Project title:	Brassicas: module drenches to control cabbage root fly
Project number:	FV 416a
Project leader:	Dr Rosemary Collier Warwick Crop Centre School of Life Sciences The University of Warwick
Report:	Final report, January 2015
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Key staff:	Rosemary Collier – project management Andrew Jukes – establishment of field trial and data collection Julie Jones – experimental design Andrew Mead and Jess Evans - analysis
Location of project:	Warwick Crop Centre, Wellesbourne, Warwick, CV35 9EF
Industry Representative:	Andy Richardson Allium and Brassica Centre Wash Road, Kirton,Boston Lincs, PE20 1QQ
Date project commenced:	1 May 2014
Date project completed (or expected completion date):	31 January 2015 (with extension to 30 April 2015)

[The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the trials were carried out and the results have been reported in detail and with 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.]

AUTHENTICATION

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

Dr Rosemary Collier
Director
Warwick Crop Centre, School of Life Sciences, University of Warwick

Signature ..... Date .....

Report authorised by:

[Name]
[Position]
[Organisation]

Signature ..... Date .....

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GROWER SUMMARY

Headline

Plants treated with Tracer or a novel product HDCI 065 as module drenches can be held on nurseries, and with exposure to heavy watering, for at least 2 weeks without significant reduction in control of cabbage root fly damage in the root zone compared with Dursban WG. In commercial situations, the amount of insecticide applied to individual modules pre-planting may be very variable. Further more extensive research work is necessary to determine if the variability seen is due to the sampling procedure used and if variability is proven then the possible reasons for it. Cabbage root fly may be a threat to swede crops until egg-laying ceases at the end of the summer.

Background

For many years the cabbage root fly (*Delia radicum*) has been controlled on transplanted brassica crops through the application of an organophosphorus insecticide (chlorpyrifos – Dursban WG) to the modules prior to transplanting. However, the future of this treatment is now uncertain. Within the last decade, an alternative treatment (spinosad – Tracer) has become available to growers, but whilst Dursban has been available, Tracer has not been used widely. One of the reasons for its limited use is the perception that Tracer is not such an effective treatment. Now that future use of Dursban is likely to be time-limited, it is important to establish whether there are limitations in the performance of Tracer.

The main aim of this project (FV 416a) is to evaluate further the performance of module drench treatments to control cabbage root fly. This includes a novel product applied as a drench that has been evaluated in the SCEPTRE project and shown to be effective at controlling cabbage root fly. The project objectives are to 1) assess the performance of pre-planting module drench treatments with Tracer, Dursban and the novel product under 'normal' and 'sub-optimal' conditions i.e. when planting is delayed post-treatment and 2) compare the performance of post-planting drench treatments (with the same products), and a novel granule treatment, with the pre-planting treatments. A bio-insecticide applied pre-planting was also assessed. In addition, the project assessed application efficiency in a commercial nursery (Objective 3). With the likely removal of chlorpyrifos as a modular drench, application efficiency (both in terms of mean dose and module-module variability) could become more significant.

Finally, the method used most widely to minimize damage to swede crops by cabbage root fly larvae is to enclose the crops with fine mesh netting. This is because there are no

effective methods of insecticidal control of either cabbage root fly adults or larvae available currently. In recent years, Scottish growers in particular have asked when it is safe to remove crop covers from swede crops in late summer/autumn. This is often desirable to maximise crop development at the end of the season. There has never been any experimental work to determine what happens to the larvae arising from eggs laid very late in the season i.e. do they develop sufficiently to cause economic damage or do they perish as temperatures fall. A final objective of this project (Objective 4) was to determine when cabbage root fly eggs and larvae cease to be a threat to swede crops at the end of the season.

Summary

Objectives 1 and 2

Assess the performance of pre-planting module drench treatments with Tracer, Dursban and a novel product (evaluated in the SCEPTRE project) under 'normal' and 'sub-optimal' conditions i.e. when planting delayed post-treatment and compare the performance of post-planting drench treatments (with the same products), and a novel granule treatment, with the pre-planting treatments.

Objectives 1 and 2 were addressed through two field trials. One was timed to coincide with the peak of first generation cabbage root fly egg-laying and the other with the peak of second generation egg-laying. For both trials there were 11 insecticide treatments (Table A), one of which was biological (HDCI 067). The seed (Cauliflower cv Skywalker, Elsoms Seeds) was sown on 19 March 2014 (Trial 1) and 20 May 2014 (Trial 2). Drench treatments were applied using a 1 ml automatic pipette according to the treatment schedule. Treatments were washed onto the modules with an equivalent volume of water. The modules treated 14 days before planting were additionally subjected to 4 heavy watering events 4 hours, 2 days, 4 days and 6 days after treatment. All other watering was applied from below via capillary matting. All plants were transplanted on 29 April 2014 (Trial 1) or 3 July 2014 (Trial 2). The post-planting treatments (with Dursban WG, Tracer, HDCI 065) were applied in 70 ml water, around the base of the plant, using a beaker. The granule treatment (HDCI 066) was applied in furrow before planting using a modified Stanhay seed drill. Treatments were replicated 4 times. Each plot was 3.5 m x 1 bed (1.83 m wide) and there were 4 rows per bed. The plants were spaced at 50 cm along rows and 35 cm between rows. In total, each plot contained 32 plants.

Table A Treatments used in trials on cauliflower

	Product	a.i.	Application timing	Rate (product/1000 plants)	Watering
T1	Untreated				Maintain at moisture capacity with capillary matting
T2	Dursban WG	Chlorpyrifos	1 day pre-transplanting	6 g[1]	Maintain at moisture capacity with capillary matting
T3	Tracer	Spinosad	1 day pre-transplanting	12 ml[1]	Maintain at moisture capacity with capillary matting
T4	HDCI 065		1 day pre-transplanting	15 ml	Maintain at moisture capacity with capillary matting
T5	Dursban WG	Chlorpyrifos	14 days pre-transplanting	6 g[1]	Maintain at moisture capacity with capillary matting 4 x 3 l water/tray overhead 4 hours, 2, 4 and 6 days after treatment
T6	Tracer	Spinosad	14 days pre-transplanting	12 ml[1]	Maintain at moisture capacity with capillary matting 4 x 3 l water/tray overhead 4 hours, 2, 4 and 6 days after treatment
T7	HDCI 065		14 days pre-transplanting	15 ml	Maintain at moisture capacity with capillary matting 4 x 3 l water/tray overhead 4 hours, 2, 4 and 6 days after treatment
T8	Dursban WG	Chlorpyrifos	Post-transplanting	60g/100l[1] (=42 g)	Maintain at moisture capacity with capillary matting
T9	Tracer	Spinosad	Post-transplanting	12 ml	Maintain at moisture capacity with capillary matting
T10	HDCI 065		Post-transplanting	15 ml	Maintain at moisture capacity with capillary matting
T11	HDCI 066		Pre-planting In-furrow	10 kg/ha (=0.5 g/m row)	Maintain at moisture capacity with capillary matting
T12	HDCI 067		1 day pre-transplanting	120 ml	Maintain at moisture capacity with capillary matting

[1] Recommended rates

On 4 June (Trial 1) and 12 August (Trial 2), 12 cauliflower plants were sampled from the centre of each plot. After washing, the roots and stems of each plant were assessed for damage caused by cabbage root fly larvae and the plants were weighed.

Plant weight

In Trial 1, treatment had a statistically significant effect on plant weight. Plants from all treatments apart from HDCI 066 and HDCI 067 were heavier than the untreated plants. The plants from the Dursban WG and Tracer treatments applied 1-day before planting were heavier than those from all other treatments. In Trial 2, the plants were much larger overall and there was no statistically significant effect of treatment on plant weight.

Root damage

In Trial 1, all of the treatments except HDCI 066 (Pre-planting In-furrow) decreased root damage compared with the untreated control ($p<0.05$) (Figure A). Of the 'better'

treatments, the Dursban WG treatments and the pre-planting treatments with Tracer or HDCI 065 were equally effective ($p<0.05$). The post-transplanting treatment with Tracer was less-effective than the post-transplanting treatment with HDCI 065 or the treatment with HDCI 067 ($p<0.05$).

In Trial 2, the reduction in damage due to all of the insecticide treatments was less pronounced than in Trial 1 (Figure A). However, as in Trial 1, all of the treatments except HDCI 066 (Pre-planting In-furrow) decreased root damage compared with the untreated control ($p<0.05$). Of the 'better' treatments, the 1-day pre-transplanting treatments with Dursban WG, Tracer or HDCI 065, the 14-day pre-transplanting treatments with HDCI 065 or Tracer and the post-transplanting treatment with Dursban WG were equally effective ($p<0.05$).

Stem damage

In Trial 1, all of the treatments except those with HDCI 066 or HDCI 067 reduced stem damage compared with the untreated control ($p<0.05$). Of the 'better' treatments, the treatments with Dursban WG and the 14-day pre-transplanting and post-transplanting treatments with HDCI 065 were equally effective. In Trial 2, the 1-day pre-transplanting treatments with Dursban WG, Tracer and HDCI 065 and the post-planting treatments with Dursban WG and Tracer all reduced stem damage compared with the untreated control ($p<0.05$). Of the 'better' treatments, the 1-day pre-transplanting treatments with Dursban WG, Tracer and HDCI 065 and the post-planting treatment with Dursban WG were all equally effective ($p<0.05$).

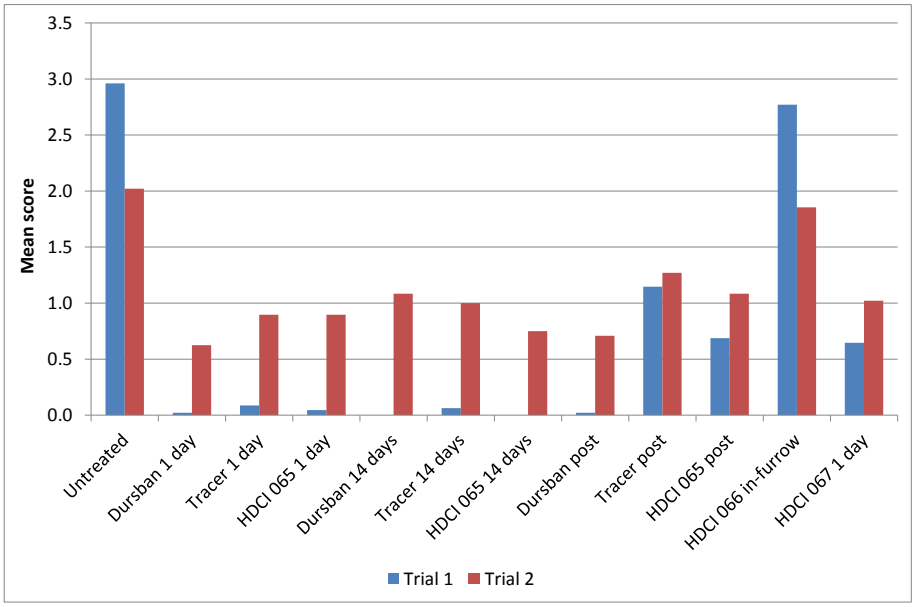

Figure A Root damage score in Trials 1 and 2.

Objective 3: Assess the application efficiency of module drench treatments in a commercial nursery. With the likely removal of chlorpyrifos as a modular drench application efficiency (both in terms of mean dose and module-module variability) could become more significant.

Plant propagation modules treated with Dursban WG (chlorpyrifos) in commercial plant raising nurseries were sampled after delivery to growers. Three sets of 50 samples were taken from different nurseries and/or different applications. Samples were frozen and transported to Warwick Cop Centre for analysis of chlorpyrifos residues. The treatment dates, sampling dates, crop, sampling details and nursery details are shown in Table B.
Mean dose and module-module variability were calculated.

Table B Sample details of plant propagation modules tested for chlorpyrifos concentration

Sample code	Dates		Nursery Code	Number of trays sampled from	Crop
	Treatment	Sampling			
1	25/7	28/7	A	Multiple	Broccoli
2	25/7	28/7	A	Multiple	Pointed cabbage
3	28/7	29/7	B	One	Broccoli

The rate of application of Dursban WG to modules pre-planting is 30 g product per 5000 modules which equates to 4.5 mg chlorpyrifos per module. Results from the three samples tested (Table C) show that in two samples this mean dose was not achieved (samples 1 and 3) and in one it was exceeded (sample 2). Achieved doses were 66, 138 and 61% of target with 22, 48 and 16% of modules having the target dose +/- 20% in samples 1 to 3 respectively. However, the coefficient of variation between modules was similar for the three samples (49.2 – 55.8%)

Table C Summary of chlorpyrifos residue in peat modules results

Sample code	Dose (mg/module)		Standard deviation	Coefficient of variation (%)	Percentage of modules +/- 20% of target
	Mean	Range			
1	2.97	0.78 – 7.40	1.462	49.2	22
2	6.23	2.32 – 15.39	3.477	55.8	48
3	2.75	0.76 – 7.65	1.388	50.4	16

Objective 4 : Determine when cabbage root fly larvae cease to be a threat to swede crops at the end of the season

Plant pots, each containing a single harvested swede and back-filled with soil, were inoculated with 100 newly-laid cabbage root fly eggs per pot. Twenty pots of swede per occasion were inoculated at intervals from 11 September until 20 November 2014. The pots were buried in a field plot and covered in insect-proof netting to exclude 'wild' cabbage root flies. The cover was removed on 12 January 2015. The pots from each inoculation date were sampled on 5 January, 4 February, 11 March and 23 April to determine the survival and life-stages of the insects.

From soil temperature data, cabbage root fly development would have been able to continue until at least early December. This enabled most of the insects in pots inoculated up to 23 October to complete development to the pupal stage and spend the winter as diapausing pupae. The insects in pots inoculated on 29 October managed to complete most of their larval development and a few reached the pupal stage, but then they spent the coldest part of the winter as large larvae, before pupating by the March sampling date (when temperatures were beginning to rise). All of these insects caused considerable damage to the swede roots. Very few insects were recovered in January and February from the pots inoculated in November and the swede roots suffered little damage. However, by March, larger numbers of pupae were recovered from these pots indicating that they had survived the winter, probably as larvae. By April the swede roots had rotted so it was not possible to assess damage.

Financial Benefits

Without adequate insecticidal control, crop losses due to cabbage root fly damage would be considerable. It is estimated that about 24% of the plants in field brassica crops would be rendered unmarketable by the cabbage root fly without the application of effective control methods.

Action Points

- Plants treated with Tracer as a module drench can be held on nurseries, and with exposure to heavy watering, for at least 2 weeks without significant reduction in control of cabbage root fly damage in the root zone compared with Dursban WG.
- Cabbage root fly may be a threat to swede crops until egg-laying ceases at the end of the summer. Thus it would be advisable to leave netting covers in place until egg-

laying has ceased. If eggs are laid, development of damage prior to harvest will depend on the warmth of the weather after egg-laying.

SCIENCE SECTION

Introduction

Insecticidal control of cabbage root fly

For many years the cabbage root fly (*Delia radicum*) has been controlled on transplanted brassica crops through the application of an organophosphorus insecticide (chlorpyrifos – Dursban) to the modules prior to transplanting. However, the future of this treatment is now uncertain. Within the last decade, an alternative treatment (spinosad – Tracer) has become available to growers, but whilst Dursban has been available, Tracer has not been used widely. One of the reasons for its limited use is the perception that Tracer is not such an effective treatment. Now that future use of Dursban is likely to be time-limited, it is important to establish whether there are limitations in the performance of Tracer.

Tracer drench treatments have been evaluated extensively in HDC projects on control of cabbage root fly and in general, when modules are transplanted immediately after treatment, there is little difference (on average) in the levels of control achieved with Tracer and Dursban. However, until 2013, the performance of Tracer under sub-optimal conditions had not been evaluated, particularly in relation to delays in planting, where the modules have been treated but planting is delayed, often due to adverse weather conditions. An HDC-funded project in 2013 (FV 416) showed that module drench treatments of Tracer were as effective as Dursban WG at protecting the root zone of transplanted cauliflowers from attack by cabbage root fly larvae. The efficacy of Tracer was only marginally diminished when planting was delayed for 2 weeks following treatment or by heavy watering of the modules pre-planting. Residue studies suggested that Tracer was at least as persistent as Dursban WG when treated modules were exposed to a series of heavy watering events and stored at maximum moisture capacity. Most of the treated plants had less stem damage than the untreated control, but this was only statistically significant with all of the Dursban WG treatments. Overall the project indicated that in most circumstances Tracer is likely to be an acceptable alternative to Dursban WG.

The aim of this project (FV 416a) was to evaluate further the performance of module drench treatments to control cabbage root fly. This included a novel product (HDCI 065) applied as a drench that has been evaluated in the SCEPTRE project and shown to be effective at controlling cabbage root fly. The project objectives were to 1) assess the performance of pre-planting module drench treatments with Tracer, Dursban and HDCI 065 under ‘normal’ and ‘sub-optimal’ conditions i.e. when planting is delayed post-treatment and is

accompanied by heavy watering and 2) compare the performance of post-planting drench treatments (with the same products), and a novel granule treatment (HDCI 066), with the pre-planting treatments. A bio-insecticide (HDCI 067) applied pre-planting was also assessed.

The project also assessed application efficiency of Dursban WG drenches in a commercial nursery. With the likely removal of chlorpyrifos as a modular drench application efficiency (both in terms of mean dose and module-module variability) could become more significant.

At what point do cabbage root fly larvae cease to be a threat to swede crops at the end of the season?

The method used most widely to minimize damage to swede crops by cabbage root fly larvae is to enclose the crops with fine mesh netting. This is because there are no effective methods of insecticidal control of either cabbage root fly adults or larvae available currently. In recent years, Scottish growers in particular have asked when it is safe to remove crop covers from swede crops in late summer/autumn. This is often desirable to maximise crop development at the end of the season.

There has never been any experimental work to determine what happens to the larvae arising from eggs laid very late in the season i.e. do they develop sufficiently to cause economic damage or do they perish as temperatures fall. Some work of this nature was undertaken on carrot fly many years ago and indicated that larvae hatching from eggs laid late in the season (by third generation flies) did not receive sufficient heat units (day-degrees) to develop into damaging larvae, so control of the later flies was unnecessary. It is not clear whether the same is true for cabbage root fly.

The objectives of the project were to:

1. Assess the performance of pre-planting module drench treatments with Tracer, Dursban and a novel product (evaluated in the SCEPTRE project) under 'normal' and 'sub-optimal' conditions i.e. when planting is delayed post-treatment, accompanied by heavy watering.
2. Compare the performance of post-planting drench treatments (with the same products), and a novel granule treatment, with the pre-planting treatments.
3. Assess the application efficiency of module drench treatments in a commercial nursery. With the likely removal of chlorpyrifos as a modular drench application efficiency (both in terms of mean dose and module-module variability) could become more significant.

4. Determine when cabbage root fly larvae cease to be a threat to swede crops at the end of the season.

Materials and methods

Objectives 1 and 2 - field trials

1. Assess the performance of pre-planting module drench treatments with Tracer, Dursban and a novel product (evaluated in the SCEPTRE project) under 'normal' and 'sub-optimal' conditions i.e. when planting delayed post-treatment.
2. Compare the performance of post-planting drench treatments (with the same products), and a novel granule treatment, with the pre-planting treatments.

Cabbage root fly numbers (yellow water traps) and egg-laying (plant sampling) were monitored in swede and cauliflower crops respectively at Warwick Crop Centre, Wellesbourne. Two trials (1 and 2) were conducted near to the monitoring plots. One was timed to coincide with the peak of first generation cabbage root fly egg-laying and the other with the peak of second generation egg-laying. For both trials the crop investigated was cauliflower and there were 11 insecticide treatments (Table 1), one of which was a biological treatment.

The trial was laid out as a balanced row and column design with 4 rows and 12 columns and treatments were replicated 4 times. Each plot was 3.5 m x 1 bed (1.83 m wide) and there were 4 rows per bed. The plants were spaced at 50 cm along rows and 35 cm between rows. In total, each plot contained 32 plants.

The cauliflower seed (cv Skywalker, Elsoms Seeds) was sown in 308 Hassy trays on 19 March 2014 (Trial 1) and 20 May 2014 (Trial 2). Six trays were sown with insecticide-free seed. All of the trays were placed in a greenhouse. Drench treatments were applied using a 1 ml automatic pipette at various times (Table 2) according to the treatment schedule. Treatments were washed onto the modules with an equivalent volume of water. The modules treated 14 days before planting (T5, T6 and T7) were additionally subjected to 4 heavy watering events 4 hours, 2 days, 4 days and 6 days after treatment. All other watering was applied from below via capillary matting.

The granule treatment (T11) was applied in furrow, just below the soil surface, immediately before planting using a modified Stanhay seed drill. All plants were transplanted on 29

April 2014 (Trial 1) or 3 July 2014 (Trial 2). The post-planting treatments (T8, T9 and T10) were applied in 70 ml water, around the base of the plant, using a beaker.

Table 1 Treatments used in trials on cauliflower

	Product	a.i.	Application timing	Rate (product/1000 plants)	Watering
T1	Untreated				Maintain at moisture capacity with capillary matting
T2	Dursban WG	Chlorpyrifos	1 day pre-transplanting	6 g[1]	Maintain at moisture capacity with capillary matting
T3	Tracer	Spinosad	1 day pre-transplanting	12 ml[1]	Maintain at moisture capacity with capillary matting
T4	HDCI 065		1 day pre-transplanting	15 ml	Maintain at moisture capacity with capillary matting
T5	Dursban WG	Chlorpyrifos	14 days pre-transplanting	6 g[1]	Maintain at moisture capacity with capillary matting 4 x 3 l water/tray overhead 4 hours, 2, 4 and 6 days after treatment
T6	Tracer	Spinosad	14 days pre-transplanting	12 ml[1]	Maintain at moisture capacity with capillary matting 4 x 3 l water/tray overhead 4 hours, 2, 4 and 6 days after treatment
T7	HDCI 065		14 days pre-transplanting	15 ml	Maintain at moisture capacity with capillary matting 4 x 3 l water/tray overhead 4 hours, 2, 4 and 6 days after treatment
T8	Dursban WG	Chlorpyrifos	Post-transplanting	60g/100l[1] (=42 g)	Maintain at moisture capacity with capillary matting
T9	Tracer	Spinosad	Post-transplanting	12 ml	Maintain at moisture capacity with capillary matting
T10	HDCI 065		Post-transplanting	15 ml	Maintain at moisture capacity with capillary matting
T11	HDCI 066		Pre-planting In-furrow	10 kg/ha (=0.5 g/m row)	Maintain at moisture capacity with capillary matting
T12	HDCI 067		1 day pre-transplanting	120 ml	Maintain at moisture capacity with capillary matting

[1] Recommended rates

Table 2 Treatment dates in trials on cauliflower

	Product	a.i.	Application timing	Trial 1	Trial 2
T1	Untreated				
T2	Dursban WG	Chlorpyrifos	1 day pre-transplanting	29-Apr	02-Jul
T3	Tracer	Spinosad	1 day pre-transplanting	29-Apr	02-Jul
T4	HDCI 065		1 day pre-transplanting	29-Apr	02-Jul
T5	Dursban WG	Chlorpyrifos	14 days pre-transplanting	15-Apr	19-Jun
T6	Tracer	Spinosad	14 days pre-transplanting	15-Apr	19-Jun
T7	HDCI 065		14 days pre-transplanting	15-Apr	19-Jun
T8	Dursban WG	Chlorpyrifos	Post-transplanting	29-Apr	04-Jul
T9	Tracer	Spinosad	Post-transplanting	29-Apr	04-Jul
T10	HDCI 065		Post-transplanting	29-Apr	04-Jul
T11	HDCI 066		Pre-planting In-furrow	29-Apr	03-Jul
T12	HDCI 067		1 day pre-transplanting	29-Apr	02-Jul

Assessments

On 4 June (Trial 1) and 12 August (Trial 2), 12 cauliflower plants were sampled from the centre of each plot. After washing, the roots and stems of each plant were assessed for damage caused by cabbage root fly larvae. The stem covers the area of the plant above the module but below the soil surface. Root and stem damage were assigned a score based on the estimated surface area which had been visibly damaged due to feeding by larvae of the cabbage root fly. The scale used was 0 = no damage, 1 = 0 - 5%, 2 = 5 - 10%, 3 = 10 - 25%, 4 = 25 - 50% and 5 = >50%. The total plant weights (roots and foliage) were also recorded.

Objective 3: Assess the application efficiency of module drench treatments in a commercial nursery

Plant propagation modules treated with Dursban WG (chlorpyrifos) in commercial plant raising nurseries were sampled by Simon Jackson (Allium and Brassica Centre) after delivery to growers. Three sets of 50 samples were taken from different nurseries and/or different applications. Samples were frozen and transported to Warwick Cop Centre for analysis of chlorpyrifos residues. The treatment dates, sampling dates, crop, sampling details and nursery details are shown in Table 3.

Samples were allowed to defrost before analysis. Chlorpyrifos was extracted from individual modules by shaking with methanol (50 ml, HPLC grade). Samples were analysed by HPLC using a 10 cm C8 column, a mobile phase of 75:25 acetonitrile:water and flow rate

of 1.2 ml/min. Chlorpyrifos concentration was quantified by comparison with external standards. Mean dose and module-module variability were calculated.

Table 3 Samples details of plant propagation modules tested for chlorpyrifos concentration

Sample code	Dates		Nursery Code	Number of trays sampled from	Crop
	Treatment	Sampling			
1	25/7	28/7	A	Multiple	Broccoli
2	25/7	28/7	A	Multiple	Pointed cabbage
3	28/7	29/7	B	One	Broccoli

Objective 4: Determine when cabbage root fly larvae cease to be a threat to swede crops at the end of the season

Plant pots (6" plastic dumpy pots) containing a single harvested swede and back-filled with soil were inoculated with 100 newly-laid cabbage root fly eggs per pot. Twenty pots of swede per occasion were inoculated at intervals from 11 September until 20 November 2014. The pots were buried in a field plot and covered in insect-proof netting to exclude 'wild' cabbage root flies. The cover was removed on 12 January 2015. The pots from each inoculation date were sampled on 5 January, 4 February, 11 March and 23 April to determine the survival and life-stages of the insects. The insects were extracted by flotation.

Statistical analysis

All field trial analyses were performed using analysis of variance (ANOVA). Interpretations were made using the treatment means together with standard errors of the difference (SED) and least significance difference (LSD) values. There were 4 replicates of each treatment arranged in a balanced row and column design with 12 rows and 4 columns.

Results

Objectives 1 and 2 – field trials

Cabbage root fly activity

The numbers of eggs laid on cauliflower plants in the monitoring plot (cauliflower) are shown in Figure 1. First, second and third generation egg-laying peaked in mid May, mid July and early September respectively.

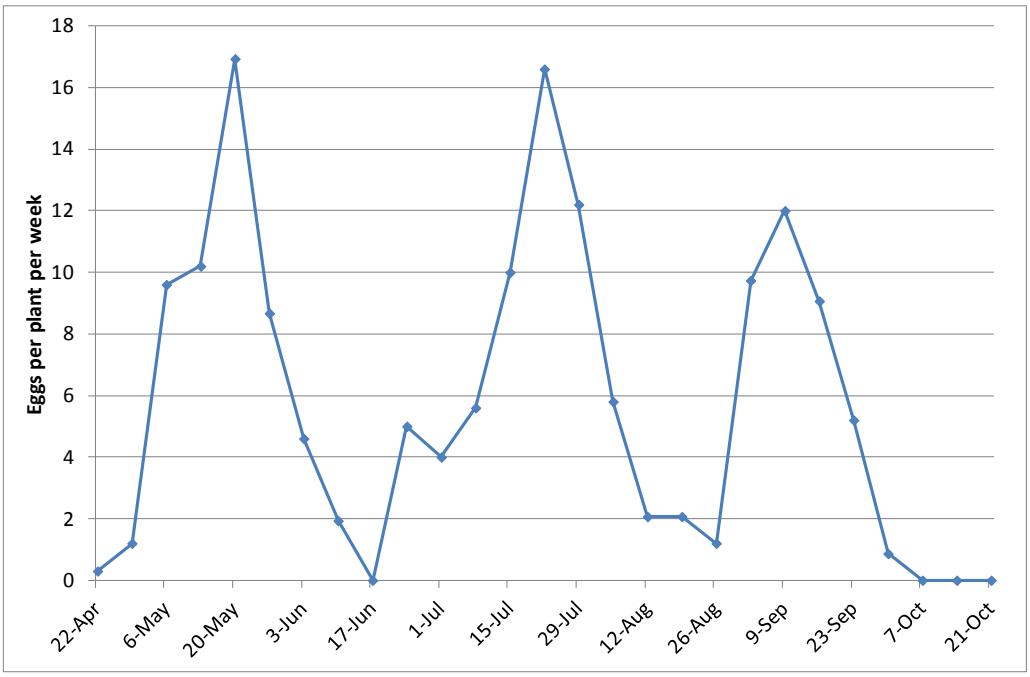

Figure 1 The numbers of cabbage root fly eggs laid per plant per week on cauliflower plants at Warwick Crop Centre, Wellesbourne in 2014

Phytotoxicity

None of the insecticide treatments had phytotoxic effects.

Mid-season assessments

No data transformations were required for any of the analyses (root damage, stem damage, plant weight).

Plant weight

In Trial 1, treatment had a statistically significant effect on plant weight. Plants from all treatments apart from HDCI 066 and HDCI 067 were heavier than the untreated plants. The plants from the Dursban WG and Tracer treatments applied 1-day before planting were heavier than those from all other treatments.

In Trial 2, the plants were much larger overall and there was no statistically significant effect of treatment on plant weight (foliage and root data analysed separately).

The results are summarised in Table 4 and Figure 2.

Table 4 Mean total plant weight in two cauliflower trials

	Treatment		Trial 1	Trial 2		
			Total plant	Foliage	Root	Total plant
T1	Untreated		20.37	307.2	21.83	329.03
T2	Dursban WG	1 day pre-transplanting	59.94	256.4	19.21	275.61
T3	Tracer	1 day pre-transplanting	55.62	304.4	22.88	327.28
T4	HDCI 065	1 day pre-transplanting	39.44	331.5	24.08	355.58
T5	Dursban WG	14 days pre-transplanting	38.94	365.6	26.58	392.18
T6	Tracer	14 days pre-transplanting	36.21	360.3	26.25	386.55
T7	HDCI 065	14 days pre-transplanting	40.86	352.8	21.33	374.13
T8	Dursban WG	Post-transplanting	44.1	302.5	23.04	325.54
T9	Tracer	Post-transplanting	34.29	292.7	20.96	313.66
T10	HDCI 065	Post-transplanting	38.96	308.6	21.96	330.56
T11	HDCI 066	Pre-planting In-furrow	25.29	333.1	21.79	354.89
T12	HDCI 067	1 day pre-transplanting	29.85	318.8	23.13	341.93
p			<0.001	0.201	0.219	
df			30	30	30	
LSD (5%)			9.758	74.79	5.138	

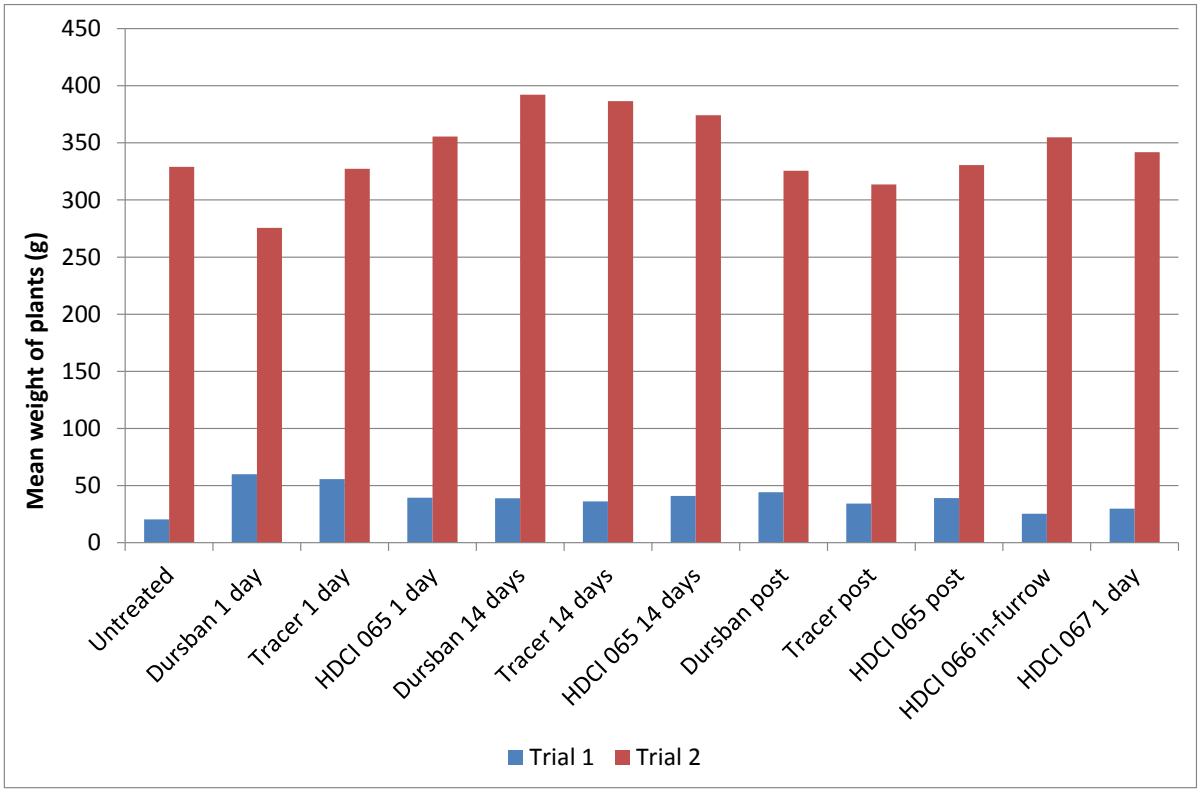

Figure 2 Mean weight of plants in Trials 1 and 2.

Root damage

In Trial 1, all of the treatments except T11 (HDCI 066 Pre-planting In-furrow) decreased root damage compared with the untreated control ($p<0.05$). Of the 'better' treatments, the Dursban WG treatments and the pre-planting treatments with Tracer or HDCI 065 were equally effective ($p<0.05$). The post-transplanting treatment with Tracer was less-effective than the post-transplanting treatment with HDCI 065 or the treatment with HDCI 067 ($p<0.05$).

In Trial 2, the reduction in damage due to all of the insecticide treatments was less pronounced than in Trial 1. However, as in Trial 1, all of the treatments except T11 (HDCI 066 Pre-planting In-furrow) decreased root damage compared with the untreated control ($p<0.05$). Of the 'better' treatments, the 1-day pre-transplanting treatments with Dursban WG, Tracer or HDCI 065, the 14-day pre-transplanting treatments with HDCI 065 or Tracer and the post-transplanting treatment with Dursban WG were equally effective ($p<0.05$).

The results are summarised in Table 5 and Figure 3.

Table 5 Root damage score in two cauliflower trials

	Treatment		Trial 1	Trial 2
T1	Untreated		2.96	2.02
T2	Dursban WG	1 day pre-transplanting	0.02	0.63
T3	Tracer	1 day pre-transplanting	0.09	0.90
T4	HDCI 065	1 day pre-transplanting	0.05	0.90
T5	Dursban WG	14 days pre-transplanting	0.00	1.08
T6	Tracer	14 days pre-transplanting	0.06	1.00
T7	HDCI 065	14 days pre-transplanting	0.00	0.75
T8	Dursban WG	Post-transplanting	0.02	0.71
T9	Tracer	Post-transplanting	1.15	1.27
T10	HDCI 065	Post-transplanting	0.69	1.08
T11	HDCI 066	Pre-planting In-furrow	2.77	1.85
T12	HDCI 067	1 day pre-transplanting	0.65	1.02
p			<0.001	<0.001
df			30	30
LSD			0.4809	0.3176

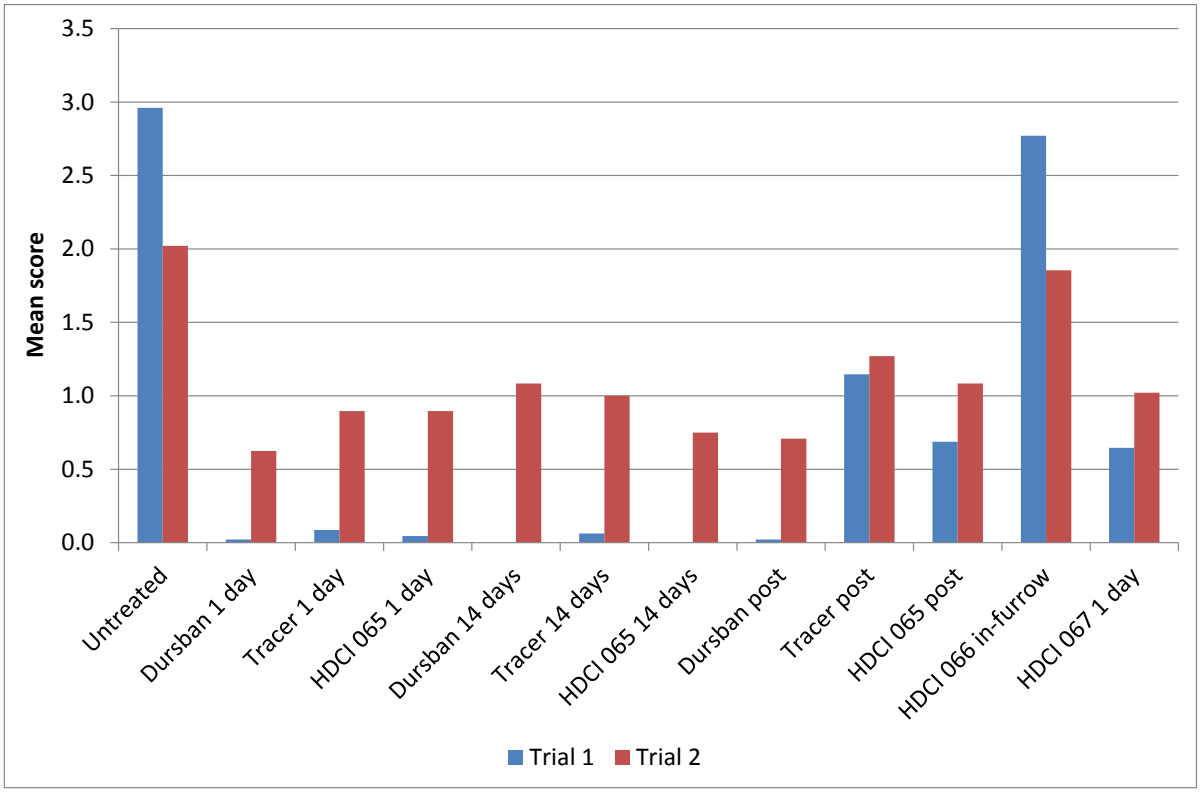

Figure 3 Root damage score in Trials 1 and 2.

Stem damage

In Trial 1, all of the treatments except those with HDCI 066 or HDCI 067 reduced stem damage compared with the untreated control ($p<0.05$). Of the 'better' treatments, the treatments with Dursban WG and the 14-day pre-transplanting and post-transplanting treatments with HDCI 065 were equally effective. In Trial 2, the 1-day pre-transplanting treatments with Dursban WG, Tracer and HDCI 065 and the post-planting treatments with Dursban WG and Tracer all reduced stem damage compared with the untreated control ($p<0.05$). Of the 'better' treatments, the 1-day pre-transplanting treatments with Dursban WG, Tracer and HDCI 065 and the post-planting treatment with Dursban WG were all equally effective ($p<0.05$).

The results are summarised in Table 6 and Figure 4.

Table 6 Stem damage score in two cauliflower trials.

	Treatment		Trial 1	Trial 2
T1	Untreated		2.19	1.56
T2	Dursban WG	1 day pre-transplanting	0.22	0.85
T3	Tracer	1 day pre-transplanting	1.31	0.92
T4	HDCI 065	1 day pre-transplanting	0.86	0.90
T5	Dursban WG	14 days pre-transplanting	0.08	1.46
T6	Tracer	14 days pre-transplanting	1.31	1.06
T7	HDCI 065	14 days pre-transplanting	0.53	1.21
T8	Dursban WG	Post-transplanting	0.17	0.29
T9	Tracer	Post-transplanting	1.08	1.02
T10	HDCI 065	Post-transplanting	0.63	1.04
T11	HDCI 066	Pre-planting In-furrow	1.75	1.92
T12	HDCI 067	1 day pre-transplanting	1.79	1.58
p			<0.001	<0.001
df			30	36
LSD (5%) (one-sided)			0.5646	0.5751

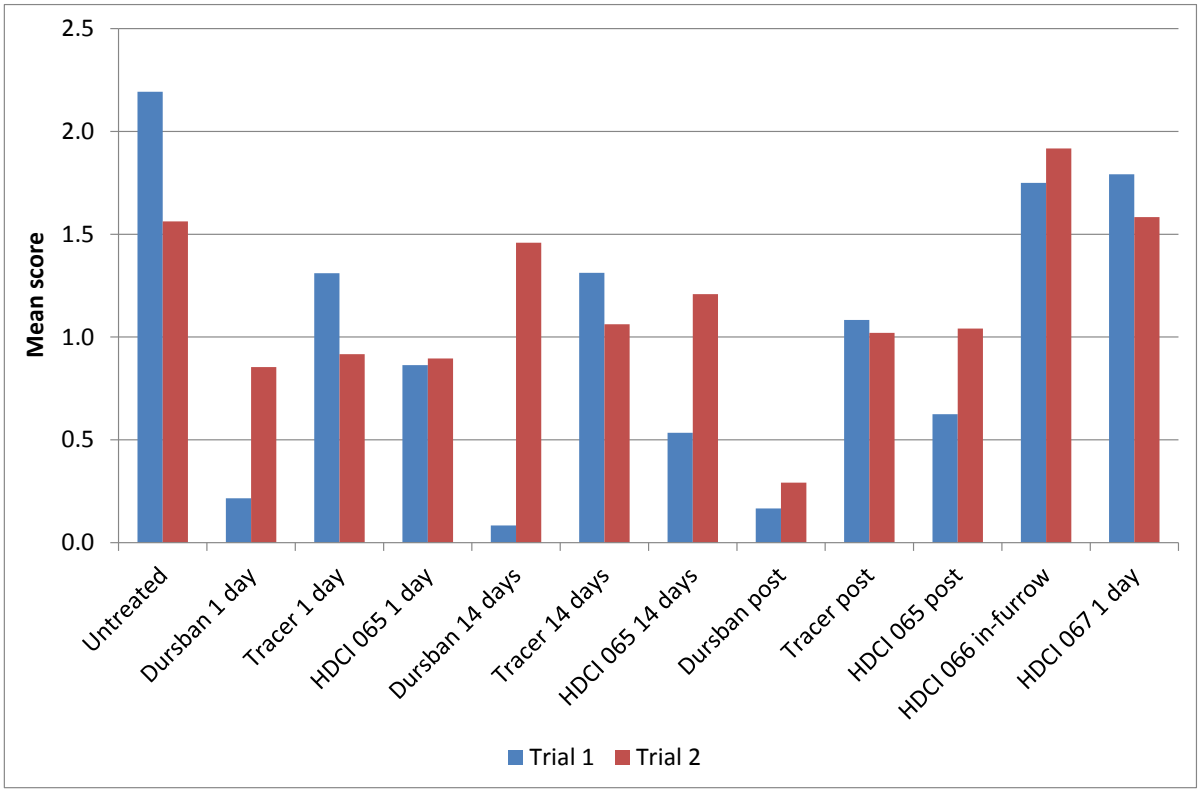

Figure 4 Stem damage score in Trials 1 and 2.

Objective 3: Assess the application efficiency of module drench treatments in a commercial nursery.

The rate of application of Dursban WG to modules pre-planting is 30 g product per 5000 modules which equates to 4.5 mg chlorpyrifos per module. Results from the three samples tested (Table 7 and Figures 5-7) show that in two samples this mean dose was not achieved (samples 1 and 3) and in one it was exceeded (sample 2). Achieved doses were 66, 138 and 61% of target with 22, 48 and 16% of modules having the target dose +/- 20% in samples 1 to 3 respectively. However, the coefficient of variation between modules was similar for the three samples (49.2 – 55.8%)

Table 7 Summary of chlorpyrifos residue in peat modules results

Sample code	Dose (mg/module)		Standard deviation	Coefficient of variation (%)	Percentage of modules +/- 20% of target
	Mean	Range			
1	2.97	0.78 – 7.40	1.462	49.2	22
2	6.23	2.32 – 15.39	3.477	55.8	48
3	2.75	0.76 – 7.65	1.388	50.4	16

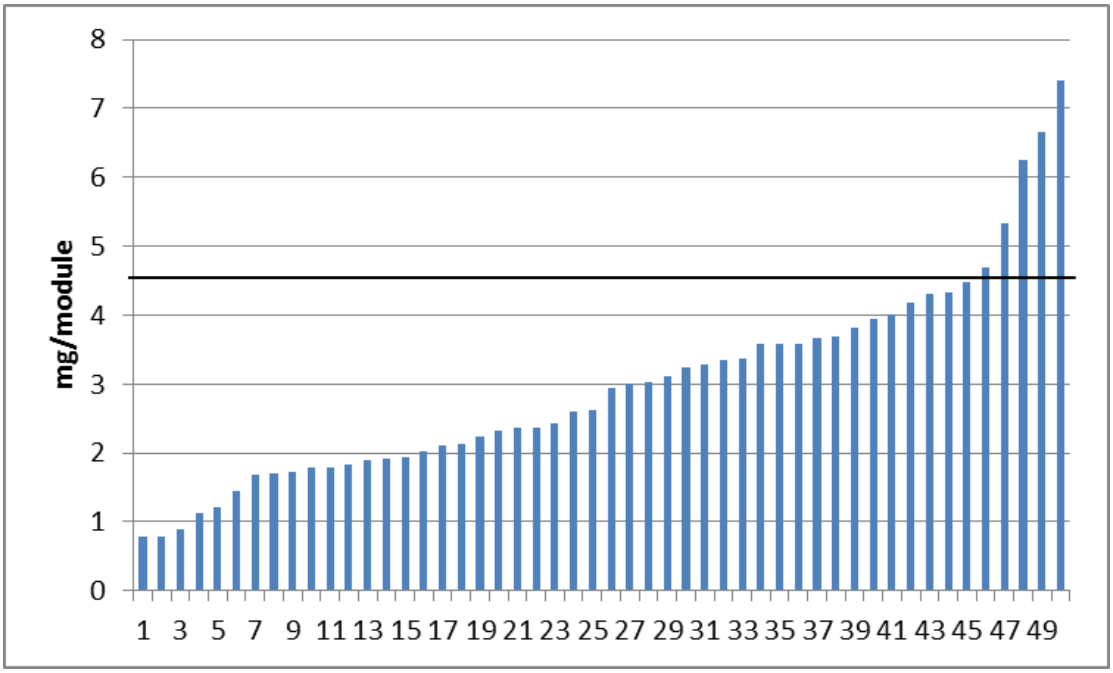

Figure 5 Chlorpyrifos residues in peat modules – Sample 1 (Nursery A)

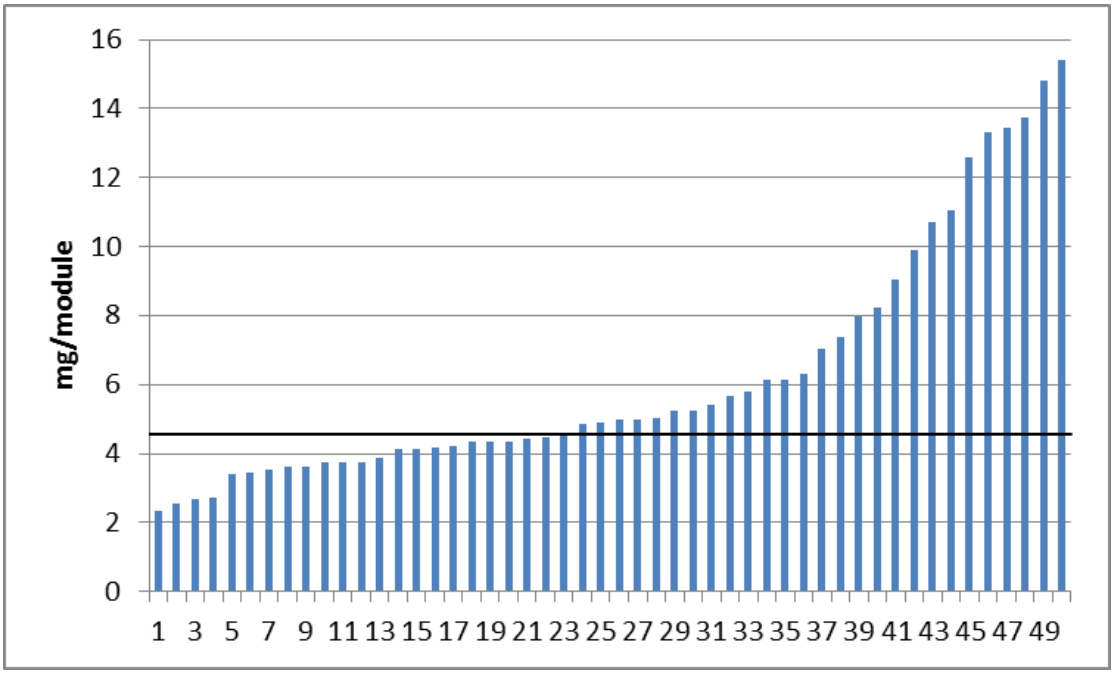

Figure 6 Chlorpyrifos residues in peat modules – Sample 2 (Nursery A)

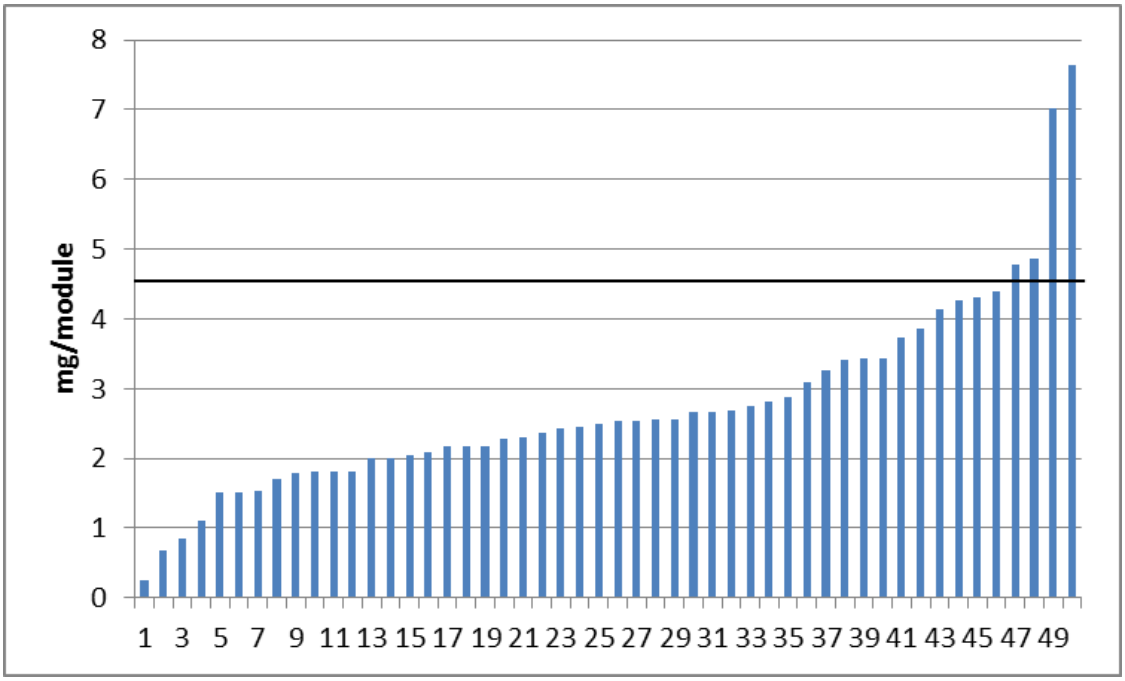

Figure 7 Chlorpyrifos residues in peat modules – Sample 3 (Nursery B)

Objective 4: Determine when cabbage root fly larvae cease to be a threat to swede crops at the end of the season

The first samples were taken in early January (5 pots per treatment). Further samples were taken in February, March and April (sampling dates were 5 January, 4 February, 11 March and 23 April). Figure 8 shows the total numbers of pupae recovered from each inoculation date on each sampling date. There was considerable variation from pot to pot in the numbers of insects recovered. From January onwards, relatively large numbers of pupae (approximately 25-30% of eggs inoculated) were recovered from pots inoculated up to mid October. However, in January, no pupae were recovered from the pots inoculated in November and this was also the case for the pots sampled in February. During March and April, larger numbers of pupae were recovered from the pots inoculated in November; these pupae were relatively small in size, indicating a 'poor diet'. In April, some of the pupae recovered from the pots were not cabbage root fly pupae and were most likely to be predatory fly pupae (*Phaonia* spp.). These are not included in Figure 8.

The numbers of larvae recovered (second or third instar) were generally low overall, with the exception of the pots inoculated on 29 October and sampled in January and February (Figure 9). As with the total number of insects, very few or no larvae were recovered in January or February from the pots inoculated in November. The numbers increased in

samples in March and April. However, In April these were not cabbage root fly larvae and were most likely to be predatory fly larvae (*Phaonia* spp.). These are not included in the data on total number of larvae shown in Figure 9.

The mean damage score declined gradually with later inoculation date (Figure 10). No swedes were recovered in April; they had all rotted.

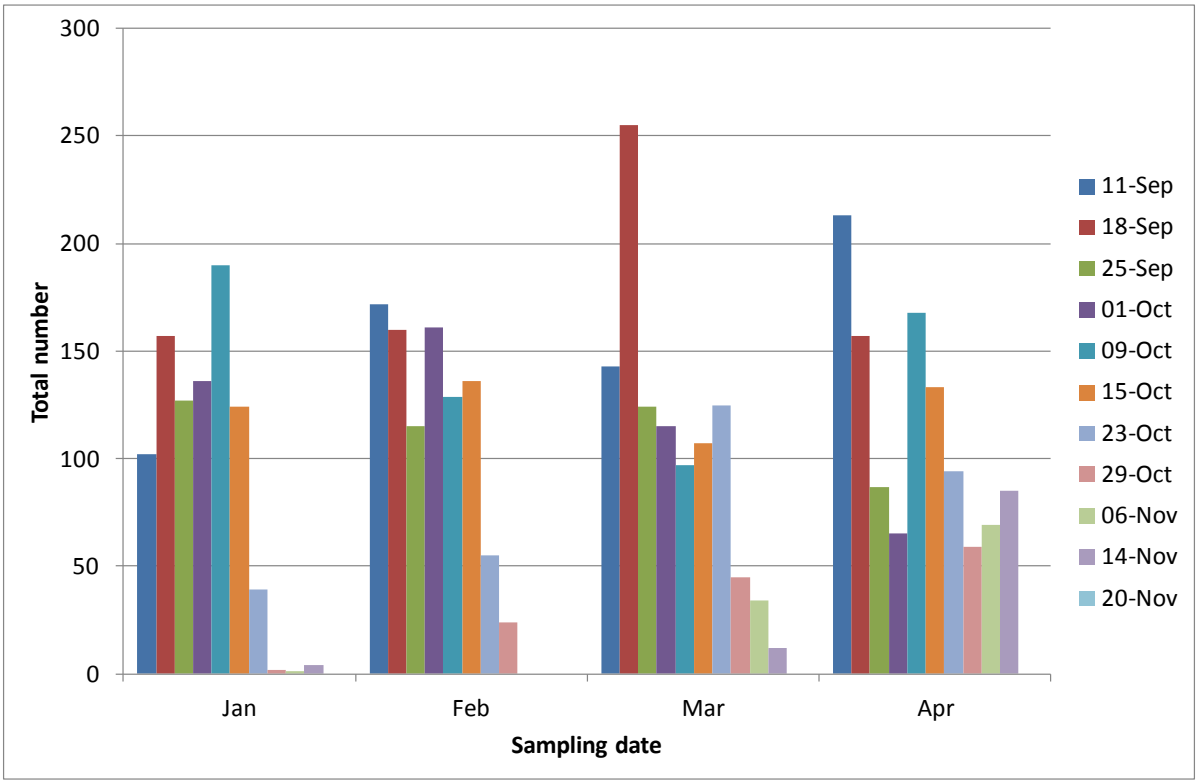

Figure 8 Number of pupae recovered on four sampling occasions from swede roots inoculated with 100 cabbage root fly eggs on dates from 11 September to 20 November 2014.

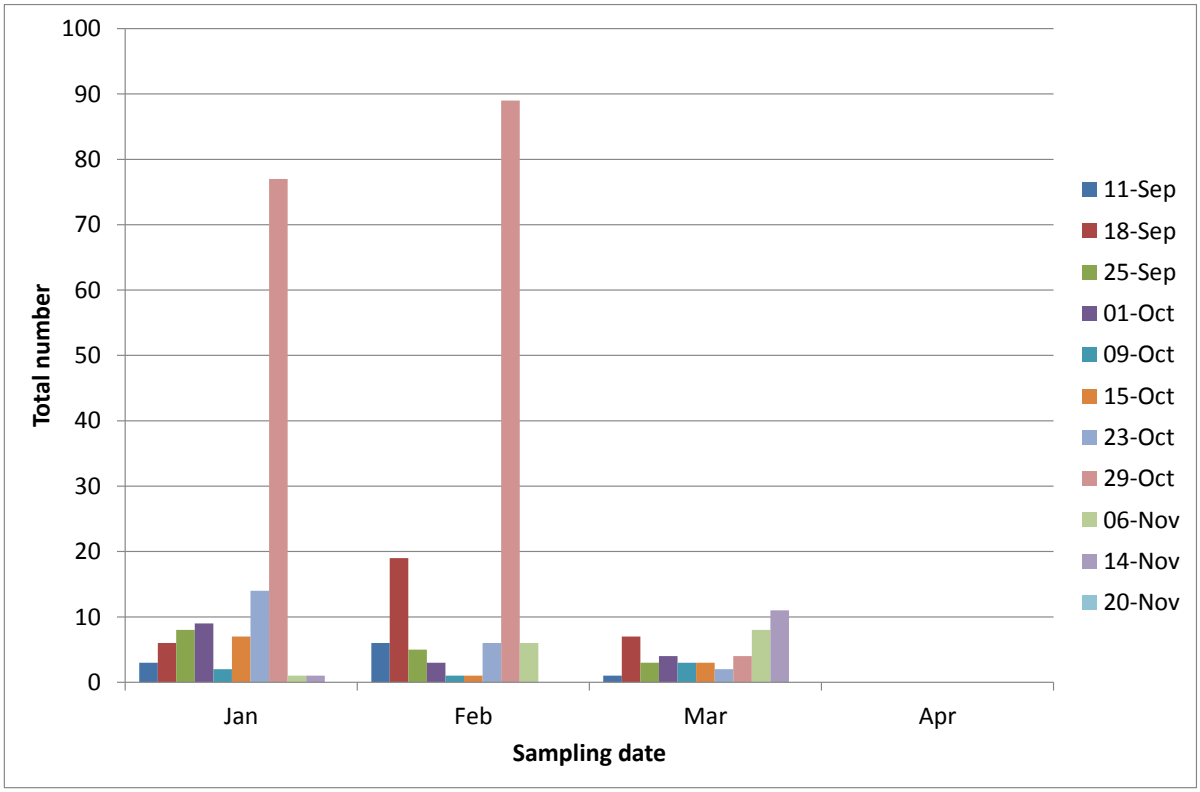

Figure 9 Number of larvae in samples recovered on four sampling dates from swede roots inoculated with 100 cabbage root fly eggs on dates from 11 September to 20 November 2014. Larvae found in April were not cabbage root fly and so are not included.

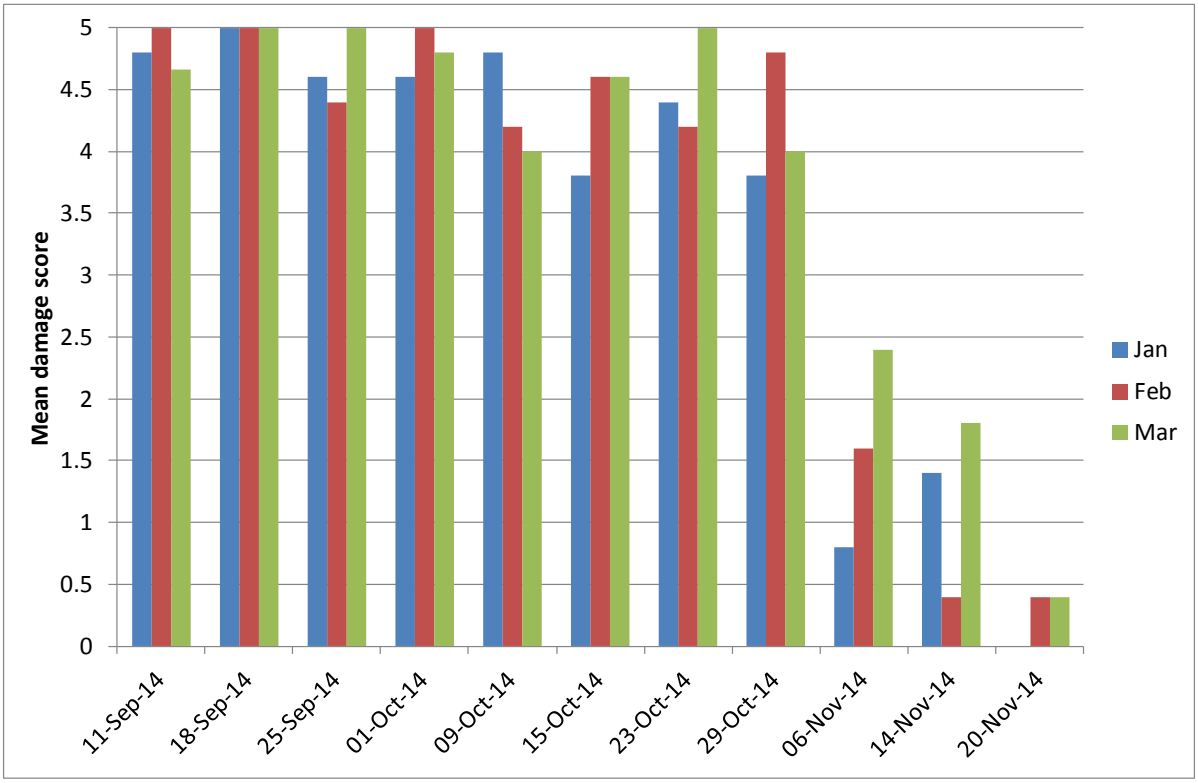

Figure 10 Damage to swede roots (score 0-5) on 3 sampling dates on roots inoculated with 100 cabbage root fly eggs on dates from 11 September to 20 November 2014.

Finally Figure 11 shows the soil temperature (10 cm depth) from September 2014 to April 2015, expressed as accumulated day-degrees above either 4°C or 6°C (this was recorded using a weather station managed by Plantsystems and located close to the Met Office weather station at Wellesbourne). This is the temperature range below which development of cabbage root fly is likely to cease (low temperature threshold). Where the lines are close to horizontal indicates when cabbage root fly development is likely to have ceased. The soil temperature at this depth did not go below zero. In broad terms, cabbage root fly requires 50 day-degrees above 6°C from egg laying to egg hatch and a further 250 day-degrees to pupation.

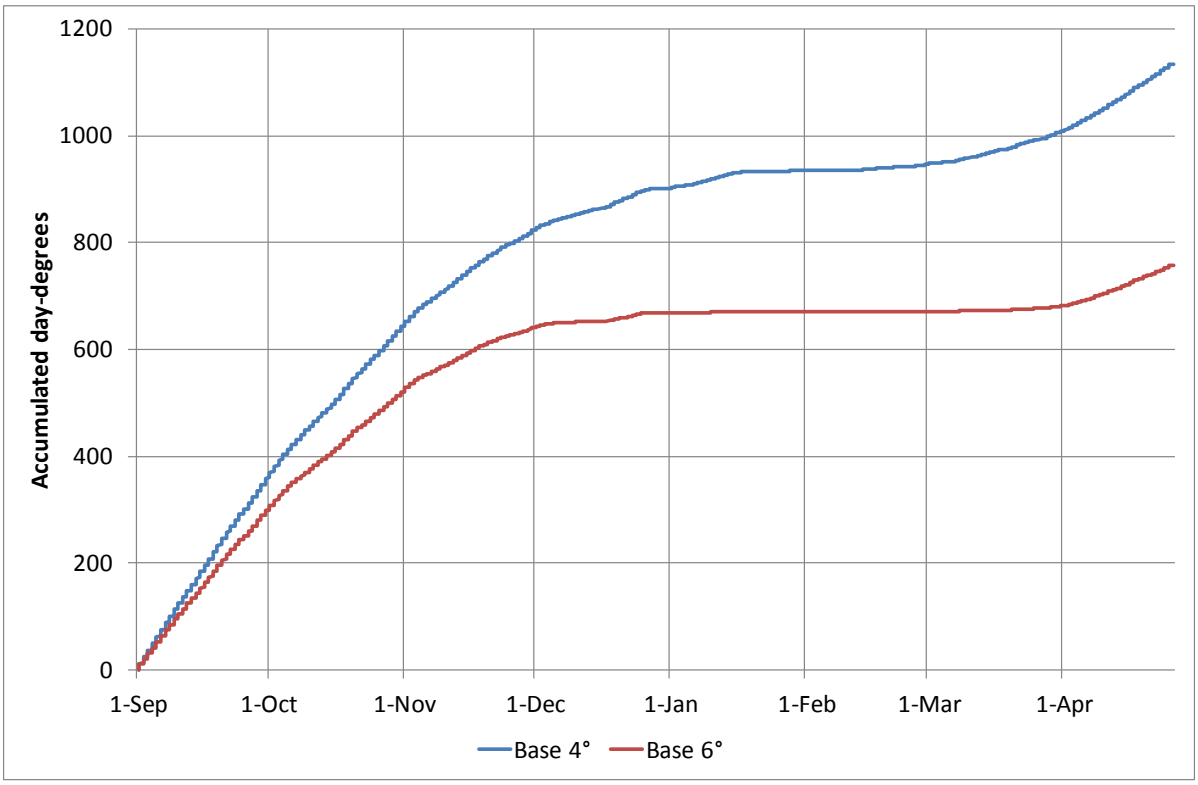

Figure 11 Accumulated day-degrees in the soil (10 cm deep) above either 4°C or 6°C

Interpretation

From the soil temperature data (Figure 11), cabbage root fly development would have been able to continue until at least early December. This enabled most of the insects in pots inoculated up to 23 October to complete development to the pupal stage and spend the winter as diapausing pupae. The insects in pots inoculated on 29 October managed to complete most of their larval development and a few reached the pupal stage, but then they spent the coldest part of the winter as large larvae, before pupating by the March sampling date (when temperatures were beginning to rise). All of these insects caused considerable damage to the swede roots.

Very few insects were recovered in January and February from the pots inoculated in November and the swede roots suffered little damage. However, by March, larger numbers of pupae were recovered from these pots. By this time the swede roots had rotted so it was not possible to assess damage.

Discussion

Objectives 1 and 2: Assess the performance of pre-planting module drench treatments with Tracer, Dursban and a novel product (evaluated in the SCEPTRE project) under 'normal' and 'sub-optimal' conditions i.e. when planting delayed post-treatment and compare the performance of post-planting drench treatments (with the same products), and a novel granule treatment, with the pre-planting treatments.

The efficacy of the test insecticides was assessed 36 and 40 days after planting (Trials 1 and 2), which is after the critical period for plant establishment, and was tested, in separate trials, against the first and second generations of the cabbage root fly. In both trials, all of the treatments, with the exception of HDCI 066, which was applied as a pre-planting in-furrow treatment, reduced root damage by cabbage root fly. Results suggest that if root damage alone is considered then there is little difference between the pre-planting treatments of Dursban WG, Tracer or HDCI 065, irrespective of when the plants were treated. However, the post-planting treatment with Dursban WG (for which there is a recommended rate which equates to 7 times the pre-planting rate) was more effective than either Tracer or HDCI 065 (both of which do not have recommended field application rates so the pre-planting rate was used). It is worth noting that HDCI 067, which is a biopesticide, reduced root damage in both trials when applied as a drench one day before transplanting.

When considering stem damage, which covers the area of the plant above the module but below the soil surface, Dursban WG was consistently effective at reducing damage when applied either 1-day before transplanting or post-transplanting. Some of the treatments with either Tracer or HDCI 065 also reduced stem damage and this variability in performance is consistent with the results of other trials. Neither HDCI 066 or HDCI 067, as applied in these trials, reduced stem damage.

It is worth noting that although the plants in Trials 1 and 2 were assessed for damage at similar times from the planting date (36 and 40 days after planting respectively), the plants in Trial 2 were much larger and the treated plots suffered a relatively lower level of damage compared to the untreated control. The difference in plant size probably reflects the better growing conditions during the later trial, particularly temperature, and the smaller difference between treated and untreated plots indicates that the plants were probably 'growing away' from the damage at that point.

Objective 3 Assess the application efficiency of module drench treatments in a commercial nursery.

Despite coming from different plant raising nurseries and being sampled at different time intervals after treatment, two of the three samples tested (both were broccoli) were very similar in the mean dose and module-module variation achieved. However, this was only 61-66% of the target dose with module-module variation of about 50%. Some modules in both samples had doses so low they would be unlikely to control cabbage root fly even partially.

In contrast, the other sample, containing pointed cabbage, which had come from the same plant raising nursery as one of the broccoli samples and was treated and sampled on the same day had a mean dose 138% of the target. In this sample the dose was so high in some modules it would almost certainly have been phytotoxic, leading to stunted plant growth at best or potentially even plant death if the plants were stressed in dry weather conditions. Interestingly, despite the much higher dose the module-module variation was very similar to the other two samples.

Objective 4: Determine when cabbage root fly larvae cease to be a threat to swede crops at the end of the season

The experimental method used was successful in providing quite large numbers of cabbage root fly larvae and pupae to determine the influence of inoculation date on survival, development stage and level of damage. However, there was considerable variation from pot to pot in the numbers of insects recovered. A larger number of replicates might have 'smoothed out' this variation to a greater extent.

When the pots were sampled in early January 2015, relatively large numbers of larvae and/or pupae were recovered from pots inoculated up to the end of October and, for inoculation dates before 29 October, almost all of these were pupae. The mean damage score was quite high for inoculation dates until the end of October. Thus it appears that eggs laid up to the end of October (at least in 2014) constitute a threat to swede crops in central England. In fact, in 2014, no eggs were recovered from the cauliflower monitoring plots after the end of September so the actual threat from the wild population of cabbage root fly ceased a month earlier.

Few larvae or pupae were recovered from pots inoculated after October when they were sampled in January or February and it was assumed that the eggs/larvae in the pots

inoculated in November had died. However, when the remaining pots were sampled in March and April, larger numbers of pupae were recovered from the pots inoculated in November, indicating that they had survived the winter, probably as small larvae. These would not have been detected in the pots sampled in January-February with the sampling method used. The pupae from pots inoculated in November were relatively small in size, indicating that the conditions for development were not 'ideal'. This suggests that these insects overwintered, probably as small larvae, in arrested development and were able to continue development once the temperature rose in the spring. Whilst this may not be immediately important for growers it may indicate the capacity of the immature stages to survive the winter.

Conclusions

- Tracer-treated or HDCI 065-treated plants can be held on nurseries and with exposure to heavy watering for at least 2 weeks without significant reduction in performance compared with Dursban WG.
- Tracer and HDCI 065 applied pre-planting are as effective as Dursban WG in control of damage in the root zone irrespective of treatment time.
- Tracer and HDCI 065 were less effective than Dursban WG at controlling damage in the stem zone (between the module and the soil surface).
- The bio-insecticide HDCI 067 was reasonably effective in the root zone as a pre-planting treatment but ineffective in the stem zone.
- The granule HDCI 066 was ineffective when applied in-furrow pre-planting
- In commercial situations, the amount of Dursban WG applied to individual modules pre-planting may be very variable. Further more extensive research work is necessary to determine if the variability seen is due to sampling procedure used and if variability is proven then the possible reasons for it.
- Eggs laid up to the end of October 2014 constituted a threat to swede crops in central England. In fact, in 2014, no eggs were recovered from the cauliflower monitoring plots at Wellesbourne after the end of September so the actual threat from the wild population of cabbage root fly ceased a month earlier.
- Immature cabbage root flies overwintered, probably as larvae, and were able to continue development once the temperature rose in the spring. Whilst this may not be immediately important for growers it may indicate the capacity of the immature stages to survive the winter.

Knowledge and Technology Transfer

28 January 2015	Presentation at UK Brassica and Leafy Salads Conference
Spring 2015	Article in HDC News

Acknowledgements

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