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| **Project title:** | Optimising carrot fly control using pyrethroids and Coragen® |
| **Project number:** | FV 414 |
| **Project leader:** | Dr Rosemary Collier<br>Warwick Crop Centre<br>School of Life Sciences<br>The University of Warwick |
| **Report:** | Final report, March 2014 |
| **Previous report:** | None |
| **Key staff:** | Rosemary Collier – project management<br><br>Andrew Jukes – establishment of field trial and data collection<br><br>Marian Elliott – insect rearing and data collection<br><br>Julie Jones – experimental design and analysis |
| **Location of project:** | Warwick Crop Centre, Wellesbourne, Warwick, CV35 9EF |
| **Industry Representative:** | Mr Ian Hall, Tompsett Burgess Growers Limited |
| **Date project commenced:** | 1 May 2013 |
| **Date project completed** | 31 March 2014 |

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[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
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Signature ..... Date .....

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## *GROWER SUMMARY*

### Headline

A single spray of Coragen® can persist for at least 6 weeks but is insufficient, on its own, to provide more than about a 25% reduction in damage. Two sprays of Coragen® timed 1 week before carrot fly emergence and 3 weeks after, or at 0 and 2 weeks after emergence, offered similar levels of damage reduction to a full pyrethroid programme. Timing of Coragen® applications may not be as critical as Hallmark applications but they should be applied at the start of a programme to get maximum benefit from these treatments.

### Background

An authorisation for the use of `Coragen®` on carrots was approved following an application submitted to the UK regulators by the HDC. The EAMU (0615/2012) was emailed to growers on 24 April 2012. This new EAMU (formerly SOLA), permits the use of 'Coragen®' (active ingredient DuPontT Rynaxypyr® chlorantraniliprole) as an insecticide for controlling carrot fly on carrot.

For nearly 20 years, carrot fly (*Psila rosae*), has been controlled effectively using pyrethroid insecticides, applied either as seed treatments or foliar sprays (lambda-cyhalothrin, deltamethrin, tefluthrin seed treatments). Whilst there is no evidence that populations of carrot fly have become resistant to pyrethroids, the addition of this new active offers industry another tool to control this pest and could reduce the risk of resistance developing through reliance on just one group of insecticides.

In HDC-funded trials (FV 312 and FV 375) looking at the control of carrot fly, Rosemary Collier and Andrew Jukes of Warwick Crop Centre demonstrated that programmes containing Coragen® provided levels of control that were at least as effective as, and sometimes better than, the standard insecticide programme used in the trials. As this is a new active for carrot growers, a summary document was produced in May 2012 to summarise the results from HDC projects FV 312 and FV 375 and this was sent to growers.

However, Coragen® is more expensive than foliar sprays of pyrethroids and so it is important to work out where Coragen® would fit best in a spray programme for carrot fly control. In the projects FV 312 and FV 375, Coragen® was used in the same way as a

pyrethroid insecticide might be used in terms of timing and the intervals between treatments. However, there are indications that it may be possible to 'optimise' its use and this requires a better understanding of the activity and persistence of individual Coragen® treatments and therefore of the likely role of Coragen® in a full spray programme.

## Summary

Four trials were conducted. Two field trials investigated the persistence and timing of Coragen® sprays. In the laboratory, two trials were conducted to look at mortality of carrot fly adults and larvae after Coragen® sprays.

### *Field trials*

Both trials were conducted in a field adjacent to the field where a population of carrot fly (*Psila rosae*) is maintained. Carrot seed (cv Nairobi) was drilled on 4 June 2013 and the carrots were harvested on 12 November. The roots were classified into categories according to the extent of carrot fly damage. The damage categories were 0%, <5%, 5-10%, 10-25%, 25-50% and >50% of the surface area affected by carrot fly. These equate to damage scores of 0, 1, 2, 3, 4 and 5 respectively. The total weight of roots in each plot and the mean root weight were also recorded.

#### *Persistence trial*

After drilling, the whole trial was covered with horticultural fleece to exclude adult carrot flies. The trial contained 4 replicates of 5 treatments (4 spray treatments and an untreated control). On each spray occasion, Coragen® was applied at 175 ml product/ha in 300 l/ha water using a Knapsack sprayer. Single sprays were applied 6, 4, 2 and 0 weeks before exposure to carrot flies. The fleece was removed for spray applications then replaced immediately. After the final spray application the fleece was not replaced and the trial was left open to carrot fly invasion. Although not statistically-significant there was a clear reduction in damage as a result of all of the treatments compared to the untreated control, but there were no consistent differences between spray treatments, suggesting that Coragen® applied 6 weeks before exposure to flies was as effective as the Coragen® applied immediately before exposure to flies (Figure A).

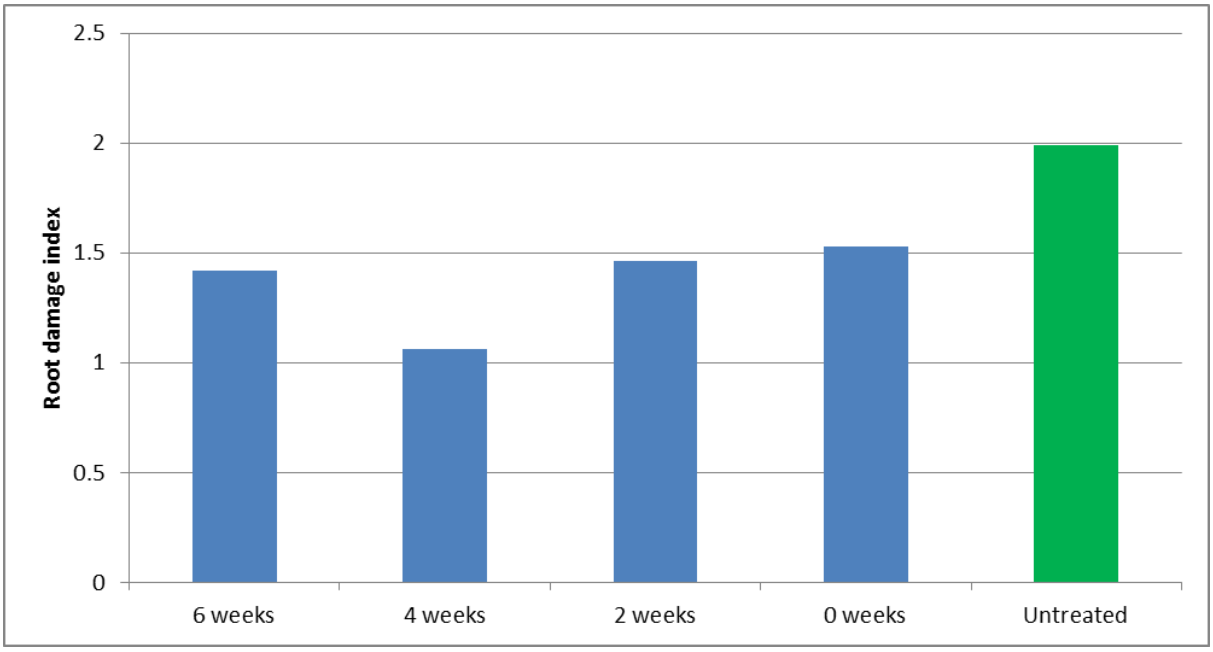


**Figure A** The mean Root Damage Index of carrot roots – persistence trial

*Timing trial*

The trial contained 4 replicates of 5 treatments (4 spray programmes and an untreated control). Spray timing was determined using the HDC carrot fly forecast. Week zero was taken as the forecasted date for 10% emergence of second generation carrot fly. The treatments included a full pyrethroid programme, a single spray of Coragen® and two two-spray Coragen® programmes (0 + 2 weeks and -1 + 3 weeks). All Coragen® sprays were applied at 175 ml product/ha and all sprays were applied in 300 l/ha water using a Knapsack sprayer. The analysis of root damage was statistically significant and there was a clear reduction in damage in all of the treatments compared to the untreated control. Coragen® (applied at -1 and 3 weeks), Coragen® (applied at 0 and 2 weeks) and the full pyrethroid programme had significantly less damage than the untreated control and the single spray of Coragen® but there were no statistically significant differences between either 2 spray Coragen® treatment and the full pyrethroid programme (Figure B).

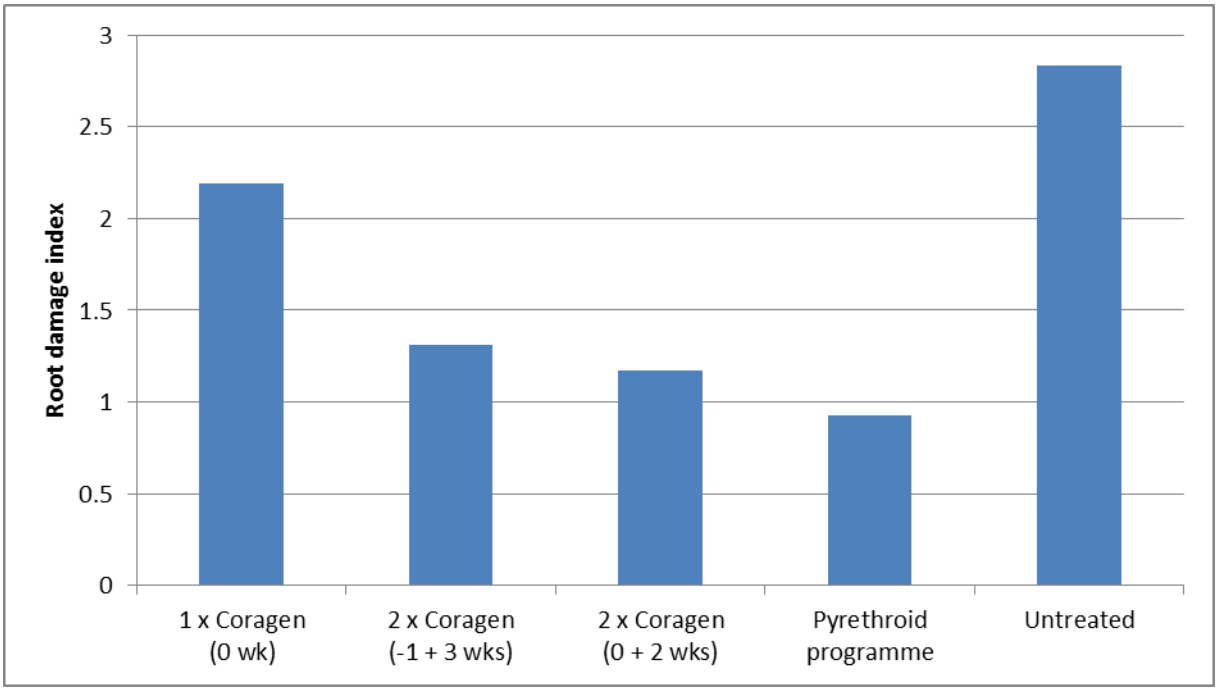


**Figure B** The mean Root Damage Index of carrot roots – timing trial.

### *Laboratory trials*

#### *Mortality of adult carrot flies exposed to Coragen® spray residues*

Field grown carrots were transplanted into 11 cm square pots (2 roots/pot) in M2 compost during January 2014 when the previous years' summer foliage had died-back. The plants were kept at 15$^{o}$C until approximately 50 mm of foliage had regrown. On three occasions five pots were taken outside and Coragen® was applied at 175 ml product/ha in 300 l/ha water using a Knapsack sprayer. The pots were transferred into insect cages (1 pot/cage) containing fresh water and sugar solution. Five untreated pots were placed in similarly prepared cages. Twenty laboratory-reared carrot fly were placed in each cage. Carrot fly mortality was assessed up to 7 days after spraying. Whilst Coragen® sprays increased adult mortality compared with untreated controls in some instances, the level of mortality was relatively low and results were variable.

*Mortality of carrot fly larvae exposed to Coragen® spray residues*

Carrot seeds (cv Nairobi) were sown in F2S compost and maintained at 18$^{o}$C until they had two true leaves. Fifty seedlings were transplanted into 7 cm square pots (1 plant/pot) containing sterile loam soil. The seedlings were allowed to grow to about 50 mm before treatments were applied. Before application of treatments the pots were inoculated with 5 carrot fly eggs obtained from a laboratory-reared culture. The treatments were targeted at either the foliage or the soil. To exclude treatments from the foliage, the plants were covered with 50 ml centrifuge tubes (supported on small sticks) and to exclude treatments from the soil, the soil surface was covered with tissue paper. The pots were taken outside and treatments were applied in 300 l/ha water using a Knapsack sprayer. Ten pots were treated with each treatment and the trial was done on two occasions. The treatments were either Coragen® at 175 ml/ha or Hallmark at 150 ml/ha. After spraying, the tubes and paper were removed and the pots were returned to the Insect Rearing Unit where they were maintained at 15$^{o}$C. Damage to the carrot roots and larval survival (number of pupae) were assessed and treatment differences for root damage were almost statistically significant (p=0.06). The treatment where Coragen® was applied to the soil appeared to be the most effective.

## Financial Benefits

Even a small amount of carrot fly damage can reduce the quality and value of a carrot crop. Whilst there is no evidence that populations of carrot fly have become resistant to pyrethroids, the addition of a new active with a different mode of action offers the industry another tool to control this pest and could reduce the risk of resistance developing through reliance on just one group of insecticides. However, Coragen® is more expensive than pyrethroid insecticides. This project confirms the efficacy of Coragen® and shows that there is potential to reduce the total number of spray treatments applied to the crop.

## Action Points

- A single spray of Coragen® can persist for at least 6 weeks but is insufficient, on its own, to provide more than about a 25% reduction in damage.
- Two sprays of Coragen® timed 1 week before carrot fly emergence and 3 weeks after, or at 0 and 2 weeks after emergence, offered similar levels of damage reduction to a full pyrethroid programme.
- Timing of Coragen® applications may not be as critical as Hallmark applications but they should be applied at the start of a programme to get maximum benefit from these treatments.
- In terms of insecticide resistance management, it is best practice to alternate treatments with different modes of action.

## *SCIENCE SECTION*

### Introduction

For over ten years, carrot fly (*Psila rosae*), has been controlled effectively using pyrethroid insecticides, applied either as seed treatments or foliar sprays (lambda-cyhalothrin, deltamethrin, tefluthrin seed treatments). Whilst there is no evidence that populations of carrot fly have become resistant to pyrethroids, the addition of a new active offers industry another tool to control this pest and could reduce the risk of resistance developing through reliance on just one group of insecticides. 'Coragen®' (active ingredient DuPont Rynaxypyr® chlorantraniliprole) has efficacy against carrot fly and has a different mode of action from pyrethroid insecticides. An authorisation for the use of Coragen® on carrots was approved following an application submitted to the UK regulators by the HDC. The EAMU (0615/2012) was emailed to growers on 24 April 2012. This new EAMU (formerly SOLA), permits the use of Coragen® as an insecticide for controlling carrot fly on carrot.

In HDC-funded trials (FV 312 and FV 375) looking at the control of carrot fly, Rosemary Collier and Andrew Jukes of Warwick Crop Centre demonstrated that programmes containing Coragen® provided levels of control that were at least as effective as, and sometimes better than, the standard insecticide programme used in the trials. As this is a new active for carrot growers, a summary document was produced in May 2012 to summarise the results from HDC projects FV 312 and FV 375 and this was sent to growers.

However, Coragen® is more expensive than foliar sprays of pyrethroids and so it is important to work out where Coragen® would fit best in a spray programme for carrot fly control. In the projects FV 312 and FV 375, Coragen® was used in the same way as a pyrethroid insecticide might be used in terms of timing and the intervals between treatments. However, there are indications that it may be possible to 'optimise' its use and this requires a better understanding of the activity and persistence of individual Coragen® treatments and therefore of the likely role of Coragen® in a full spray programme.

The aim of this project was to determine the best way to use Coragen® as part of a carrot fly control programme by gaining more information about its activity and persistence.

Four trials were conducted. Two field trials looked at persistence and timing of Coragen® spray treatments and two laboratory trials investigated whether Coragen® killed adult flies or larvae.

## Materials and methods

### *Field trials*

The numbers of carrot fly/trap/week were recorded in a nearby carrot fly monitoring plot in Long Meadow Centre at Warwick Crop Centre using orange sticky traps (Rebell®). The field trials were timed to avoid first generation flies and be exposed to second generation flies and resulting damage due to second generation larvae.

#### *Trial 1 – Coragen® persistence*

The study was conducted at Warwick Crop Centre, Wellesbourne within the field known as Long Meadow West which is adjacent to a field (Long Meadow Centre) where a population of carrot fly (*Psila rosae*) is maintained.

The field site and crop were maintained in a commercially acceptable condition. Weeds were kept to a minimum by the application of approved herbicides when required or by hand weeding. Irrigation was applied using oscillating lines when needed. No other insecticides or fungicides were applied.

The trial was designed by a qualified biometrician and the layout was a Trojan square for 5 treatments (4 spray treatments and an untreated control). The field plots were 3.5 m x 1 bed (1.83 m each) in size and there were 4 replicates of the 5 treatments. Plots were separated by 1 m along beds. Seed was drilled on 4 June 2013 at a spacing of 100 seeds/m within rows and 0.35 m between rows. Four rows were sown in each bed.

After drilling, the whole trial was covered with horticultural fleece to exclude adult carrot flies. The fleece was removed for spray applications and then replaced immediately. After the final spray application the fleece was not replaced and the trial was left open to carrot fly invasion.

On each spray occasion Coragen® was applied at 175 ml product/ha in 300 l/ha water using a Knapsack sprayer fitted with 3 x 02F110 nozzles. Sprays were applied at the times described in Table 1.1.

**Table 1.1** The spray timings used to assess the persistence of Coragen® applied to control carrot fly.

| Date | 17 June | 1 July | 15 July | 29 July |
|---|---|---|---|---|
| **Weeks before exposure to carrot fly** | **6** | **4** | **2** | **0** |
| **Treatment number** | | | | |
| 1 | Spray | | | |
| 2 | | Spray | | |
| 3 | | | Spray | |
| 4 | | | | Spray |
| 5 | Untreated | | | |

**Assessments**

A visual assessment of phytotoxicity was made 1 week after the first spray.

At harvest, carrot roots were taken from 1 m of row (0.5 m from each of the middle 2 rows) per plot (4 replicates per treatment), washed and placed in a cold store until they could be assessed for carrot fly damage. The harvest date was 12 November 2013. Data were collected on the numbers of roots per metre length of row, as well as classifying the roots into categories according to the extent of carrot fly damage. The damage categories were 0%, <5%, 5-10%, 10-25%, 25-50% and >50% of the surface area affected by carrot fly. These equate to damage scores of 0, 1, 2, 3, 4 and 5 respectively. The total weight of roots in each plot and the mean root weight were also recorded.

*Trial 2 – Coragen® timing*

The trial was conducted at Warwick Crop Centre, Wellesbourne within the field known as Long Meadow West, which is adjacent to a field (Long Meadow Centre) where a population of carrot fly (*Psila rosae*) is maintained.

The field site and crop were maintained in a commercially acceptable condition. Weeds were kept to a minimum by the application of approved herbicides when required or by hand weeding. Irrigation was applied using oscillating lines when needed. No other insecticides or fungicides were applied.

The trial was designed by a qualified biometrician and the layout was a Trojan square for 5 treatments (4 spray programmes and an untreated control). The field plots were 3.5 m x 1 bed (1.83 m each) in size and there were 4 replicates of the 5 treatments. Plots were separated by 1 m along beds. Seed was drilled on 4 June 2013 at a spacing of 100 seeds/m within rows and 0.35 m between rows. Four rows were sown in each bed.

Spray timing was determined using the HDC carrot fly forecast. Week zero was taken as the forecasted date for 10% emergence of second generation carrot fly.

Spray programmes were followed as described in Table 1.3 using the products specified in Table 1.2. A Knapsack Sprayer fitted with 3 x 02F110 nozzles was used with a spray rate of 300 l water/ha for all applications. The performance of Coragen® was compared with a standard pyrethroid programme.

**Table 1.2** The products used in the spray programmes to control carrot fly

| **Code** | **Product** | **Active Ingredient** | **Rate (ml product/ha)** |
|---|---|---|---|
| H 100 | Hallmark[1] | Lambda cyhalothrin | 100 |
| H 150 | Hallmark[1] | Lambda cyhalothrin | 150 |
| D 500 | Decis Protech | Deltamethrin | 500 |
| C 175 | Coragen® | Rynaxypyr | 175 |

[1]Hallmark with Zeon Technology

**Table 1.3** The spray programmes used to control carrot fly using the products shown in Table 1.2.

| **Date** | **31 Jul** | **06 Aug** | **20 Aug** | **27 Aug** | **03 Sep** | **17 Sep** | **01 Oct** | **15 Oct** |
|---|---|---|---|---|---|---|---|---|
| **Weeks from week zero** | **-1** | **0** | **1** | **2** | **4** | **6** | **8** | **10** |
| **Treatment** | | | | | | | | |
| 1 | | C175 | | | | | | |
| 2 | C175 | | | C175 | | | | |
| 3 | | C175 | C175 | | | | | |
| 4 | | H 150 | H 100 | | H 100 | H 100 | D 500 | D 500 |
| 5 | Untreated | | | | | | | |

**Assessments**

A visual assessment of phytotoxicity was made 1 week after the first spray.

At harvest, carrot roots were taken from 1 m of row (0.5 m from each of the middle 2 rows) per plot (4 replicates per treatment), washed and placed in a cold store until they could be assessed for carrot fly damage. The harvest date was 12 November 2013. Data were collected on the numbers of roots per metre length of row, as well as classifying the roots into categories according to the extent of carrot fly damage. The damage categories were 0%, <5%, 5-10%, 10-25%, 25-50% and >50% of the surface area affected by carrot fly. These equate to damage scores of 0, 1, 2, 3, 4 and 5 respectively. The total weight of roots in each plot and the mean root weight were also recorded.

## *Laboratory trials*

### *Trial 3 - Mortality of adult carrot flies exposed to Coragen® spray residues*

The trial was conducted at Warwick Crop Centre, Wellesbourne within the Insect Rearing Unit. Field grown carrots were transplanted into 11 cm square pots (2 roots/pot) in M2 compost during January 2014 when the previous years' summer foliage had died-back. The plants were kept at 15$^{o}$C until approximately 50 mm of foliage had regrown. On three occasions five pots were taken outside and Coragen® was applied at 175 ml product/ha in 300 l/ha water using a Knapsack sprayer fitted with 3 x 02F110 nozzles. The pots were transferred into insect cages (1 pot/cage) containing fresh water and sugar solution. Five untreated pots were placed in similarly prepared cages. Twenty laboratory-reared carrot fly were placed in each cage.

**Assessments**

Carrot fly mortality was assessed up to 7 days after spraying.

### *Trial 4 - To determine if carrot fly larvae are killed by Coragen® sprays*

This trial replaced a planned small field trial which did not succeed due to the extended emergence of carrot fly adults during the second generation in summer 2013.

The trial was conducted at Warwick Crop Centre, Wellesbourne within the Insect Rearing Unit. Carrot seeds (cv Nairobi) were sown in F2S compost and maintained at 18$^{o}$C until they had two true leaves.

Preliminary trial: Five 7 cm square pots containing sterile loam soil were taken outside and sprayed with Coragen® at 175 ml/ha in 300 l/ha water using a Knapsack sprayer fitted with 3 x 02F110 nozzles. One seedling was transplanted in to each pot and each pot was inoculated with 5 carrot fly eggs obtained from a laboratory-reared culture. Five untreated pots were prepared in the same way. The pots were maintained at 18$^{o}$C.

Main trial: Fifty seedlings were transplanted into 7 cm square pots (1 plant/pot) containing sterile loam soil. The seedlings were allowed to grow to about 50 mm before treatments were applied. Before application of treatments the pots were inoculated with 5 carrot fly eggs obtained from a laboratory-reared culture. The treatments were targeted at either the foliage or the soil. To exclude treatments from the foliage, the plants were covered with 50 ml centrifuge tubes (supported on small sticks) and to exclude treatments from the soil, the soil surface was covered with tissue paper. The pots were taken outside and treatments were applied in 300 l/ha water using a Knapsack sprayer fitted with 3 x 02F110 nozzles. Ten pots were treated with each treatment and the trial was done on two occasions. The treatments are described in Table 1.4. After spraying, the tubes and paper were removed and the pots were returned to the Insect Rearing Unit where they were maintained at 15$^{o}$C.

**Table 1.4** Treatments applied to pot grown carrots to determine if Coragen® kills carrot fly larvae.

| **Treatment number** | **Product** | **Active Ingredient** | **Rate (ml product/ha)** | **Target** |
|---|---|---|---|---|
| 1 | Hallmark | Lambda cyhalothrin | 150 | Soil |
| 2 | Hallmark | Lambda cyhalothrin | 150 | Foliage |
| 3 | Coragen® | Rynaxypyr | 175 | Soil |
| 4 | Coragen® | Rynaxypyr | 175 | Foliage |
| 5 | Untreated | | | |

*Assessments*

Plant mortality was assessed 4 weeks after spraying.

*Statistics*

All analyses of field trial data were carried out using Analysis of Variance (ANOVA) in the statistical package 'Genstat'. The analyses were interpreted using treatment means together with standard errors for the differences (SED) between means and associated 5% least significant differences (LSD). The laboratory data were analysed using Analysis of Variance (ANOVA) in EXCEL.

## Results

*Carrot fly activity*

Figure 2.1 shows the numbers of adult carrot flies (*Psila rosae*) captured on sticky traps in Long Meadow Centre. There was no clear peak of activity at the time of the second generation and a relatively low level of fly activity occurred over a prolonged period of time.

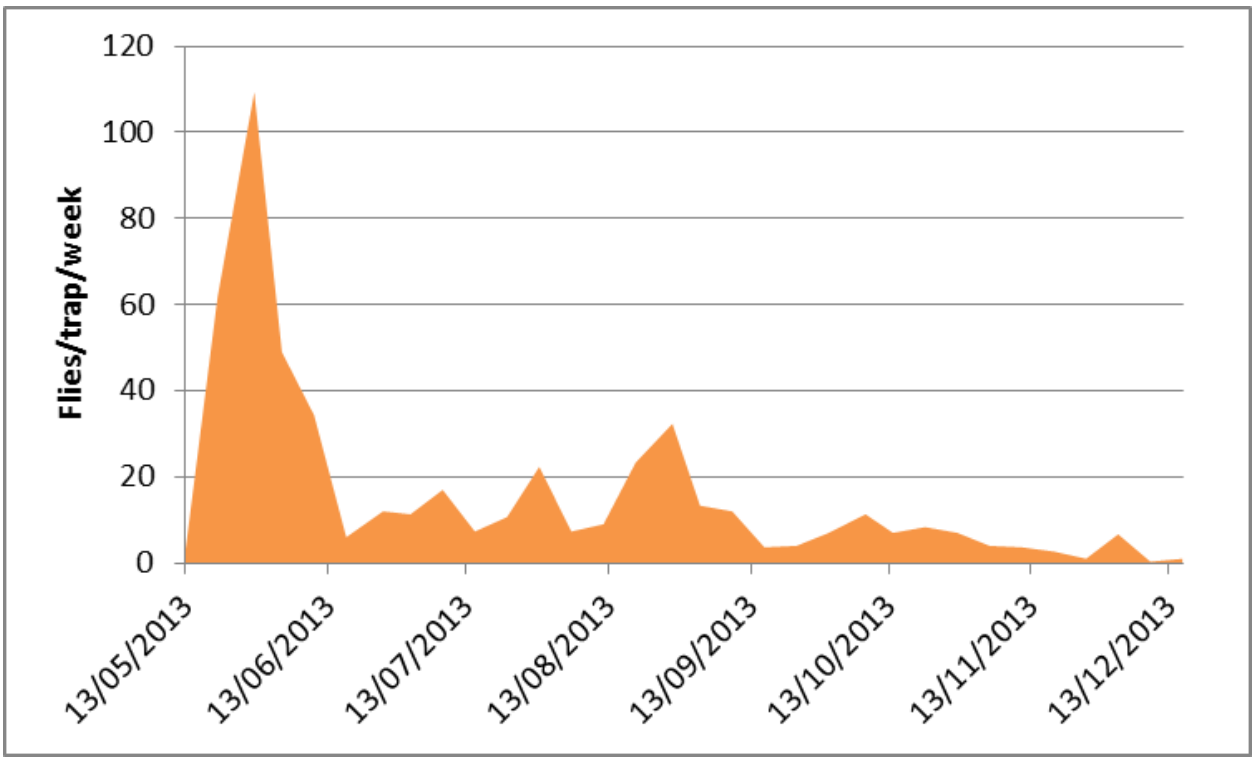


**Figure 2.1** Numbers of adult carrot flies (*Psila rosae*) captured on sticky traps in Long Meadow Centre during 2013.

*Phytotoxicity*

There was no evidence of phytotoxic effects due to any of the treatments in any of the trials, therefore no detailed data are presented.

## *Field trials*

### *Trial 1 – Coragen® persistence*

**Harvest assessments**

Data were collected on the numbers of carrot roots in 1 m of row. The roots were classified into categories according to the extent of carrot fly damage. The mean damage score was calculated by giving each damage category a numeric value, which were: (0) - 0%, (1) - <5%, (2) - 5-10%, (3) - 10-25%, (4) - 25-50% and (5) - >50% damage. A mean damage score was then calculated for each plot. The mean damage score (Root Damage Index) was calculated for each plot using the following formula:

RDI (Root Damage Index) = $(1_n \times 1 + 2_n \times 2 + 3_n \times 3 + 4_n \times 4 + 5_n \times 5)/Total_n$

Where n was the number of roots in a particular category.

The roots in each damage category were weighed separately and the total weight in 1 m row and the mean root weight were calculated.

Analyses were carried out on: the percentage of carrots showing no damage, the cumulative percentage of carrots with less than 5% damage, the Root Damage Index, the total number of roots, weight of roots in 1m row and mean root weight. The percentage roots with no damage or less than 5% damage required an Angular transformation before analysis to ensure homogeneity of variance between treatments. None of the treatment terms were significant using an F-test at the 5% level.

The results for percentage of undamaged carrots (Figure 2.2), cumulative percentage of carrots with less than 5% damage and mean RDIs (Figure 2.3) are shown in Table 2.1. Although none of these analyses were statistically-significant there was a clear reduction in damage in all of the treatments compared to the untreated control. There were no consistent differences between spray treatments.

The results for the total number of roots, weight of roots in 1m row and mean root weight are shown in Table 2.2. There was little difference between treatments with any of these factors.

**Table 2.1** The mean percentage of roots undamaged by carrot fly larvae, the cumulative percentage of roots with less than 5% damage and the Root Damage Index.

| Treatment | Weeks before exposure to carrot fly | % undamaged roots | | % roots with < 5% damage | | Root Damage Index (RDI) |
|---|---|---|---|---|---|---|
| | | ANG | Back trans | ANG | Back trans | |
| 1 | 6 | 37.0 | 36.3 | 45.7 | 51.1 | 1.42 |
| 2 | 4 | 45.0 | 50.0 | 54.4 | 66.0 | 1.06 |
| 3 | 2 | 38.5 | 38.8 | 45.6 | 51.0 | 1.46 |
| 4 | 0 | 32.3 | 28.6 | 42.2 | 45.1 | 1.53 |
| 5 | Untreated | 28.6 | 22.9 | 34.4 | 31.9 | 1.99 |
| F-value | | 1.13 | | 1.88 | | 1.75 |
| P-value | | 0.388 | | 0.179 | | 0.203 |
| SED | | 8.33 | | 7.42 | | 0.355 |
| 5% LSD | | 18.14 | | 16.17 | | 0.774 |
| df | | 12 | | 12 | | 12 |

**Table 2.2** Total weight of carrot roots in 1 m row, mean root weight and number of carrots in 1 m row.

| Treatment | Weeks before exposure to carrot fly | Weight of carrots in 1 m row | Mean root weight | Number of roots in 1 m row |
|---|---|---|---|---|
| 1 | 6 | 3324 | 56.2 | 59.5 |
| 2 | 4 | 3410 | 53.1 | 64.5 |
| 3 | 2 | 3382 | 57.3 | 66.0 |
| 4 | 0 | 3327 | 56.5 | 60.0 |
| 5 | Untreated | 3592 | 55.0 | 67.8 |
| F-value | | 0.23 | 0.06 | 0.21 |
| P-value | | 0.916 | 0.992 | 0.927 |
| SED | | 322.7 | 9.17 | 11.24 |
| 5% LSD | | 703.0 | 19.98 | 24.48 |
| df | | 12 | 12 | 12 |

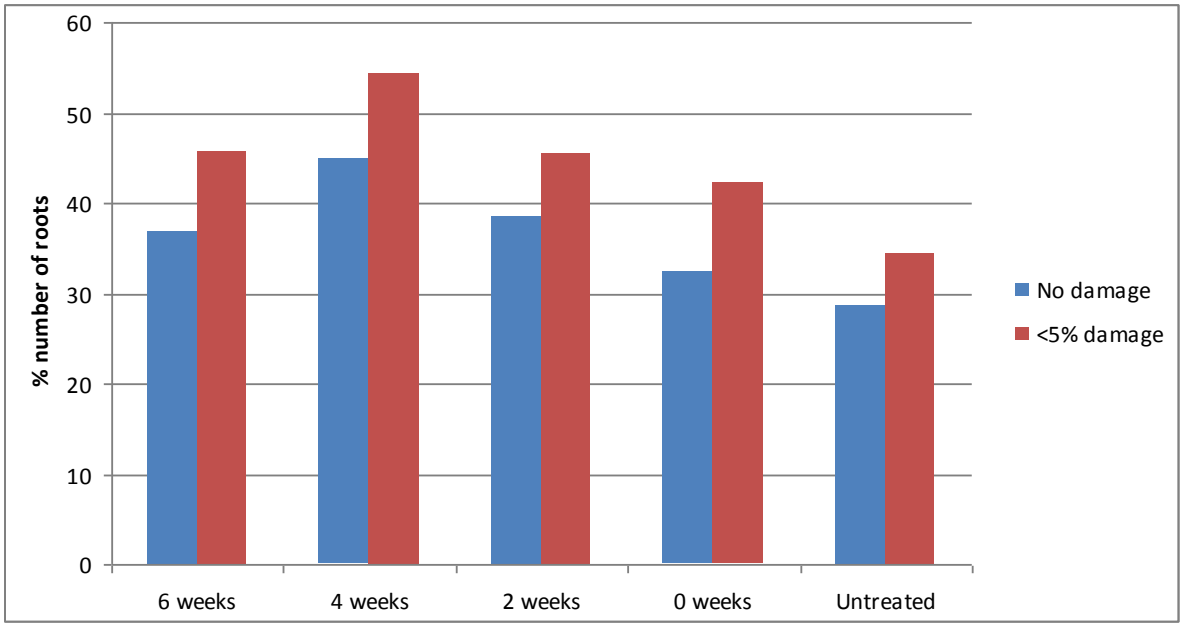


**Figure 2.2** The mean percentage of carrot roots undamaged and superficially damaged by carrot fly.

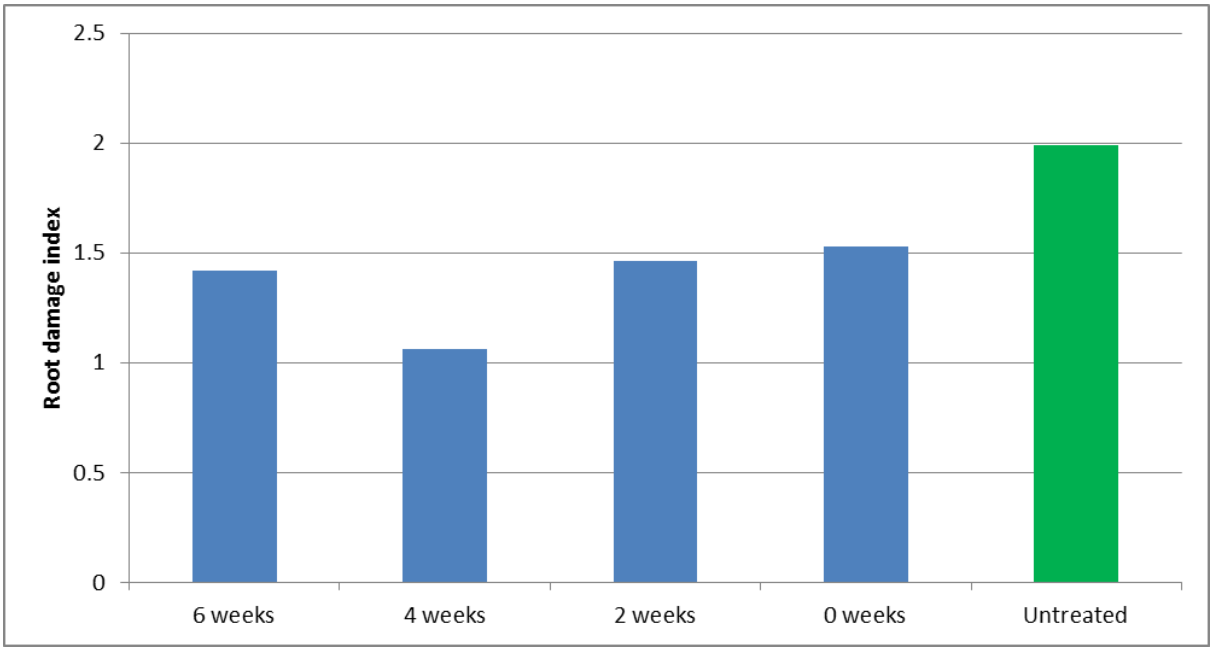


**Figure 2.3** The mean Root Damage Index of carrot roots.

*Trial 2 – Coragen® timing*

**Harvest assessments**

Data were collected on the number of carrot roots in 1 m of row. The roots were classified into categories according to the extent of carrot fly damage. The Root Damage Index was calculated as described for Trial 1.

The roots in each damage category were weighed separately and the total weight in 1 m row and the mean root weight were calculated.

Analyses were carried out on: the percentage of carrots showing no damage, the cumulative percentage of carrots with less than 5% damage, the Root Damage Index, the total number of roots, weight of roots in 1m row and mean root weight. The percentage roots with no damage or less than 5% damage required an Angular transformation before analysis to ensure homogeneity of variance between treatments.

The results for percentage of undamaged carrots (Figure 2.4), cumulative percentage of carrots with less than 5% damage and mean RDIs (Figure 2.5) are shown in Table 2.3. All of these analyses were statistically significant at the 5% level. There was a clear reduction in damage in all of the treatments compared to the untreated control. Treatments 2 (2 sprays of Coragen® at -1 and 3 weeks), 3 (2 sprays of Coragen® at 0 and 2 weeks) and 4

(full pyrethroid programme) had significantly less damage than the untreated control and treatment 1 (single spray of Coragen®), but there are no significant differences between treatments 2, 3 and 4. Treatment 1 was not significantly different from the untreated control but would appear to have offered some control of carrot fly.

The results for the total number of roots, weight of roots in 1m row and mean root weight are shown in Table 2.4. The only analysis which was statistically significant was the mean root weight where the pyrethroid programme had larger roots than most of the other treatments, but it seems likely this is more due to a smaller number of roots (not significant) in this treatment than any real treatment affects.

**Table 2.3** The mean percentage of roots undamaged by carrot fly larvae, the cumulative percentage of roots with less than 5% damage and the Root Damage Index.

| Treatment | Description | % undamaged roots | | % roots with < 5% damage | | Root Damage Index |
|---|---|---|---|---|---|---|
| | | ANG | Back trans | ANG | Back trans | |
| 1 | Coragen® 0 wk | 24.2 | 16.76 | 33.8 | 30.88 | 2.19 |
| 2 | Coragen® -1 + 3 Wk | 37.0 | 36.27 | 49.4 | 57.63 | 1.31 |
| 3 | Coragen® 0 + 2 Wk | 39.8 | 41.01 | 54.7 | 66.68 | 1.17 |
| 4 | Pyrethroid | 43.0 | 46.43 | 56.7 | 69.85 | 0.93 |
| 5 | Untreated | 18.2 | 9.72 | 24.9 | 17.67 | 2.83 |
| F-value | | 4.41 | | 8.03 | | 8.86 |
| P-value | | 0.020 | | 0.002 | | 0.001 |
| SED | | 7.21 | | 6.96 | | 0.378 |
| 5% LSD | | 15.71 | | 15.16 | | 0.824 |
| df | | 12 | | 12 | | 12 |

**Table 2.4** Total weight of carrot roots in 1 m row, mean root weight and number of carrots in 1 m row.

| Treatment | Description | Weight of carrots in 1 m row | Mean root weight | Number of roots in 1 m row |
|---|---|---|---|---|
| 1 | Coragen® 0 wk | 3152 | 32.71 | 96.8 |
| 2 | Coragen® -1 + 3 Wk | 3266 | 37.62 | 87.0 |
| 3 | Coragen® 0 + 2 Wk | 3394 | 34.92 | 97.5 |
| 4 | Pyrethroid | 3654 | 43.37 | 84.2 |
| 5 | Untreated | 3373 | 36.62 | 93.8 |
| F-value | | 1.88 | 3.93 | 1.61 |
| P-value | | 0.178 | 0.029 | 0.235 |
| SED | | 192.3 | 2.850 | 6.61 |
| 5% LSD | | 419.1 | 6.210 | 14.40 |
| df | | 12 | 12 | 12 |

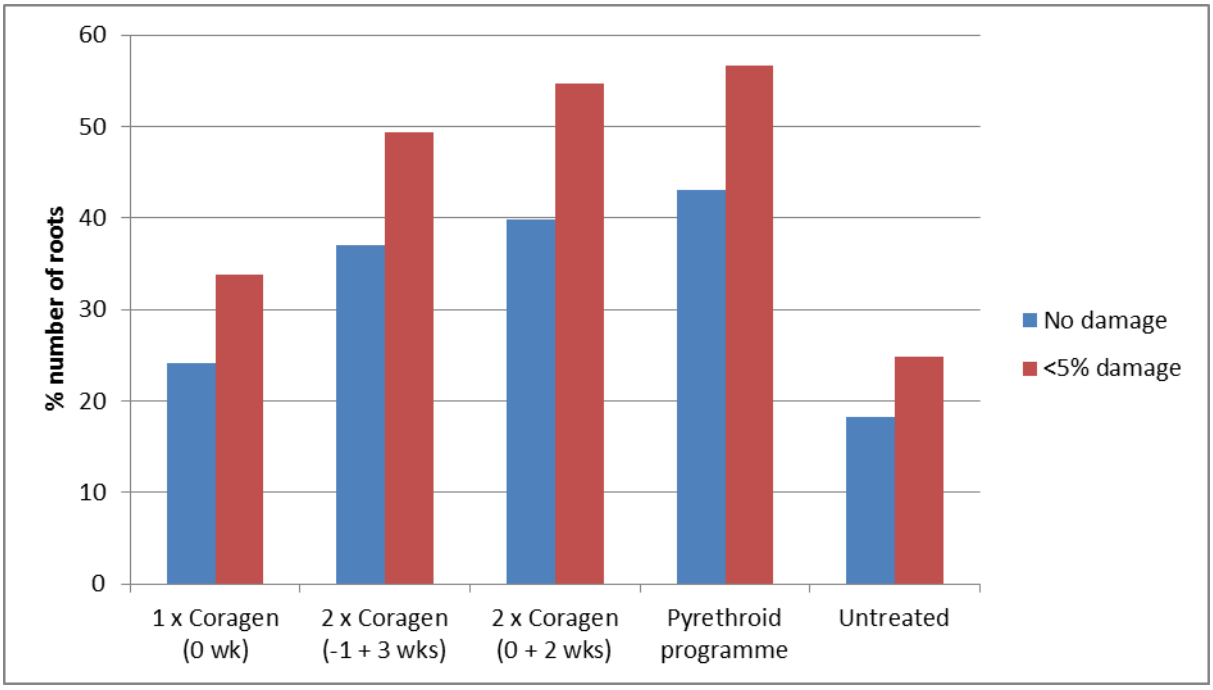


**Figure 2.4** The mean percentage of carrot roots undamaged and superficially damaged by carrot fly.

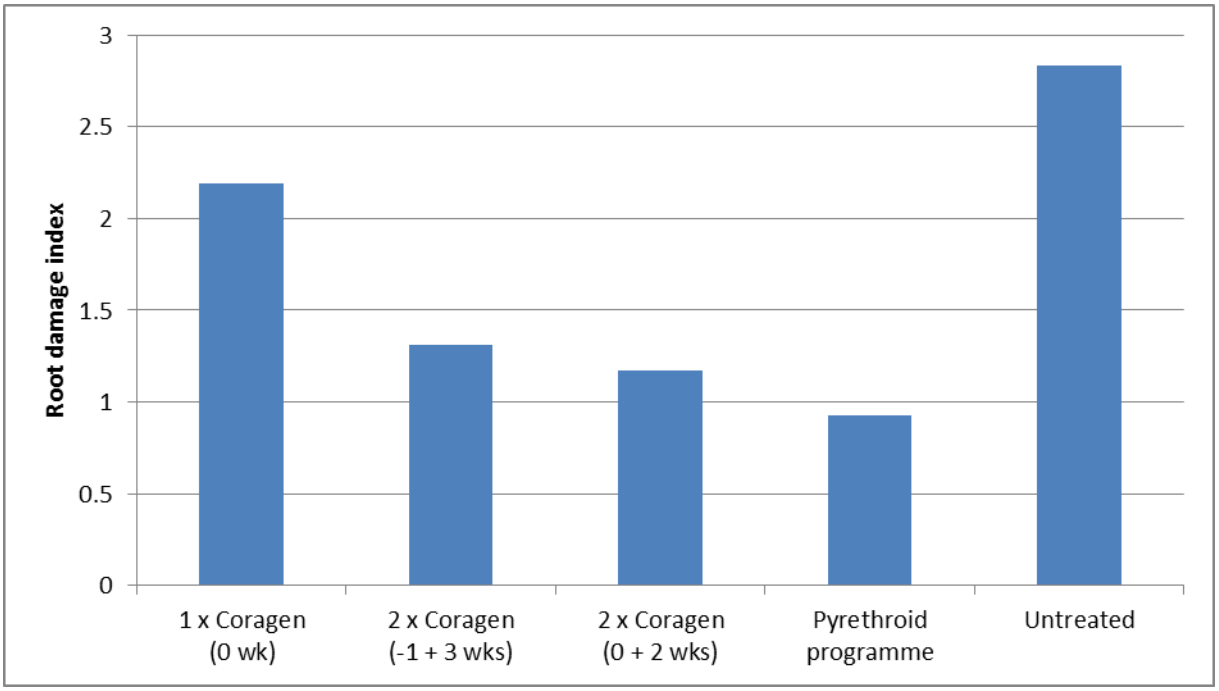


**Figure 2.5** The mean Root Damage Index of carrot roots.

### *Trial 3 Mortality of adult carrot flies exposed to Coragen® spray residues*

The cumulative percentage of dead carrot flies from three trials is presented in Table 2.5. The percentage of dead flies after 3 days in the 3 trials is presented in Figure 2.6. The numbers of dead flies after 3 days in Trial 3 were extrapolated from the data. The difference between the flies exposed to Coragen® and the untreated controls was only statistically significant (t-test $p<0.05$) for Trial 1.

**Table 2.5** The cumulative percentage number of dead flies up to 7 days exposure to Coragen® residues compared to untreated controls.

| Days after treatment | | 2 | 3 | 4 | 5 | 7 |
|---|---|---|---|---|---|---|
| Treatment | Trial number | | | | | |
| Coragen® | 1 | | 20 | 34 | | 55 |
| Untreated | 1 | | 36 | 55 | | 77 |
| Coragen® | 2 | | 10 | 14 | | 22 |
| Untreated | 2 | | 9 | 14 | | 26 |
| Coragen® | 3 | 8 | | | 16 | 22 |
| Untreated | 3 | 14 | | | 25 | 34 |

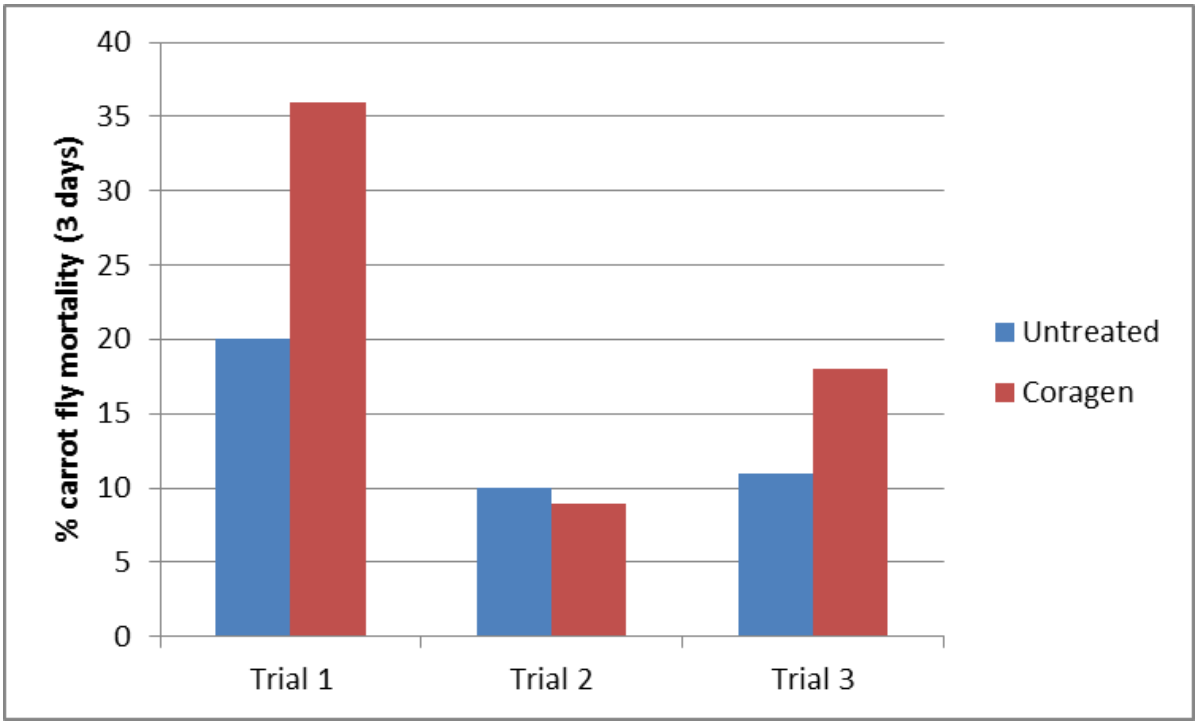


**Figure 2.6** The cumulative percentage number of dead flies after 3 days exposure to Coragen® residues compared to untreated controls.

### *Trial 4 - To determine if carrot fly larvae are killed by Coragen® sprays*

Preliminary trial: Figure 2.7 shows pots of carrot seedlings inoculated with carrot fly eggs where the soil surface had been treated with Coragen® (T) compared with untreated controls (U). Seedlings in four of the 5 pots treated with Coragen® had died.


**Figure 2.7** Pots of carrot seedlings inoculated with carrot fly eggs where the soil surface had been treated with Coragen® (T) compared with untreated controls (U).

Main trial: There was insufficient survival of larvae in the first set of replicates to assess treatment differences. In the second set of replicates, more pupae were recovered and there were higher levels of root damage. The results (10 replicates) are presented in Figures 2.8 and 2.9. The treatment differences for root damage were almost statistically-significant ($p=0.06$) but the treatment differences for the number of pupae were not statistically-significant. The treatment where Coragen® was applied to the soil appeared to be the most effective.

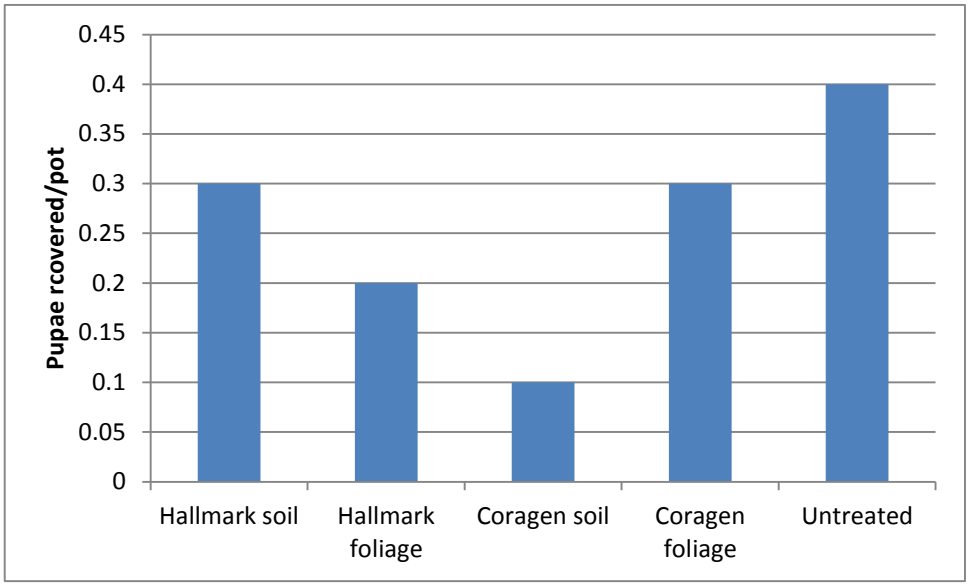


**Figure 2.8** Number of pupae recovered from pots of carrot seedlings inoculated with carrot fly eggs where Coragen® or Hallmark were applied either to the soil surface or to the foliage.

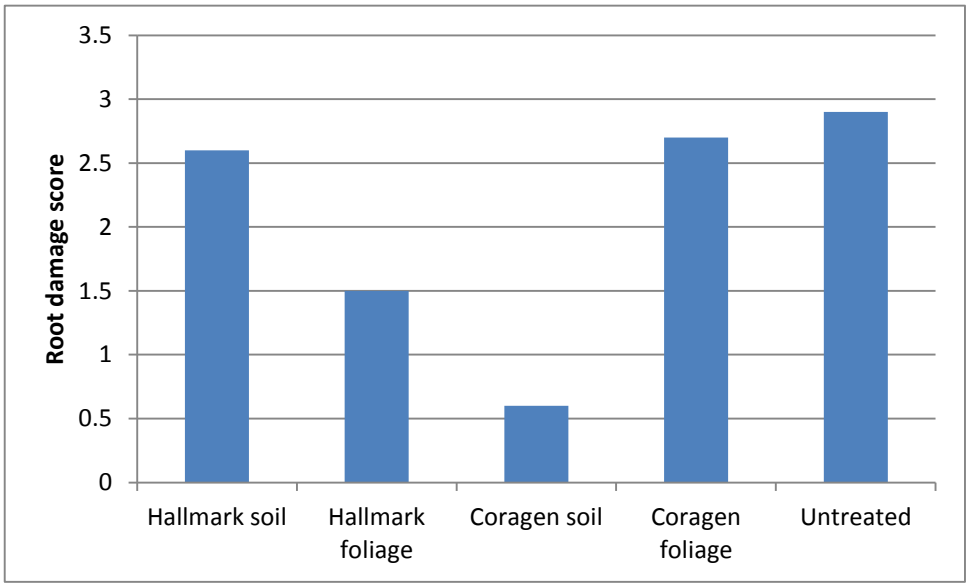


**Figure 2.9** Root damage score from pots of carrot seedlings inoculated with carrot fly eggs where Coragen® or Hallmark were applied either to the soil surface or to the foliage.

## Discussion

The emergence of second generation carrot fly at Wellesbourne in 2013 was extremely prolonged and there was no clear peak of activity. This followed a very late start to first generation emergence as a result of the very cold spring weather that year. It is thought that the 'normal' pattern of activity at the time of the second generation was disrupted by the very high temperatures that occurred before and during the start of the second generation (July 2013 – Figure 3.1), this may have caused some pupae to aestivate, delaying fly emergence (Collier & Finch, 1996). This disrupted a planned small field trial, which was subsequently replaced by a laboratory trial (Trial 4).

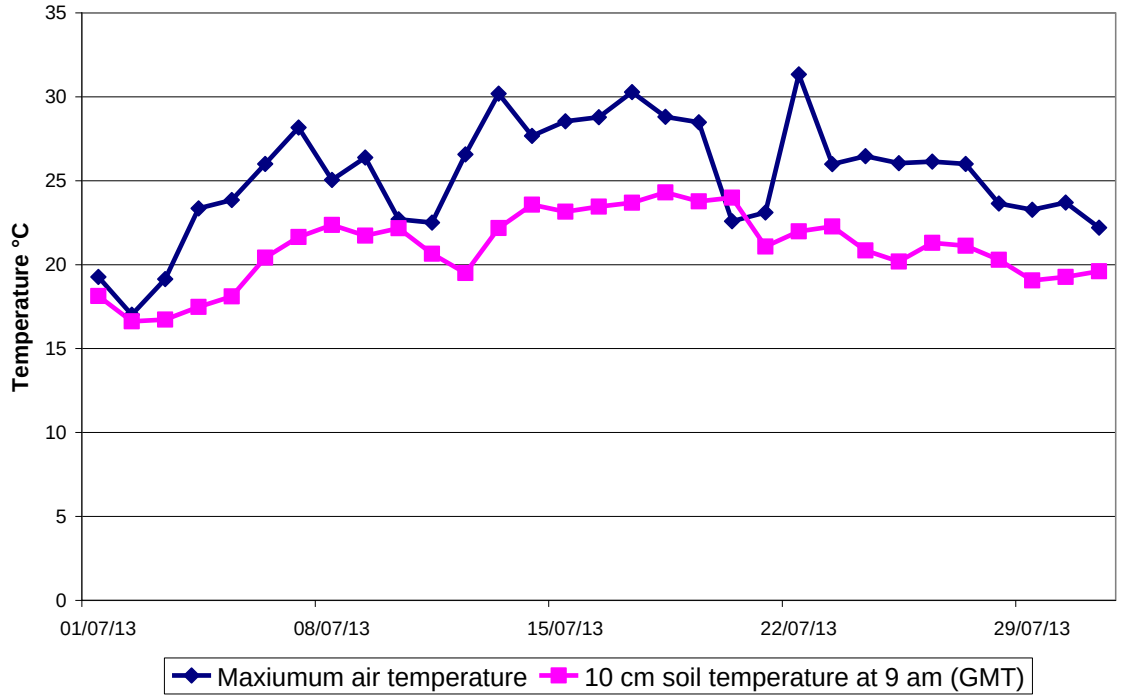


**Figure 3.1** Daily maximum air temperatures and 10 cm soil temperatures at 9 am (GMT) at Warwick Crop Centre, Wellesbourne in July 2013.

The laboratory trial on adult carrot fly (Trial 3) indicated that whilst Coragen® sprays increased adult mortality compared with untreated controls, the level of mortality was relatively low and results were variable. However, in contrast to previous studies on pyrethroid sprays, Coragen® applied to the soil surface (Trial 4) appeared to control carrot fly larvae.

Despite the 'abnormal' second generation activity, carrot fly damage in November 2013 was sufficiently great to determine whether there were differences between experimental

treatments in Trials 1 and 2. Obviously, in a trial such as this, which is sown to avoid damage by the first generation of carrot fly, the damage assessed in November is the result of accumulated damage due to flies that emerge from late July onwards. In 'normal' years the greatest proportion of this damage in untreated plots is due to the flies that emerge towards the start of the second generation, when there is also usually a clear peak in activity. Based on this 'normal' pattern of activity, recommendations have been made that growers should apply their most effective treatments at the start of the second generation, when fly pressure is greatest and this is why the standard programme of pyrethroid sprays used in Trial 2 starts with the highest permitted rate of Hallmark and finishes with sprays of Decis (Decis is less effective against carrot fly than Hallmark).

The trials undertaken in the current project show that Coragen® is relatively persistent (and based on the results of previous HDC-funded work on pyrethroid sprays, more persistent than these) and also suggest that although it may have some activity against adult carrot fly (as do foliar sprays of pyrethroid insecticides) it also appears to be active against the larvae in the soil. This may mean that treatment timing is not quite so 'critical' as with pyrethroid sprays, firstly because Coragen® appears more persistent and so potentially could be applied slightly 'early' and also because it may not be so critical to kill the insects within a relatively small window of time, as it is with the pyrethroid sprays. Since a single treatment of Coragen® appears to be relatively more effective than a single spray of Hallmark, both in terms of persistence and in control of larval carrot fly, it is suggested that it should be used at the beginning of a spray programme against second generation carrot fly. In terms of insecticide resistance management, it is best practice to alternate treatments with different modes of action.

## Conclusions

- A single spray of Coragen® is insufficient to significantly reduce damage by second generation carrot fly to carrots.
- However, two sprays of Coragen® spaced 4 weeks apart provided similar control to a 6-spray programme of pyrethroid sprays.
- Adult carrot fly mortality due to Coragen® is low and can be variable.
- There is strong evidence to suggest that Coragen® applied to the soil surface controls carrot fly larvae.

## Knowledge and Technology Transfer

20 March 2014 Presentation at HDC/BCGA Carrot Technical Seminar.

## References

COLLIER, R.H. & FINCH, S. (1996). Field and laboratory studies on the effects of temperature on the development of the carrot fly (*Psila rosae* F.). *Annals of Applied Biology* **128**, 1-11.