ferramol against slugs and snails on a commercial HNS nursery. Metaldehyde was tested in laboratory pot tests in the first year of the previous project, HNS 105, when it killed the target snail species but not slugs, although it reduced leaf damage by both slugs and snails. As metaldehyde acts mainly by dehydrating slugs and snails, it may not be fully effective on crops such as HNS receiving regular overhead irrigation, which can allow affected molluscs to recover.

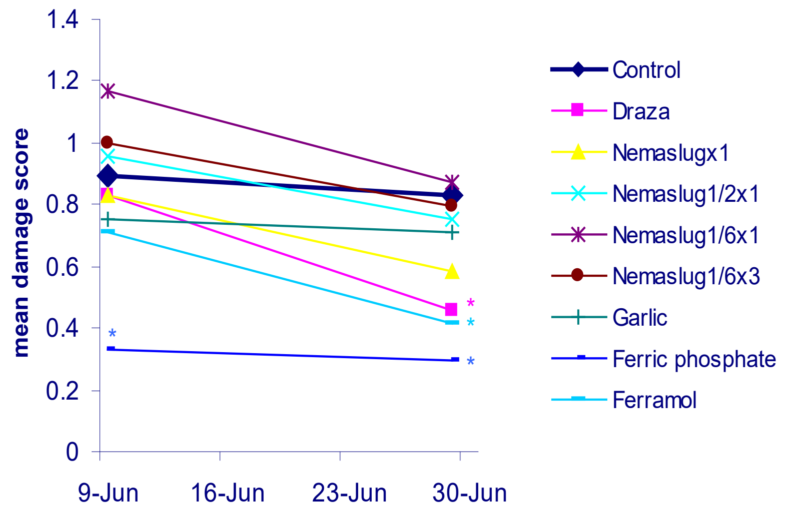

Fig. 2 Mean plant damage severity ranking for original undamaged plants treated with curative treatments. (* significantly less than control, P<0.05).

- Garlic applied as a single spray at a 2% concentration did not reduce numbers of slugs or snails and did not reduce plant damage. Some growers of HNS are now applying repeated sprays of a lower concentration of garlic as a preventive treatment for slugs and snails and there is anecdotal evidence of this being effective. Garlic is not approved as a pesticide and any use for the control of slugs and snails is at grower's own risk.
- 'Nemaslug' applied at full, half, and one sixth rates, the latter rate either as a single application, or as three weekly applications, did not reduce numbers of slugs or snails and did not reduce plant damage. The high compost temperatures after the experiment was set up will have reduced survival of the nematodes. Previous research in HNS 105 showed that Nemaslug can kill both these slug and snail species in the laboratory and it is likely that the nematodes would have given a better result if compost temperatures had remained within the optimal range of 5-25°C. The optimum time for application of Nemaslug is likely to be April or September, when both slugs and snails are active and when compost temperatures

are within this optimum range. In this project, suitable trial sites were not available in autumn 04 or April 05.

- Tex-R matting did not prevent migration of slugs and snails from adjacent plants when used as a border of 31 cm. It is likely that wider strips are needed to act as a barrier for both slugs and snails and commercial experience indicates that when used over the entire floor of a tunnel or sandbed, Tex-R matting reduces the numbers of slugs and snails infesting ‘clean’ plants.

Financial benefits

- In HNS 105, case studies of slug and snail damage on ten selected HNS nurseries showed that plant losses and downgrading of individual plant species was variable, with estimated plant losses ranging from less than 1% to 100%.
- The average value of containerised HNS plants at point of sale is £6,000 per 100m^2, although pot-thick high value perennials can be worth up to £9,000 per 100m^2. At a conservative estimate of a minimum of 1% losses due to slug and snail damage, these losses represent a minimum of £60 per 100 m^2. Losses can be much higher on individual highly susceptible crops. Further losses are incurred in time spent monitoring for damage and in applying control measures, selecting undamaged plants or removing damaged leaves. Selling periods for certain plants can be lost if the plants are recovering from damage at the time of sale.
- Draza and Ferramol were the only commercial products reducing numbers of slugs and slug damage in this project. Retail prices for Ferramol vary between £40 and £51 per 12.5 kg pack. Ferramol may be applied at up to 50 kg/ha in an individual dose. One application of Ferramol at 25 or 50 kg/ha respectively would cost £80-£102 or £160-204 per ha respectively, equivalent to 80 pence to £2 per 100m^2. Draza is no longer approved but an example approved methiocarb product, New Draza costs an average of £54 per 10 kg pack. One application of New Draza at the recommended rate of 5 kg per ha would cost an average of £27 per ha, equivalent to 27 pence per 100 m^2. Metaldehyde products vary in recommended rate and price, and not all are approved for use under protection. An example metaldehyde product, Lynx, is approved for use on outdoor and protected ornamentals and the average retail price is £12.50 per 10 kg pack. One application of Lynx at the maximum recommended rate of 15 kg/ha would cost an average of £18.75 per ha, equivalent to 19 pence per 100 m^2. The efficacy of metaldehyde on protected HNS on a commercial nursery was not tested in this project. Some growers wish to use Ferramol as a more environmentally-friendly alternative to other molluscicides and are prepared to pay the higher price, even if repeated applications are necessary, as there is growing customer demand for plants produced with more environmentally-acceptable production methods.

Action points for growers

- Maintain good nursery hygiene to reduce shelter and food for slugs and snails. Control algae, mosses, weeds and liverworts as thoroughly and frequently as possible and dispose of unmarketable plants and waste plant material promptly.
- Avoid over-watering as wet conditions favour both slug and snail activity and also the growth of algae, mosses and liverworts, on which they feed.
- Remove any slugs and snails on bought-in plants, checking under pots and trays where slugs often hide during the day.
- Encourage natural predation of slugs and snails by providing habitats for birds, hedgehogs and beetles, and by minimising the use of pesticides by adopting IPM.
- Use molluscicide pellets if necessary at recommended rates to control existing infestations. Ferramol is claimed to be more environmentally-friendly than other molluscicides. Check product labels for dose rates and numbers of applications.
- Although the results of this project showed that Tex-R matting did not prevent migration of slugs and snails from adjacent plants when used as a border of 31 cm, commercial experience indicates that when used over the entire floor of a tunnel or sandbed, the matting can give long-term protection against slugs and snails. Choice of specific matting and methods for keeping it clean and effective should be discussed with the supplier.
- Although the results of this project showed that Nemaslug was ineffective due to prolonged high compost temperatures shortly after the trial was set up, the nematodes can kill both slugs and snails and are likely to have given a better result if compost temperatures had remained within the optimum range. If interested, try on a small scale first on susceptible plants, in spring or autumn, when slugs and snails are active and when compost temperatures are 5-25ºC. Follow label directions carefully, apply the product to moist compost and keep the compost damp for at least two weeks after application.
- The results of this project showed that garlic applied as a single spray at 2% concentration was ineffective against both slugs and snails. Some growers are now applying repeated sprays of a lower concentration of garlic as a preventive treatment for slugs and snails. Garlic is sold as a biostimulant and is not approved for use as a pesticide. Any use of garlic products for the control of slugs and snails is at grower's own risk.

SCIENCE SECTION

Introduction

UK growers of hardy nursery stock are experiencing difficulties in controlling slugs and snails on container-grown plants with conventional molluscicide pellets, and growers would prefer to use non-chemical, environmentally-acceptable methods of pest control wherever possible. Slug and snail populations have become established on many nurseries, both under protection and outdoors, and are damaging plants in plugs, liners and containers. Plants affected include high value shrub and herbaceous subjects, alpines, grasses and herbs. As feeding damage to foliage and flowers is very obvious and can be severe, considerable losses and downgrading of marketable plants can occur in susceptible species.

In project HNS 105, co-funded by HDC and Defra (Bennison 2003), the research partners (ADAS and University of Newcastle) showed that:

- The main slug species found on ten selected HNS nurseries throughout England was *Deroceras panormitanum* and the main snail species was the small semi-aquatic snail, *Oxyloma pfeiferri*.
- Use of Tex-R ground-cover mattings can reduce the immigration of slugs and snails onto uninfested plants and these mattings are beginning to be used on commercial nurseries. However, their efficacy and persistence have not been fully tested on a commercial scale.
- The parasitic nematode 'Nemaslug' (*Phasmarhabditis hermaphrodita*) gave good control of *D. panormitanum* and *O. pfeifferi* in the laboratory and could offer an effective and environmentally-acceptable alternative to conventional slug pellets for control of existing infestations. Efficacy of 'Nemaslug' against both pests on a commercial HNS crop still needed to be demonstrated. Recent research in the Netherlands has demonstrated improved and more cost-effective control of slugs by a 'little and often' approach to using 'Nemaslug' on field vegetables (Ester *et al.*, 2003). This approach is worth testing on HNS, as splitting the dose between repeated applications might give more robust control than relying on one application at the full rate.
- Several novel potential molluscicides were identified, but these compounds varied in their potential for gaining approval as molluscicides. One of these compounds was garlic extract, in which growers are increasingly becoming interested as a potential pesticide. A refined high quality, high consistency garlic oil was shown to repel slugs and snails in laboratory tests and the University of Newcastle subsequently found that very low concentrations kill slug eggs in the soil (Schüder & Port, unpublished). A proposal to the HNS Panel in late 2003 included a full investigation by the University of Newcastle of the modes of action of garlic on slugs and snails, but this was not supported by the Panel. The Panel requested that garlic should be tested very simply in this project. Although it was originally proposed that a slow-release pelleted formulation should be tested, as this is hoped to be approved for use on field vegetable pests, subsequent discussions between the project leader, the project co-ordinators and the suppliers of the garlic led to a liquid formulation being tested. This was due to the lack of data on the efficacy of the garlic pellets against slugs and snails.

- In year 1 of HNS 105, both methiocarb (Draza) and metaldehyde (Doff Horticultural Slug Killer Mini Pellets) were tested against the target slug and snail species (*Deroceras panormitanum* and *Oxyloma pfeifferi* respectively) in 'semi-field' laboratory pot tests. Draza killed significant numbers of slugs and snails and the metaldehyde pellets killed significant numbers of snails but not slugs. Both products reduced slug and snail leaf damage. Draza was selected as the 'standard' molluscicide to use in subsequent trials on commercial nurseries where 'Nemaslug' was tested, as it was the market leader and more widely used on HNS than metaldehyde (Garthwaite & Thomas, 1999,). Draza was used by the majority of HNS growers visited in the case studies in year 1 of HNS 105 (Bennison, 2001). Metaldehyde acts mainly by dehydrating slugs and snails and is known to be less reliable on crops such as protected HNS which receive regular overhead irrigation, which can allow affected molluscs to recover. For consistency with the work in HNS 105, Draza was also selected as the standard molluscicide in the current project, HNS 105b, and was used in accordance with SOLA 3215/02 .
- Ferric phosphate molluscicide pellets (Growing Success Advanced Slug Killer) have recently become available on the amateur market. The pellets are claimed to be specific against slugs and snails, with no harmful effects on non-target organisms or the environment. The Panel requested that this product should be included in this project. After the project had started an identical commercial formulation, Ferramol, was released and at the Panel's request some additional plots were added to the main experiment to test this product.
- Ferramol is specific to slugs and snails and has low toxicity to ground and rove beetles, birds and mammals such as hedgehogs, all of which are natural slug and snail predators. Thus Ferramol may be preferred by growers using IPM or those wishing to use a more environmentally-acceptable alternative to other molluscicides (methiocarb is toxic to beetle predators and both methiocarb and metaldehyde pose risks for birds and mammals).

The main aim of this project was to build on the results of HNS 105 and on other findings detailed above, to further evaluate 'Nemaslug', a garlic treatment, ferric phosphate pellets and Tex-R matting, in order to develop an effective, environmentally-acceptable integrated control strategy for slugs and snails on HNS. The specific objective was to test selected treatments on two commercial nurseries.

Materials and methods

Experiment location and plant material

It was originally agreed to do two experiments on commercial nurseries, one in autumn 2004, probably on slugs, and one in spring 2005, probably on snails. However, no suitably infested site could be found in autumn 2004. Therefore it was agreed with HDC to do only one experiment in spring 2005, on a nursery with both slug and snail problems. The experiment was done on potted Delphiniums in two adjacent polythene tunnels at R.A Meredith & Son (Blooms) Ltd, at Bressingham, Norfolk. These were naturally infested with the slugs and snail species identified in HNS 105 as the most common species on UK hardy nursery stock, i.e. the slug, *Deroceras panormitanum* and the small semi-aquatic snail, *Oxyloma pfeifferi* .

Treatments

Treatment dose rates and application timings are given in Table 1.

Table 1. Experimental treatments, product dose rates and dates of application.

Code	Treatment	Product dose rate	Application timing
1	Water control		19/5/05
2	Water control		19/5/05
3	Methiocarb (Draza)*	4% w/w pellets at 5.5 kg/ha	19/5/05
4	'Nemaslug'	Recommended rate (300,000 per m^2)	19/5/05
5	'Nemaslug'	Half recommended rate	19/5/05

		(150,000 per m^2)	
6	'Nemaslug'	1/6 rate (50,000 per m^2)	19/5/05
7	'Nemaslug'	1/6 rate (50,000 per m^2)	19/5/05, 26/5/05, 2/6/05
8	Garlic (coded product 0042)	99.9% e.c. at 2% v/v	19/5/05
9	Ferric phosphate ('Advanced Slug Killer')	1% w/w pellets at 5g per m^2 (50 kg/ha)	19/5/05
10	Tex-R matting	N/A	19/5/05
11	Standard ground-cover matting	N/A	19/5/05
12	Ferric phosphate ('Ferramol')	1% w/w pellets at 2.5 g per m^2 (25 kg/ha)	26/5/05

- Draza was used in accordance with SOLA 3215/02 .

Treatment application methods

All pots in all treatments were watered if necessary to ensure that the compost was moist before treatment application. Treatments 1, 2, 4, 5, 6, 7 and 8 were applied with a knapsack sprayer, using a coarse nozzle (Lurmark FCX04) without a filter. The nematode treatments and the water control treatments were applied as a drench in 10,000 l water/ha (1 litre water per m^2). During application of the nematode treatments, the spray tank was agitated to avoid nematodes settling to the bottom. The garlic treatments were applied as a foliar spray at 400 l water/ha. The pelleted treatments were broadcast over the plants by hand.

Nematode viability checks

A fresh pack of 'Nemaslug' was used on each application date. Sub-samples of each pack were taken before application to check numbers of viable nematodes per g of product, and numbers per ml of the made-up suspension in the spray tank and in replicate sprayed amounts. Numbers of viable nematodes were checked in the laboratory using a standard nematological technique. This involved taking replicate 1 ml sub-samples from the spray tank and from samples of the nematode suspension sprayed into glass beakers, and pipetting the sub-samples into a haemocytometer microscope slide. Numbers of viable nematodes per ml were then counted under a binocular microscope.

Experiment design

The experiment was set up on 19 May as a randomised complete block design with four replicates of each of 11 treatments (plate 1, Appendix II). Two replicate plots of each treatment were placed in each of the two adjacent tunnels. One week after the experiment was set up, the HNS Panel requested that an additional, newly available commercial treatment (Ferramol Advanced Slug Killer) should be included in the experiment. At this stage it was not possible to include the additional treatment within the randomised block design, therefore the HDC agreed that the additional four replicate plots should be placed in the outer row of plots, two plots being added in each of the two adjacent tunnels (see trial plan, Appendix I).

Treatments 1-9 and 12 were testing the curative control of slugs and snails present on the plants and the reduction in further plant damage. For these treatments, in each of the four replicate plots per treatment, there were three trays of Delphiniums placed side by side on the gravel floor of the tunnels. Each tray of Delphiniums contained 15 plants. The middle tray was used for assessments of numbers of slugs and snails and of damaged leaves and shoots. Each of the two outer trays contained 15 damaged plants, infested with slugs and snails. The middle tray contained nine damaged, infested plants, and six undamaged, uninfested plants. Three undamaged plants were placed in each of the two outer rows of plants in the middle 'assessment' tray (see plate 2, Appendix II). This arrangement of damaged and undamaged plants in the middle 'assessment tray' was a precaution to provide a continued source of food for the slugs and snails for the life of the experiment, as the damage to the damaged plants was very severe and there was a risk of slugs and snails moving away from the plots in search of food.

Treatments 10 and 11 were testing preventive control of slugs and snails with the repellent activity of Tex-R matting, with standard woven ground cover matting used as the 'control' for the Tex-R. For each plot in these treatments, the trays of plants were stood on a piece of the respective type of matting, measuring 116 x 77 cm. Two trays of Delphiniums were placed onto each piece of matting and the trays were placed 31 cm apart (plates 3 and 4, Appendix II). This was the maximum distance the trays could be separated from each other on the piece of matting. Each of the two trays contained 15 healthy, undamaged Delphiniums. Slugs (*D. panormitanum*) and snails (*O. pfeifferi*) were collected from elsewhere on the nursery and added to one of the trays (four snails per plant and three slugs per tray). The other tray was used for assessments, to test whether the slugs and snails were able to cross over the Tex R or woven ground cover matting to reach the tray of 'clean' plants.

Strips of Tex R matting (42 cm wide down the length of the tunnel and 81 cm wide across the width of the tunnel) were used to separate each plot, to prevent migration of slugs and snails between plots (see trial plan, Appendix I and plate 1, Appendix II).

Irrigation of plants

The grower was asked to check the plants daily and to irrigate overhead when necessary, to avoid the compost drying out and thus adversely affecting the nematodes. The aim was to keep the compost damp but to avoid waterlogging of the plots.

Assessments

Slug and snail assessments

Numbers of live slugs and snails per middle 'assessment' tray were assessed on four occasions:

1. 19 May 2005 (pre-treatment for all treatments except treatment 12).
2. 26 May 2005 (pre-treatment for treatment 12: control plots and treatment 12 plots only).
3. 9 June 2005 (two weeks after treatment 12 applied, three weeks after all other treatments applied).
4. 29 June 2005 (five weeks after treatment 12 applied, six weeks after all other treatments applied).

Records were made of slugs and snails on the plants, on the compost, on the sides and underneath of the pots and under the tray.

Plant damage assessments

Plant damage was assessed on three occasions:

1. 19 May 2005 (pre-treatment for all treatments except treatment 12).
2. 9 June 2005 (two weeks after treatment 12 applied, three weeks after all other treatments applied).
3. 29 June 2005 (five weeks after treatment 12 applied, six weeks after all other treatments applied).

In the 'curative' treatments 1-9 and 12, damage to plants in the middle 'assessment tray' was recorded. On 19 May, only the nine plants which were already damaged by slugs and snails were assessed, as the six extra plants added to the tray were free from damage. On subsequent dates, records of damage to all 15 plants in the 'assessment' tray were made. On each assessment date, severity of damage was recorded using a numerical score as follows:

0. No damage, healthy plant
1. No leaves grazed off, some leaf damage present
2. Most leaves grazed off, only a few leaves present on stem
3. Stem grazed to compost level
4. No plant visible as stem grazed to below compost level

On the final assessment date, an additional assessment was made on numbers of severed shoots per plant.

In the 'preventive' treatments 10 and 11, damage was assessed on 9 and 29 June on the 15 plants in the tray containing undamaged plants at the start of the experiment. Numbers of damaged leaves per plant (plate 5, Appendix I) were assessed on both occasions and numbers of severed shoots per plant were assessed on 29 June.

Temperature records

Compost temperatures inside each polythene tunnel were recorded for the duration of the experiment using a Tinytalk datalogger, placed inside an extra pot, under the surface of the compost.

Statistical analysis

Data from treatments 1-9 and 12 (curative treatments) were analysed separately from data from treatments 10 and 11 (preventive treatments), as the two data sets represented two different approaches to slug and snail control. Data from treatments 1 and 2 (the two untreated control treatments) were combined before analysis. Numbers of slugs and snails per plot were analysed by Analysis of Variance. Numerical scores representing plant damage severity were analysed by Analysis of Variance and the damage scores on the nine original damaged plants in each 'assessment tray' were analysed separately from those on the six original undamaged plants in each 'assessment tray'. Numbers of damaged leaves per plant and numbers of damaged shoots per plant were analysed by Analysis of Variance.

Results

'Nemaslug' viability checks

The quality control tests on nematode viability in all packs of 'Nemaslug' used in the experiment indicated that the nematodes were of good quality and numbers of viable nematodes per pack were as expected.

Reduction in numbers of slugs and snails

Mean numbers of slugs and snails per 'assessment tray' of plants in each treatment plot are given in Figs 1 and 2 respectively for the curative treatments and Table 2 for the preventive Tex-R treatment.

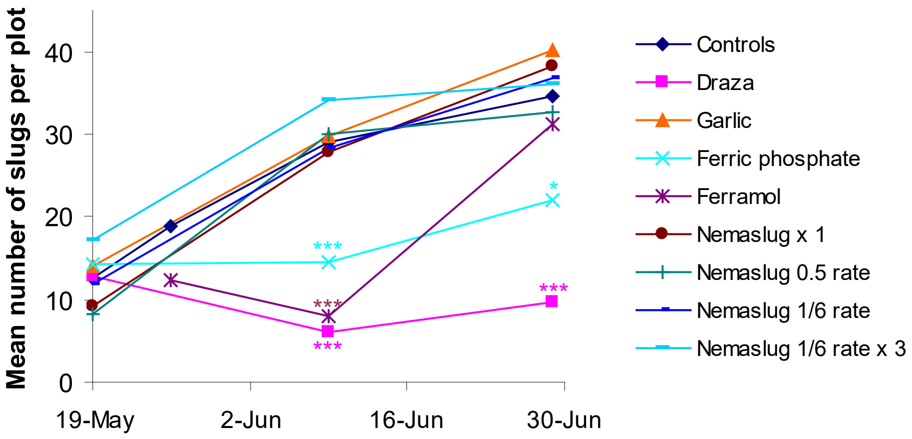

Fig. 1. Mean numbers of slugs per plot, treated with curative treatments.
(* significantly less than the controls, $P<0.05$
*** significantly less than the controls, $P<0.001$)

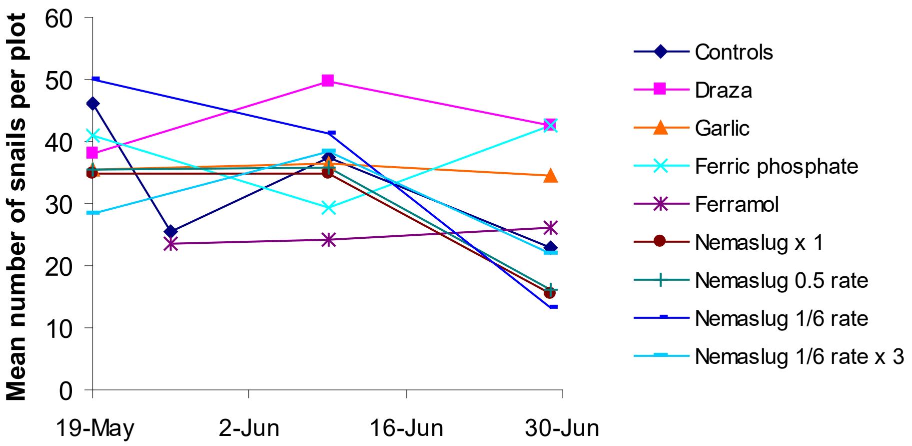

Fig.2 Mean numbers of snails per plot, treated with curative treatments. (No treatment significantly less than controls).

Table 2. Mean numbers of slugs and snails per plot treated with the preventive treatment, Tex-R matting and on the control, standard ground-cover matting.

Date	**Mean numbers of slugs (snails) per plot on standard ground-cover matting**	**Mean numbers of slugs (snails) per plot on Tex-R matting**
19 May (pre-treatment)	0 (0)	0 (0)
9 June	6.5 (8.5)	4.0 (5.8)
29 June	9.3 (17.3)	7.5 (13.5)
	N.S.	N.S.

N.S. = no statistical differences between treatments on any single date.

Reduction in plant damage

Mean plant damage severity score in each of the curative treatments are given in Fig.3 (for the original nine damaged plants in each 'assessment tray') and in Fig.4 (for the six original undamaged plants in each 'assessment tray'), and in Table 3 for the preventive matting treatments. Mean numbers of severed shoots per plant in the curative treatments are given in Fig. 5. Mean numbers of damaged leaves and severed shoots per plant in the preventive matting treatments are given in Table 3.

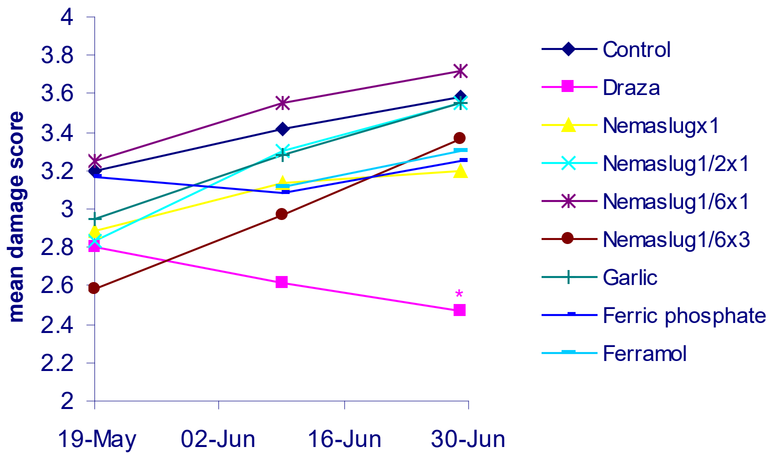

Fig.3 Mean plant damage severity score for original damaged plants.
* significantly less than control, $P<0.05$

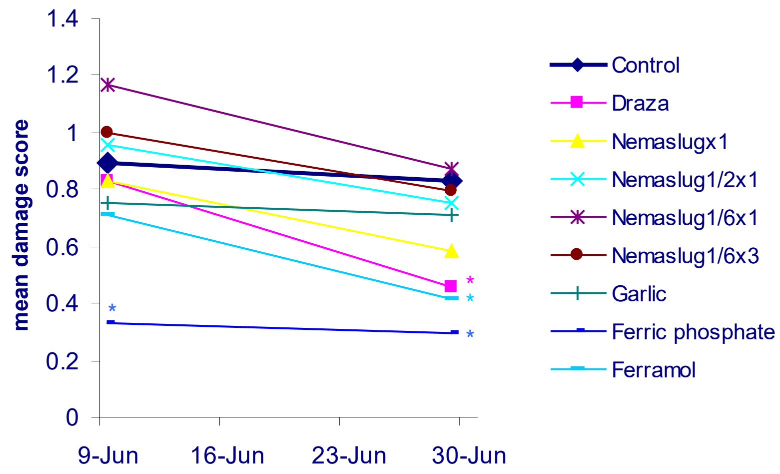

Fig.4 Mean plant damage severity score for original undamaged plants treated with curative treatments.
(* significantly less than control, $P<0.05$).

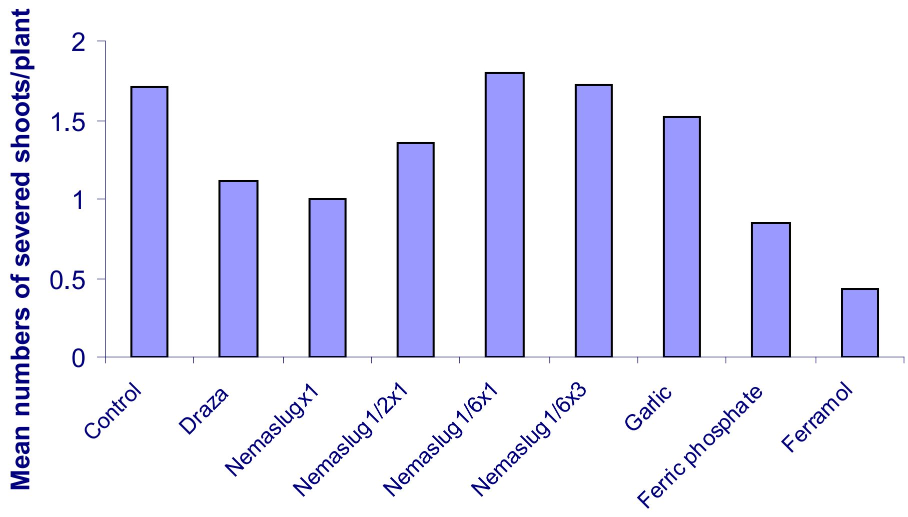

Fig.5 Mean numbers of damaged shoots per plot treated with curative treatments, assessed on final assessment date on 29 June.
(No treatments significantly lower than controls).

Table 3. Mean numbers of damaged leaves and shoots per plant treated with the preventive treatment, Tex-R matting and on the control, standard ground-cover matting. (-) = not assessed on this date.

Date	**Mean numbers of damaged leaves (shoots) per plant on standard ground-cover matting**	**Mean numbers of damaged leaves (shoots) per plant on Tex-R matting**
19 May (pre-treatment)	0 (0)	0 (0)
9 June	0.3 (-)	0.2 (-)
29 June	0.4 (1.5)	0.1 (1.5)
	N.S.	N.S.

N.S. = no statistically significant differences between treatments on any single date.

Temperature records

Mean compost temperatures in the two adjacent tunnels during the experimental period are shown in Figure 6.

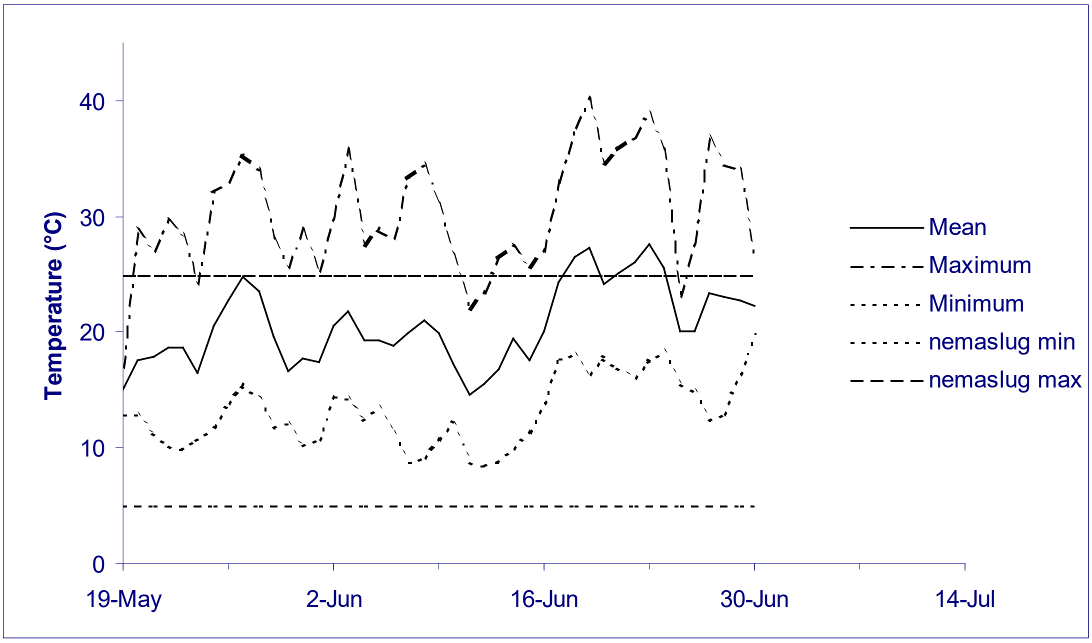

Fig. 6 Mean, maximum and minimum compost temperatures in the two adjacent tunnels used for the experiment. Minimum and maximum optimal temperature range for ‘Nemaslug’ activity is 5-25°C.

Discussion

Reduction in numbers of slugs and snails by the curative treatments

When the experiment was set up on 19 May 2005, there was a heavy infestation of both slugs (*Deroceras panormitanum*) and snails (*Oxyloma pfeifferi*). There were similar pre-treatment numbers of slugs and snails per plot in all treatments, with an overall mean of 12.5 slugs and 39.5 snails per plot (Figs 1 and 2 respectively). When the plots treated with the extra treatment (Ferramol) were set up on 26 May, there were similar pre-treatment numbers of slugs and snails in both the control plots and those treated with Ferramol, with an overall mean of 16.7 slugs and 24.9 snails per plot.

On the first post-treatment assessment date, on 9 June (two weeks after Ferramol was applied and three weeks after all other treatments were applied), there were significantly less slugs per plot treated with Draza (a mean of 6 per plot), Ferric Phosphate Advanced Slug Killer (a mean of 14.5 per plot) and Ferramol (a mean of 8 per plot) then in the untreated control plots (a mean of 21 per plot), see Fig. 1. Draza reduced numbers of slugs significantly more than Ferric Phosphate Advanced Slug Killer, but not significantly more than Ferramol. However, there was no significant difference between the numbers of slugs per plot treated with Ferric Phosphate Advanced Slug Killer and Ferramol, which are identical products. This result indicated that on this date, the active ingredient, ferric phosphate, reduced numbers of slugs at both application rates. i.e. 2.5g per m2 (Ferramol) and 5g per m2 (Ferric Phosphate Advanced Slug Killer). Neither the garlic spray nor any of the Nemaslug treatments significantly reduced numbers of slugs per plot (Fig. 1). Shortly after the experiment was set up the weather became very warm and sunny and high compost temperatures are likely to have affected Nemaslug survival. Although mean compost temperatures were between the optimum temperature range of 5-25ºC over the 3-week period from nematode application, maximum temperatures regularly exceeded 30ºC (Fig. 6). Survival of *Phasmarhabditis hermaphrodita* declines rapidly above 30ºC (Grewal & Grewal, 2003). On the same date, none of the treatments significantly reduced numbers of snails per plot, with an overall mean of 36.5 per plot (Fig. 2).

On the second post-treatment date, on 29 June, (five weeks after Ferramol was applied and six weeks after all other treatments were applied) only Draza and Ferric Phosphate Advanced Slug Killer gave significant reductions in numbers of slugs (Fig. 1) There was a mean of 9.8 and 22.1 slugs per plot for the two respective treatments, compared with a mean of 34.7 per plot in untreated controls. Numbers of slugs per plot were not significantly lower on plots treated with Draza than on those treated with Ferric Phosphate Advanced Slug Killer. Ferramol did not give a significant reduction in numbers of slugs on this date. This result indicates that the active ingredient, ferric phosphate at 2.5g per m^2 was not high enough to reduce slug numbers over a 5-week period, whereas the rate of 5g per m^2 reduced slug numbers over a 6-week period and was as effective as Draza. However, as the Ferramol at 2.5g per m^2 was applied one week later than the other treatments, true comparisons in efficacy cannot be made. As on the first assessment date, neither the garlic spray nor any of the Nemaslug treatments reduced numbers of slugs per plot. Mean compost temperatures exceeded the optimum range for Nemaslug during the last two weeks in June and maximum temperatures exceeded the lethal threshold of 30ºC for most of this period. As on the first assessment date, none of the treatments reduced numbers of snails per plot (Fig.2).

Reduction in plant damage by the curative treatments

Draza was the only curative treatment which significantly reduced further damage to the original severely damaged plants, with plants showing a slight recovery on the final assessment date (Fig. 3). Ferric phosphate Advanced Slug Killer significantly reduced the severity of leaf damage to the original undamaged plants on both assessment dates, and both Draza and Ferramol significantly reduced damage on the final assessment date (Fig. 4). None of the treatments reduced numbers of severed shoots per plant (Fig. 5). Neither the garlic spray nor any of the Nemaslug treatments reduced plant damage on either assessment date and this result was consistent with the lack in reduction of numbers of slugs per plot by these treatments. Damage to plants treated with Draza, Ferramol and Ferric Phosphate Advanced Slug Killer continued throughout the experiment despite reduction in numbers of slugs per plot, due to the heavy original infestation rate of slugs and snails. Even on plots treated with Draza, which had the lowest mean numbers of slugs on both assessment dates, there was a mean of 9.8 slugs per 'assessment tray' at the end of the experiment, which were sufficient to cause damage. Numbers of snails remained high on all treated plots and although *Oxyloma pfeifferi* is known to feed on algae and decaying plant tissue as well as causing direct plant damage (Bennison, 2003), they were observed on the damaged Delphinium leaves and shoots and are likely to have contributed to damage to these very soft, tender plants.

Reduction in numbers of slugs and snails and in plant damage by the preventive treatment

Numbers of both slugs and snails migrating from the damaged plants to the undamaged plants on stood on Tex-R matting were not significantly less than on standard ground-cover matting (Table 2). Mean numbers of damaged leaves and severed shoots per plant were not significantly reduced on plants stood on Tex-R matting. The result indicates that a border of 31 cm was not sufficient to prevent immigration of slugs and snails from adjacent infested plants. Low numbers of *Oxyloma pfeifferi* were observed on the strips of Tex-R matting used as barriers between the plots, indicating that strips of 81 cm wide were also too narrow to act as a barrier for the snails. No slugs were observed on the Tex-R matting between the plots, however, *D. panormitanum* is mainly active at night so would be mainly hidden from view during the day (Bennison, 2003). It is likely that wider strips are needed to act as a barrier and commercial experience indicates that when used over the entire floor of a tunnel or sandbed, Tex-R matting reduces the numbers of slugs and snails infesting 'clean' plants.

Conclusions

- Draza as a single application at the recommended rate gave significant reduction in numbers of slugs (*Deroceras panormitanum*) but not of snails (*Oxyloma pfeifferi*) for a 6-week period. Further damage to both the original severely damaged plants and to the original undamaged plants was significantly reduced six weeks after treatment.
- The approval for Draza has now expired, thus use under protection using SOLA 3215/02 is no longer permitted. However, 'New Draza' and certain other approved methiocarb products can be used on protected HNS under the current Long-Term Arrangements for Extension of Use, as they are approved for use on protected lettuce.
- Ferric Phosphate Advanced Slug Killer as a single application of 5g per m^2 gave significant reduction in numbers of slugs, but not of snails, for a 6-week period and significantly reduced plant damage to the original undamaged plants three and six weeks after treatment.
- Ferramol as a single application of 2.5g per m^2 gave significant reduction of numbers of slugs for a 2-week period but not for a 5-week period and reduced plant damage five weeks after treatment, possibly due to the reduction in numbers of slugs two weeks after treatment. The rate of Ferramol used in the trial was agreed with the suppliers, however the product may be used at higher rates and as repeated applications. As Ferramol is the same product as Ferric Phosphate Advanced Slug Killer, it is likely that more persistent control of a heavy slug infestation could be achieved by higher rates or repeated applications. Ferric phosphate is specific to slugs and snails and has no harmful effects on non-target organisms or the environment, so may be preferred to other molluscicides by some growers (methiocarb is toxic to beetle predators and both methiocarb and metaldehyde pose risks for birds and mammals).
- Certain metaldehyde products e.g. Lynx are approved for use on both outdoor and protected HNS. The efficacy of metaldehyde has not been compared with that of Ferramol against slugs and snails on HNS.

- Garlic applied as a single spray at a 2% concentration did not reduce numbers of slugs or snails and did not reduce plant damage. Some growers of HNS are now applying repeated sprays of a lower concentration of garlic as a preventive treatment for slugs and snails and there is anecdotal evidence of this being effective, even on highly susceptible plants such as Hosta.
- 'Nemaslug' applied at full, half, and one sixth rates, the latter rate either as a single application, or as three weekly applications, did not reduce numbers of slugs or snails and did not reduce plant damage. The high compost temperatures after the experiment was set up will have reduced survival of the nematodes. Previous research in HNS 105 (Bennison 2003) showed that Nemaslug can kill both these slug and snail species in the laboratory and it is likely that the nematodes would have given a better result if compost temperatures remained within the optimal range of 5-25°C. The optimum time for application of Nemaslug is likely to be April or September, when both slugs and snails are active and when compost temperatures are within the optimum range. In this project, suitable trial sites were not available in autumn 04 or April 05.
- Tex-R matting did not prevent immigration of slugs and snails from adjacent plants when used as a border of 31 cm. It is likely that wider strips are needed to act as a barrier for both slugs and snails and commercial experience indicates that when used over the entire floor of a tunnel or sandbed, Tex-R matting reduces the numbers of slugs and snails infesting 'clean' plants.

Future work

Future work would be needed to demonstrate:

- The efficacy of Ferramol at higher application rates or repeated applications for the control of heavy slug infestations.
- The comparative efficacy of Ferramol and metaldehyde.
- The efficacy of preventive applications of lower concentrations of garlic against both slugs and snails.
- The efficacy of Nemaslug applied against both slugs and snails during periods of optimum compost temperatures i.e. April or September.

Technology transfer

- During the life of the project, Jude Bennison discussed the results to date with HNS growers during consultancy visits, with the suppliers of the experimental treatments and with ADAS Horticultural Consultants.

- Jude Bennison included the aims of the project in a presentation on IPM in UK hardy nursery stock, at the IOBC working group meeting on IPM on protected crops, Finland, April 2005.

Acknowledgements

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- Becker Underwood for supplying the 'Nemaslug'.
- Growing Success Organics Ltd. for supplying the 'Growing Success Advanced Slug Killer' (ferric phosphate).
- Certis for supplying the 'Ferramol'.
- Fargro for supplying the 'Tex-R' matting.

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Plate 1. Experimental plots in one of the two adjacent polythene tunnels used for the trial.

Plate 2. Example plot used for 'curative' treatments. Middle tray used for assessments, with nine damaged plants (middle three rows) and six undamaged plants (two outer rows).

Plate 3. Example plot used for ‘preventive’ treatment. Trays stood on Tex-R matting.

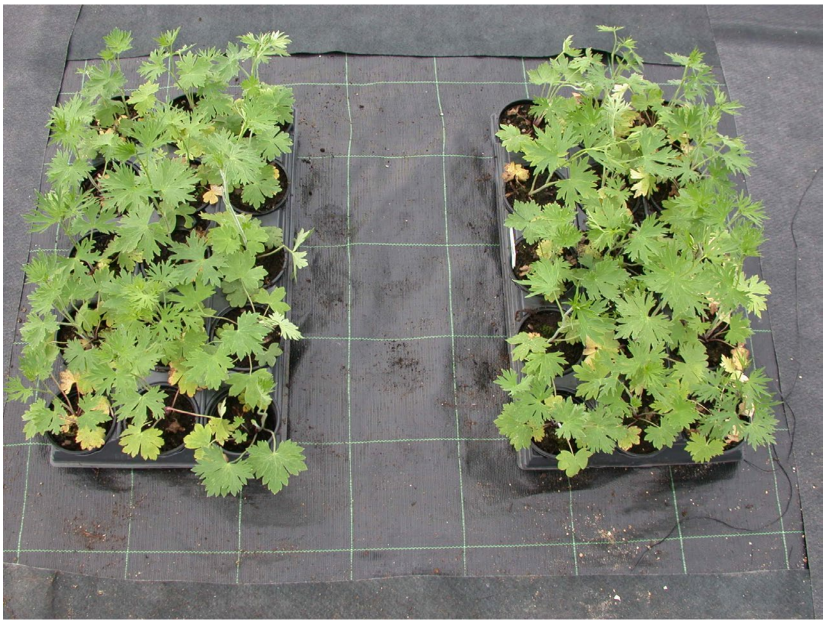

Plate 4. Example plot used for ‘preventive’ control treatment. Trays stood on standard ground-cover matting.

Plate 5. Slug and snail damage to delphinium leaf, with snails (*Oxyloma pfeifferi*) on compost.

Plate 6. Snail (*Oxyloma pfeifferi*) on Delphinium stem.