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Signed on behalf of: **Warwick HRI**

Simon Bright *26 March 2009*

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GROWER SUMMARY

Headline

Field experiments on carrot have confirmed the efficacy of current methods of carrot fly control, highlighted some experimental seed treatments and spray treatments that control aphids and/or carrot fly and examined the potential for excluding carrot fly from susceptible crops using fences.

Background and expected deliverables

For almost 10 years, carrot fly (*Psila rosae*) has been controlled effectively using pyrethroid insecticides, and foliar sprays of Hallmark with Zeon technology (will be referred to subsequently as Hallmark Zeon - the active ingredient is Lambda-cyhalothrin) have been particularly effective. However, to bring this use of Hallmark Zeon in line with other uses in the UK, the permitted number of spray applications has been decreased. This has led to concerns that the industry's ability to control carrot fly may be reduced. In addition, whilst there is no evidence that populations of carrot fly have become resistant to pyrethroids, reliance on a single group of active ingredients is a risky strategy in the long-term.

It is also becoming increasingly important to focus on an integrated approach to the control of carrot fly, aphids and cutworms, the major pest insects of carrot and related crops. This is because apart from changes to the use of Hallmark Zeon, the final use date for Temik (Aldicarb) was 31 December 2007. Temik was used for control of aphids and nematodes in carrot and parsnip, but may also have been providing a background level of carrot fly control in some crops.

The aim of this project was to evaluate novel insecticides, application methods and spray programmes for the control of carrot fly, aphids and cutworms on carrot crops and the use of exclusion fences to eliminate the need for chemical control.

The expected deliverables from this work included:

- An evaluation of novel seed treatments for the control of carrot fly and aphids on carrot
- An evaluation of novel insecticide sprays for the control of carrot fly and aphids on carrot
- An evaluation of different spray programmes for the control of carrot fly on carrot
- An evaluation of fences to exclude carrot fly from carrot crops

Summary of the project and main conclusions

Experiments were done to answer the following questions:

- Are there novel seed treatments to control carrot fly and aphids on carrot?
- Are there novel spray treatments to control carrot fly on carrot?
- What is the best spray programme, using approved and/or experimental products, for control of carrot fly on carrot?
- Are there novel spray treatments to control aphids on carrot?
- Can fences be used to exclude carrot fly from carrot crops?

Experiments 1a (2007) *and 1b (2008). Novel seed treatments to control carrot fly and aphids on carrot.*

The experiments were designed to assess novel insecticides as seed treatments for the control of carrot fly (*Psila rosae*) and aphids (willow-carrot aphid, *Cavariella aegopodii*). Seven insecticide treatments were assessed as seed treatments for the control of both pests. In each year the carrots were sown on two occasions (early-mid April and late May) to expose them to different 'pressures' from first generation carrot fly and willow-carrot aphid. In 2008, a 'standard' programme of foliar sprays of pyrethroid insecticides (Hallmark and Decis) was applied to control the second generation of carrot fly. Regular assessments were made of the numbers of seedlings/plants and the numbers of aphids infesting the plants, and samples of roots were taken between the first and second generations of carrot fly (mid-July) and in early winter to assess carrot fly damage and yield.

Results and conclusions

- In 2007, the plant count in the plots treated with Force was higher than in the other plots (although this difference was not always statistically significant), supporting the assertion that this treatment benefits seedling establishment. Some of the coded treatments increased plant numbers in 2007/2008 compared with insecticide-free controls.
- As soon as the migration started, winged and wingless willow-carrot aphids were found on the insecticide-free carrots. Winged and wingless aphids were also present on the plants treated with Force and with one of the coded products tested in 2008. However, very few wingless aphids were found on the plots treated with the other coded products, indicating that the winged aphids that colonised these plants had been unable to produce young.
- After a few weeks, and in both years, most of the aphids were parasitized by a small wasp and numbers of non-parasitized aphids declined.
- Adult carrot flies were captured on sticky traps at Wellesbourne from late April and numbers had declined by mid June. When they were harvested in mid July, the carrots sown in late May (towards the end of the first generation) suffered considerably less carrot fly damage than those sown in April.

- In 2007, all of the seed treatments reduced carrot fly damage to the first sowing compared with the insecticide-free control. Whilst the effects were not so pronounced in 2008, one of the coded products again reduced carrot fly damage mid-season.
- One of the most striking treatment effects of the seed treatments, particularly on the first sowing, was on 'yield'. The carrots harvested from the plots treated with some of the coded insecticides were considerably heavier than those recovered from the insecticide-free plots and those treated with Force. This was mainly a reflection of the increased weight of individual roots in the treated plots, but also, in most cases, of higher plant numbers.
- At harvest, in early winter 2007, none of the insecticide treatments appeared to reduce carrot fly damage in Sowing 2 compared with the untreated control. Within Sowing 1, the untreated controls for Force and Exp A both had a lower proportion of roots with <5% damage than their respective treated plots. In 2008, two of the coded treatments reduced carrot fly damage in early winter and the effects were apparent in both sowings.
- In 2007, the effects of the coded treatments on 'yield' persisted until harvest in early winter and these effects were apparent in both sowings. In 2008, the effects of the two more effective coded treatments on the mean weight of carrot roots persisted for Sowing 1.

Experiments 2a (2007) and 2b (2008). Novel spray treatments to control carrot fly on carrot.

These experiments were concerned principally with control of second generation carrot fly with foliar sprays and the carrots were sown towards the end of the first generation of carrot fly. Eleven insecticides were assessed as foliar spray treatments for the control of carrot fly. These insecticides were applied as components of spray programmes (usually 6 sprays) and sprays were applied at fortnightly intervals between mid July and early October. Root samples were taken in early winter and then early in the following year and assessed for carrot fly damage.

Results and conclusions

- All of the spray programs reduced carrot fly damage compared with the untreated control. In 2007, all of the programmes which started with Hallmark Zeon were very effective and not significantly different from each other. The experiment confirmed the efficacy of Hallmark Zeon as a spray treatment to control carrot fly.
- In 2007, in 6-spray 'standard' programmes, Biscaya was the least effective insecticide, followed by Decis. A coded product (Exp S) and Hallmark Zeon appeared to be equally effective.
- In 2007, there was one 7-spray programme, however, this did not improve control compared with the similar programme where the last Decis spray (10 October) was omitted. The programmes evaluated in these experiments did not indicate whether it would

have been possible to omit a further one or two sprays at the end of the 6-spray programmes.

- In 2008, damage to the insecticide-free control plots was heavier (93% roots damaged versus 68% in 2007). Probably as a consequence, the 'standard' 6-spray programme (1 x Hallmark 150 ml, 3 x Hallmark 100 ml, 2 x Decis) appeared to be less effective (70% versus 26% damaged roots).
- However, the 'standard' programme was surpassed by programmes containing two sprays of either of two experimental products (X1 and X2) in combination with 4 Hallmark sprays (1 x 150 ml and 3 x 100 ml).
- In addition to synthetic pesticides, two 'natural' products were also evaluated. Both reduced carrot fly damage compared with the insecticide-free control treatment, but were not as effective as the 'standard' programme.

Experiment 3. Novel spray treatments to control aphids on carrot.

This experiment was concerned principally with the application of foliar sprays of insecticide to control willow-carrot aphid. Four insecticides were evaluated in 2008 and the carrots were sown on 15 April. A 'standard' programme of foliar sprays of pyrethroid insecticides (Hallmark and Decis) was applied to control the second generation of carrot fly. Assessments were made of aphid numbers and carrot fly damage and yield.

Results and conclusions

- Following the first applications, Aphox, Exp U and Plenum all reduced the numbers of aphids compared with the insecticide-free control treatment. Biscaya did not.
- Aphid numbers had declined so much after the second assessment that it was not possible to distinguish between insecticide treatments.

Experiment 4. Fences to exclude carrot fly from carrot crops

During the spring and summer of 2007, fences were tested in small-scale experiments at Wellesbourne. There were two plots, each sown with carrots in April, and the central area of each plot (10 m x 10 m) was enclosed within the fences. The area of carrots outside the enclosed area was approximately 1 m wide. Both plots were near a source of carrot fly, but one was in a large open field whilst the other was in a small field enclosed by hawthorn hedges that were generally taller than the fence. The fences were made from fine-mesh netting, supported on a wooden frame. They were 1.7 m high and there was an external overhang, 0.4 m long, at an angle of 45^{o}.

The fences were in place before the seedling carrots emerged. To ensure that the effects of the fences could be monitored over two carrot fly generations, half of the beds within the fences were covered in fine-mesh netting to exclude any carrot fly that entered the area. The covers remained in place until mid July, between the two fly generations. The covers were then removed and placed over the beds that had been exposed during the first generation, to ensure that any flies that emerged from these beds were 'trapped' inside the covers. This meant that any second generation flies recovered inside the fences had come from outside. In addition to the plots enclosed by the fences, there were also two open 'control' plots of a similar size and the beds in these plots were covered with fine-mesh netting in a similar manner. Adult carrot fly numbers within all plots were recorded using sticky traps (3 per plot) and root samples taken in mid-July and November were assessed for carrot fly damage.

Results and conclusions

- The fences were inspected at the time that first generation carrot flies were most numerous and they, and considerable numbers of other insect species, were observed inside the overhang.
- During the first and second generations, the numbers of flies captured on sticky traps inside the fences were approximately 15% of those captured outside, so the effect was consistent throughout the summer.
- There were relatively more flies inside the fences at the time of the third generation (October) because the progeny of second generation flies that entered the enclosed area were free to emerge from the exposed carrots.
- When the carrot roots were assessed in early August, damage to the carrots within the fences was less than to those in the open plots. However, whilst the ratios of flies and damage in the fenced versus open plots were similar at the time of the first generation (all approximately 15%), damage was relatively greater after the second generation.
- Similar fences were evaluated on a field scale by organic growers and some basic data were collected as part of FV 312. The experiences of these growers have highlighted some of the practical difficulties of using such an approach on a field scale. These include making sure that the fences are in place before either the crop emerges or carrot flies start to disperse in the spring and ensuring that the gateway used by farm machinery is closed at all other times to prevent the ingress of carrot flies.

Financial benefits

- The carrot crop is Britain's major root vegetable, producing over 700,000 tonnes of sold carrots each year from 9,000 hectares. The sales value of British carrots is around £280 million.

- Multiple retailers have a very low tolerance for produce damaged by pests such as carrot fly and even low levels of infestation/damage may lead to rejection of the entire crop.
- The benefits of this project will be an assessment of new treatments for the three major pest insects of carrot and parsnip crops and an indication of those that should be taken forward for Full or Specific Off-Label Approval. It will provide information about the persistence of treatments and indicate the strategy that should be used to deploy them.

Action points for growers

1. The experiments confirmed that Force seed treatment improves plant stand and provides some control of first generation carrot fly. Not surprisingly, Force seed treatment does not control aphids.
2. The experiments confirmed that Hallmark Zeon controls adult carrot fly effectively and that it should be used at the beginning of a programme to control second generation carrot fly because it is more effective than Decis.
3. Pyrethroid insecticides kill adult flies so growers should aim to apply the first spray once carrot flies start to emerge and before they lay eggs. Use of the HDC/HRI carrot fly forecast (on the HDC Pest Bulletin website) can help growers to time sprays.
4. The dose of Hallmark Zeon applied appeared to have little effect (within the boundaries of the doses tested).
5. It should be possible to maintain adequate carrot fly control within the new PSD regulations if sprays are timed correctly.
6. It may be possible to exclude a considerable proportion of colonising carrot flies from susceptible crops using fences. However, there are practical difficulties associated with using such an approach on a field scale. These include making sure that the fences are in place before either the crop emerges or carrot flies start to disperse in the spring and ensuring that the gateway used by farm machinery is closed at all other times to prevent the ingress of carrot flies.

SCIENCE SECTION

INTRODUCTION

This report describes a two year project concerned with finding possible replacements for the insecticides applied currently to control the pest insects of carrot and with quantifying the efficacy of different methods of application and different spray programmes. The use of fences to exclude carrot fly from carrot crops was also investigated.

Experiments were done to answer the following questions:

- Are there novel seed treatments to control carrot fly and aphids on carrot? (Experiment 1a – 2007; Experiment 1b - 2008)
- Are there novel spray treatments to control carrot fly on carrot? (Experiment 2a – 2007; Experiment 2b - 2008)
- What is the best spray programme, using approved and/or experimental products, for control of carrot fly on carrot? (Experiment 2a – 2007; Experiment 2b -2008)
- Are there novel spray treatments to control aphids on carrot? (Experiment 3 –2008)
- Can fences be used to exclude carrot fly from carrot crops? (Experiment 4 - 2007)

Pest activity

The flight activity of winged willow-carrot aphids (*Cavariella aegopodii*) was monitored in a suction trap sited at Warwick HRI, Wellesbourne and belonging to the Rothamsted Insect Survey. The numbers of carrot fly/trap/week were recorded in a nearby carrot fly monitoring plot in Long Meadow Centre using orange sticky traps (Rebell®). Flight activity of the turnip moth (*Agrotis segetum*) was monitored near to the experiments using two pheromone traps (Agralan).

Figures a and b show the number of adult carrot flies (*Psila rosae*) captured on sticky traps in Long Meadow Centre in 2007 and 2008 and Figures c and d show the number of willow-carrot aphids (*Cavariellla aegopodii*) captured in the suction trap at Wellesbourne in 2007 and 2008. Figures e and f show the numbers of male turnip moth (*Agrotis segetum*) captured in two pheromone traps. All three species were active relatively early in 2007 because of the warm spring.

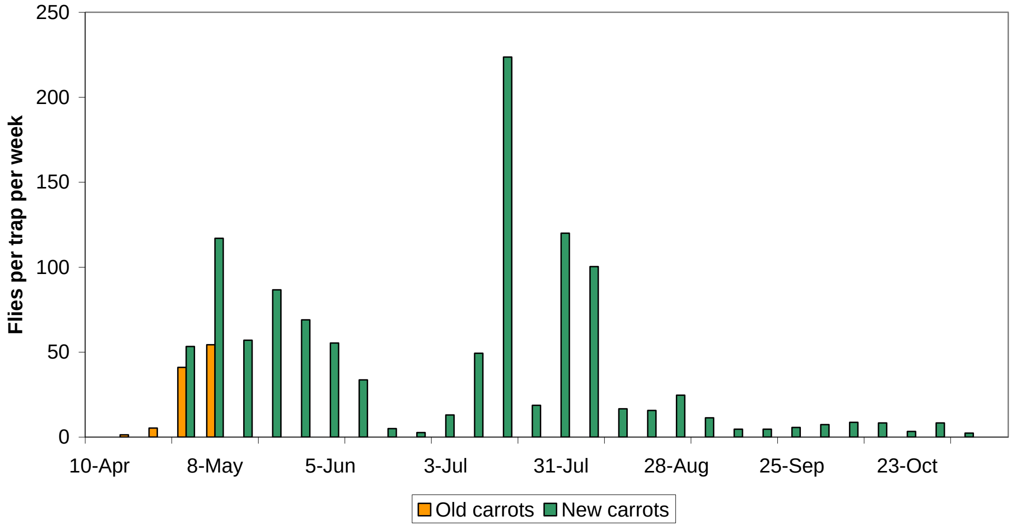

Figure a: The mean numbers of adult carrot fly (*Psila* rosae) captured on sticky traps (3) at Warwick HRI, Wellesbourne in 2007. Old carrots = overwintered crop; new carrots = drilled early April 2007

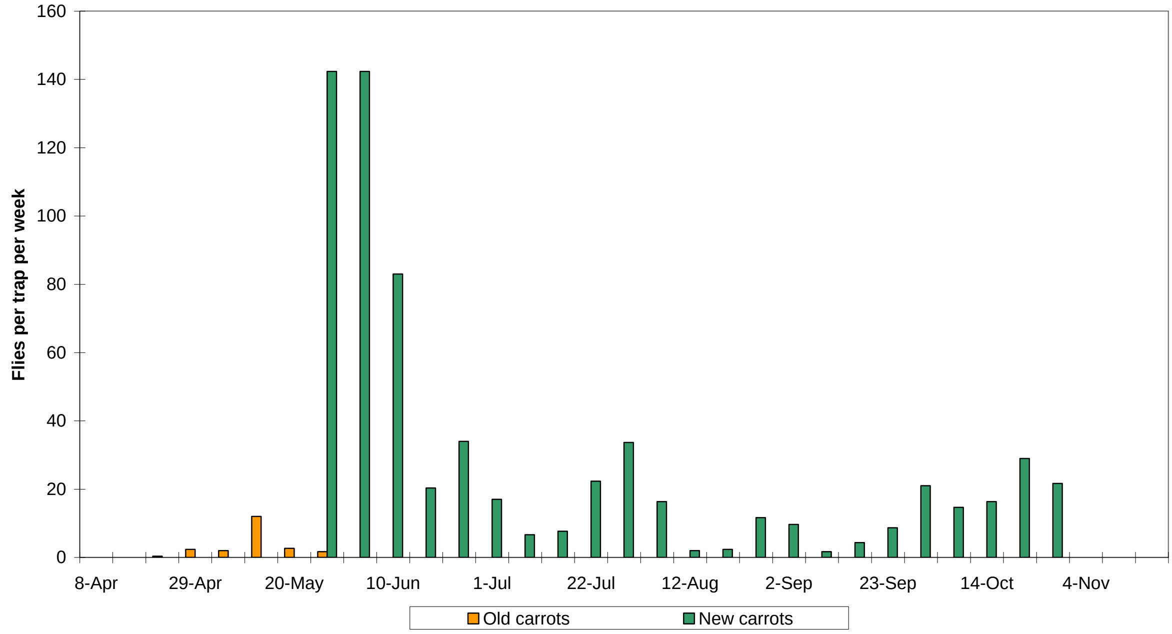

Figure b: The mean numbers of adult carrot fly (*Psila* rosae) captured on sticky traps (3) at Warwick HRI, Wellesbourne in 2008. Old carrots = overwintered crop; new carrots = drilled early April 2008

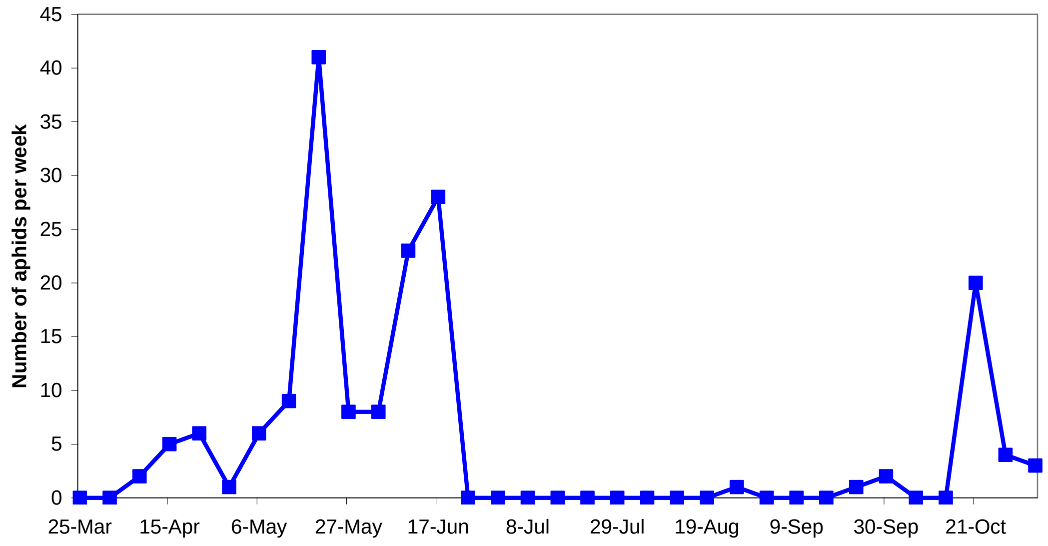

Figure c: The numbers of willow-carrot aphid (*Cavariella aegopodii*) captured in the Rothamsted suction trap at Warwick HRI, Wellesbourne in 2007

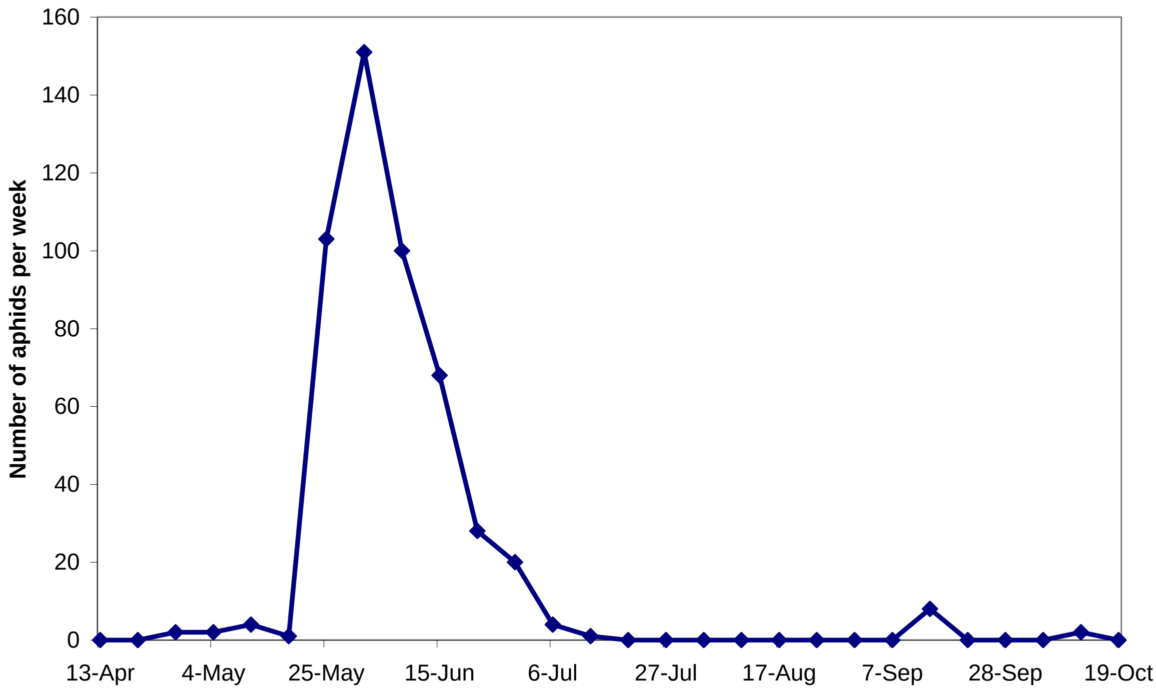

Figure d: The numbers of willow-carrot aphid (*Cavariella aegopodii*) captured in the Rothamsted suction trap at Warwick HRI, Wellesbourne in 2008

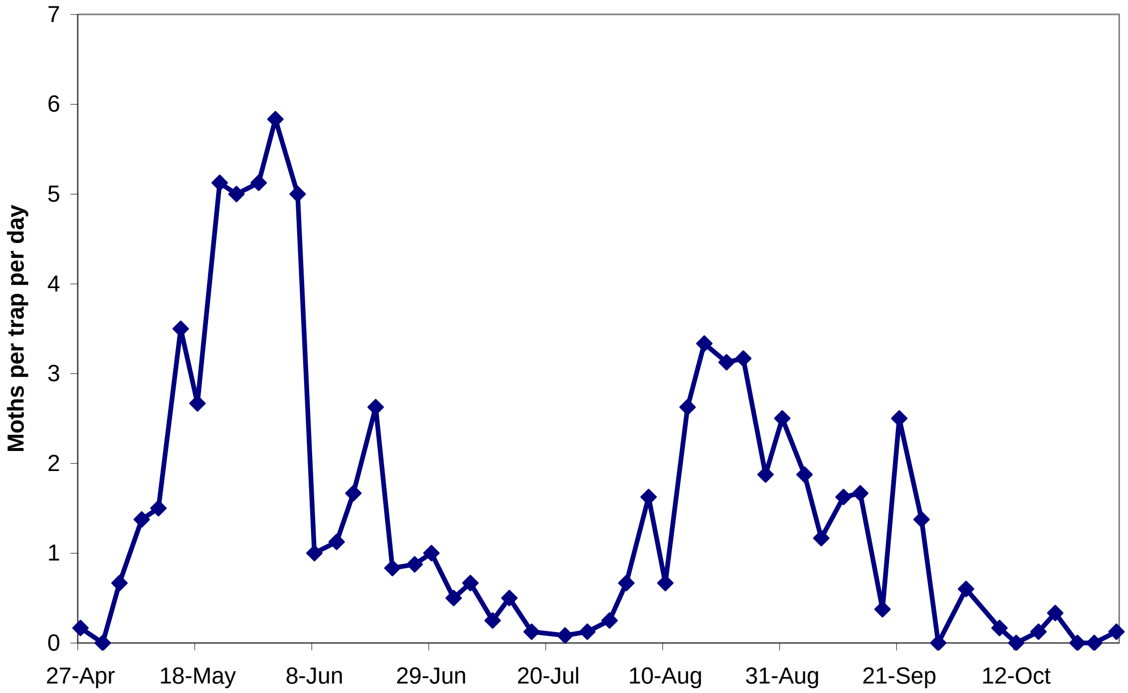

Figure e: The numbers of male turnip moth (*Agrotis segetum)* captured in pheromone traps at Warwick HRI, Wellesbourne in 2007

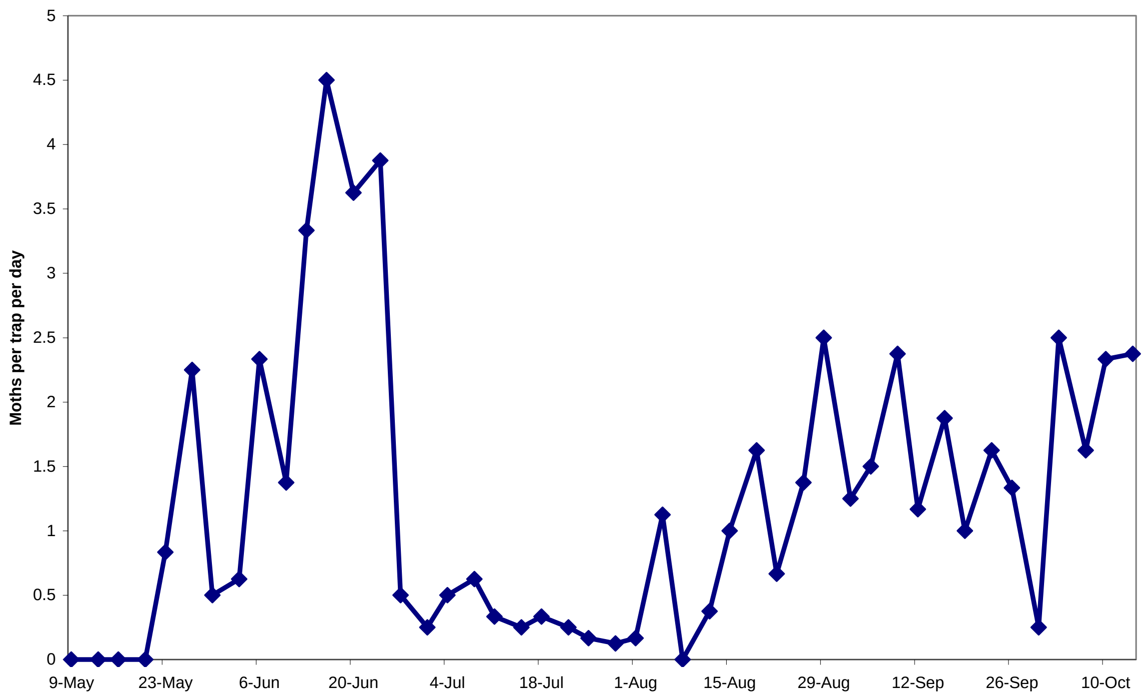

Figure f: The numbers of male turnip moth (*Agrotis segetum)* captured in pheromone traps at Warwick HRI, Wellesbourne in 2008

Novel seed treatments to control carrot fly and aphids on carrot

Experiment 1a

Materials and methods

The experiment was done within the field known as Long Meadow Centre at Warwick HRI, Wellesbourne. A population of carrot fly (*Psila rosae*) is maintained in this field.

The experiment was laid out as a complete Trojan Square with the plots split for treated and untreated seed. The field plots were 6 m x 1 bed (1.83 m each) in size and plots were separated by 1 m along beds. There were 4 replicates of each treatment and each plot consisted of two rows of insecticide-free carrots and two rows of carrots grown from insecticide-treated seed of the same carrot variety. The seed was drilled into different plots on two occasions (5 April and 23 May 2007) at a spacing of 100 seeds/m within rows and 0.38 m between rows. The treatments are listed in Table 1.1.

Table 1.1: Seed treatments evaluated for the control of carrot fly and aphids on carrot

Code	Product code	Active ingredient	Variety	Rate (mg a.i./seed)
1	Exp A – untreated *		Nairobi	
2	Exp A – treated		Nairobi	0.1 mg/seed
3	Exp B – untreated *		Nairobi	
4	Exp B – treated		Nairobi	0.07 + 0.023 mg/seed
5	Force – untreated *		Nairobi	
6	Force – treated	Tefluthrin	Nairobi	Commercial rate
7	Exp C – untreated		Namdal	
8	Exp C – treated		Namdal	Not supplied

* Insecticide-free seed from the same batch cv Nairobi carrot seed

To assess seedling emergence and seedling death due to feeding by carrot fly larvae, plant counts were made on a marked 0.5 m portion of each of the middle 2 rows in each plot (1 insecticide-free and 1 treated row). Assessments were made on 26 April, 3 May, 11 May and 24 May (first sowing) and 18 June and 28 June (second sowing).

The numbers of winged, wingless and parasitized aphids were counted on the same 0.5 m portions of row on 2 May, 10 May and 18 May (first sowing) and 18 June (second sowing).

On 18 July (between the first and second carrot fly generations) the 0.5 m marked areas, along with a further 0.5 m portion of row, were harvested from both sowings. The foliage was removed and the roots washed. The roots were stored in a cold store until assessment for damage due to carrot fly larvae. Further damage assessments were made on carrots taken from 1 m lengths of row on 27 November. Data were collected on the numbers of roots and the total weight of the roots per sample and the roots were classified into categories according to the extent of carrot fly damage. The damage categories were 0%, <5%, 5-10%, 10-25% and 25-50% of the surface area affected by carrot fly. These equate to damage scores of 0, 1, 2, 3, 4 and 5 respectively

Results

The design comprised 3 treatment factors – seed treatment, sowing and source, with 2, 2 and 4 levels respectively. The levels of each treatment factor are –

Seed treatment	untreated (insecticide-free) and treated
Sowing	Sowing 1 and Sowing 2
Source	Exp A, Exp B, Force and Exp C

The source represents the treatment names. All variates were analysed using ANOVA and no data transformations were required. Pair-wise comparisons were made using the 95% LSD.

Plant counts

Plant counts were recorded for each subplot on 4 occasions for Sowing 1 (26 April, 3 May, 11 May and 24 May), and twice for Sowing 2 (18 and 28 June). The plant counts for each plot on each occasion were analysed separately and are summarized in Table 1.2 and Figure 1.1. Statistically significant differences were only identified on the last sampling occasion for each of the two sowings, which were 24 May and 28 June respectively. On 24 May, Force treated seed had a higher plant count than Force untreated seed (its paired control) and also than Exp C untreated, Exp A treated and Exp B untreated. On 28 June, the means for treated and untreated seed show that the untreated seed subplots had lower plant counts than treated seed subplots ($p = 0.003$). The Exp B and Force untreated seed subplots had a lower plant count than their respective treated seed subplots.

Table 1.2: The total number of plants per plot (0.5 m of row) recorded in Sowing 1 (26 April, 3 May, 11 May and 24 May) and Sowing 2 (18 and 28 June). Statistically significant differences in the treatment means are shown by the letters next to each mean. Treatment means with a letter in common are said to be not significantly different

Sowing			**1**				**2**	
Date	**26 April**	**3 May**	**11 May**	**24 May**		**18 June**	**28 June**	
Treatment								
1. Exp A - untreated	42.0	42.8	41.0	42.0	ab	31.8	40.8	ab
2. Exp A - treated	34.5	36.0	34.2	35.8	a	33.0	39.2	ab
3. Exp B - untreated	37.2	38.0	36.2	35.8	a	31.5	30.0	a
4. Exp B - treated	35.5	36.2	38.0	37.8	ab	33.5	38.2	ab
5. Force - untreated	40.8	41.2	39.8	38.0	a	29.2	35.0	a
6. Force - treated	48.8	49.0	46.5	48.2	b	41.0	49.2	b
7. Exp C - untreated	38.2	39.0	38.2	36.0	a	30.8	35.2	a
8. Exp C - treated	44.5	44.0	43.5	44.0	ab	30.0	47.5	b
p-prob	0.132	0.235	0.142	0.056		0.201	0.026	
SED	4.78	5.14	4.08	4.04		4.16	4.53	
LSD	10.41	11.21	8.89	8.80		9.06	9.88	
Df	12	12	12	12		12	12	

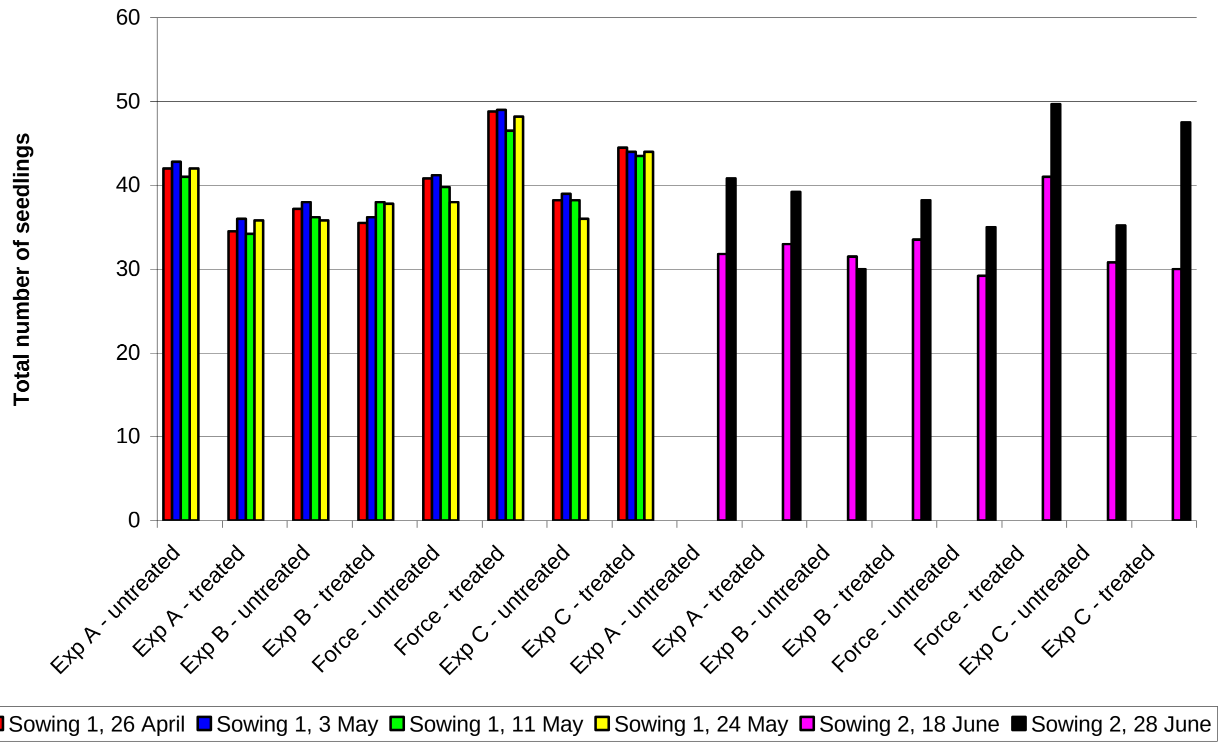

Figure 1.1: The total number of plants per plot (0.5 m of row) recorded in Sowing 1 (26 April, 3 May, 11 May and 24 May) and Sowing 2 (18 and 28 June)

Aphid Counts

On 2 May, 10 May and 18 May, the numbers of winged, wingless and parasitized aphids were recorded for the first sowing. Similar counts were recorded for the second sowing on 18 June. Several of the variables to be analysed did not have enough non-zero data present to enable a sensible analysis to be obtained.

On the first sampling occasion for Sowing 1, more winged aphids ($p < 0.001$) were found in untreated plots. The pair-wise comparisons of treated against untreated for each of the four sources found all untreated plots except Force to have more winged aphids than the corresponding treated plots (Table 1.3 and Figure 1.2). No statistically significant treatment effects were identified in data from the following three sampling occasions, most likely because very few winged aphids were found.

As with the winged aphids, more wingless aphids ($p = 0.017$) were found on untreated plots on the first sampling occasion for Sowing 1. On this occasion, the only statistically significant pair-wise difference between treated and untreated plots for each source was for Exp C (Table 1.4 and Figure 1.3), but clearly on this and subsequent occasions Exp A, Exp B and Exp C were controlling aphids effectively because virtually no aphids were found on the treated plots and substantial numbers were found on the comparable untreated plots.

Few parasitized aphids (Table 1.4) were found over the four sampling occasions and for 10 May and 18 May, where a sensible analysis was possible, the mean number of parasitized aphids in the untreated plots was higher ($p = 0.033$ and 0.032 respectively) than in the treated plots.

Table 1.3: The total number of winged aphids per plot (0.5 m of row) recorded in Sowing 1 (2, 10 and 18 May) and Sowing 2 (18 June). Statistically significant differences in the treatment means are shown by the letters next to each mean. Treatment means with a letter in common are said to be not significantly different

Sowing	**1**				**2**
Date	**2 May**		**10 May**	**18 May**	**18 June**
Treatment					
1. Exp A - untreated	30.5	bc	0.75	1.75	0
2. Exp A - treated	2.8	a	0.75	1.5	0.25
3. Exp B - untreated	49.0	c	1.25	3.75	0.25
4. Exp B - treated	0.8	a	0.75	0.75	0
5. Force - untreated	19.5	ab	0.75	1.25	0
6. Force - treated	31.5	bc	0.75	1.75	0.5
7. Exp C - untreated	27.2	b	1.25	2.5	0.25
8. Exp C - treated	2.5	a	0.5	0.75	0
p-prob	0.002		0.524	0.534	0.157
SED	8.02		0.625	1.782	0.2602
LSD	17.47		1.362	3.884	0.5669
Df	12		12	12	12

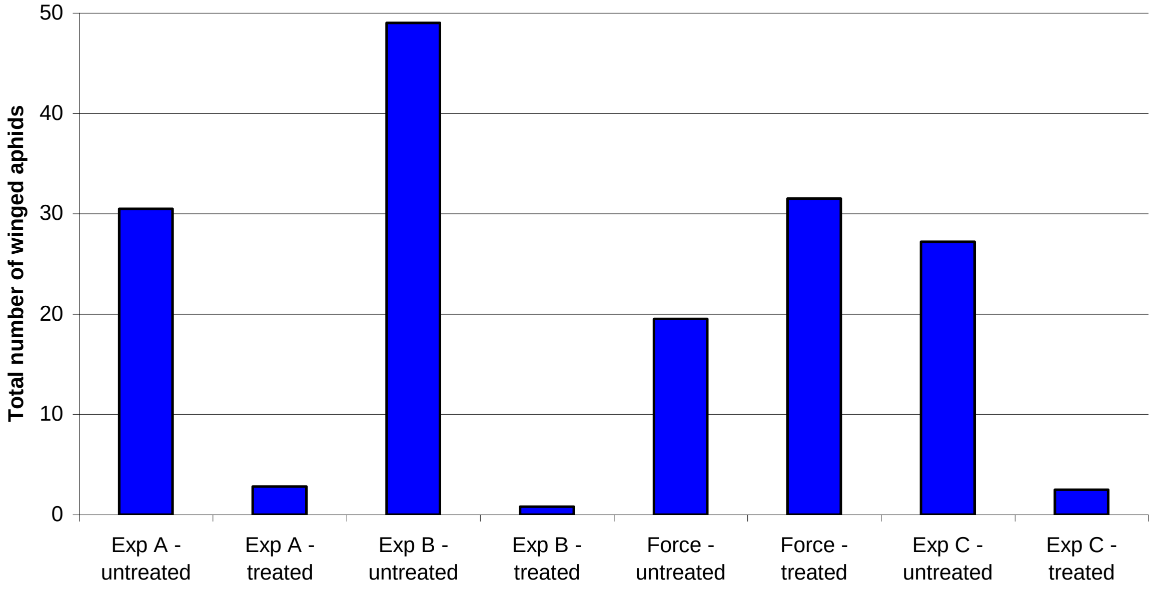

Figure 1.2: The total number of winged aphids per plot recorded in Sowing 1 on 2 May

Table 1.4: The total number of wingless aphids and parasitized aphids per plot (0.5 m of row) recorded in Sowing 1 (2, 10 and 18 May) and Sowing 2 (18 June). Statistically significant differences in the treatment means are shown by the letters next to each mean. Treatment means with a letter in common are said to be not significantly different

Sowing	**1**					
Aphid type	**Wingless aphids**				**Parasitized aphids**	
Date	**2 May**		**10 May**	**18 May**	**10 May**	**18 May**
Treatment						
1. Exp A - untreated	14.5	ab	30.8	16.8	0.50	3.25
2. Exp A - treated	0.2	a	0	0.2	0	0
3. Exp B - untreated	23.0	abc	32.2	10.0	0.50	1.00
4. Exp B - treated	0	a	0	0	0	0
5. Force - untreated	16.5	ab	14.0	2.0	1.00	6.25
6. Force - treated	31.5	bc	38.2	17.0	0	5.25
7. Exp C - untreated	45.2	c	16.8	12.8	0.50	3.00
8. Exp C - treated	0	a	0	0	0	0
p-prob	0.031		0.282	0.109	0.873	0.674
SED	12.23		22.03	9.04	0.520	1.700
LSD	26.65		47.99	19.69	1.134	3.704
df	12		12	12	12	12

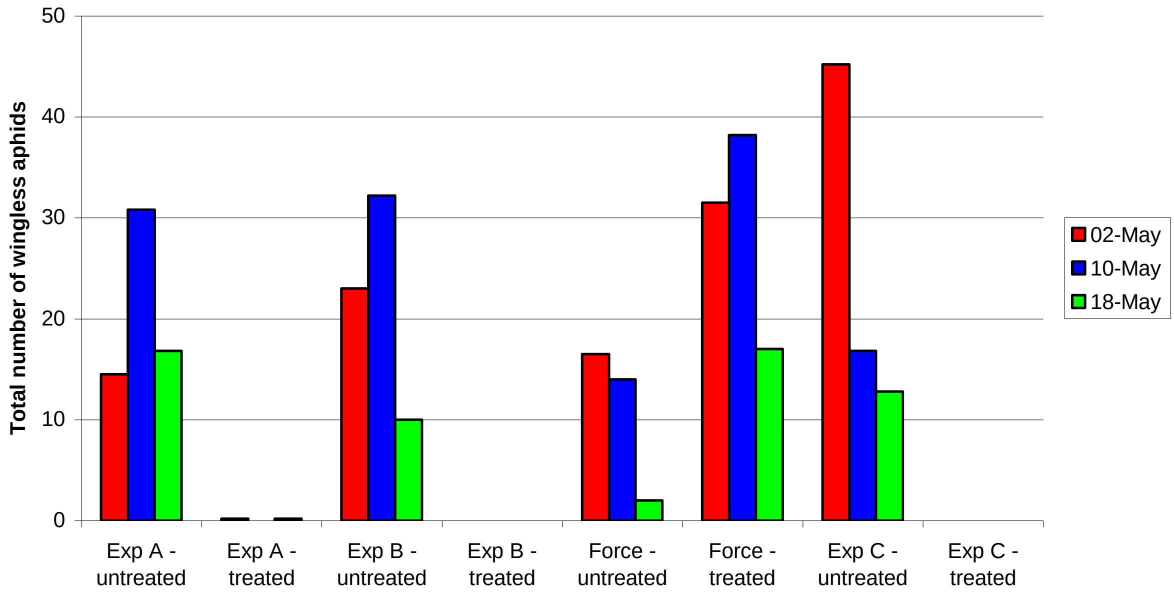

Figure 1.3: The total number of wingless aphids recorded per plot in Sowing 1 on 2, 10 and 18 May

<u>Carrot Fly Assessments</u>

a) Mid-season – 27 July

<u>Plant counts and weight</u>

Data were collected on the number of plants and the total weight of the roots, as well as classifying the plants into categories according to the extent of carrot fly damage. The results for the analysis of total plant weight, mean plant weight and the total number of plants are presented in Table 1.5 and Figure 1.4 (weight) and Table 1.6 and Figure 1.5 (plant numbers).

Total root weight:

No statistically significant differences were found in root weight per plot within Sowing 2, but within Sowing 1, the treated plots (except the Force treated seed) had a significantly higher root weight than the untreated plots.

Mean root weight:

All main effects and interactions in the mean individual root weight were highly statistically significant ($p < 0.001$) and, as with the root weight per plot, no statistically significant differences were found within Sowing 2.

Total number of roots:

At Sowing 1, Exp A was the only treatment which did not show a statistically significant difference between the number of plants in the treated and untreated plots, while at Sowing 2 Exp C and Exp A did not show a statistically significant difference between treated and untreated plots. In general, untreated plots had fewer plants and there was no difference between the two sowings.

Table 1.5: The mean weight per plot (1 m row) and per plant of carrot roots recorded from Sowing 1 and Sowing 2 on 27 July. Statistically significant differences in the treatment means are shown by the letters next to each mean. Treatment means with a letter in common are said to be not significantly different

	Plot weight				**Plant weight**			
Sowing	**1**		**2**		**1**		**2**	
Treatment								
1. Exp A - untreated	108	ab	55	a	2.02	ab	1.00	ab
2. Exp A - treated	1070	c	100	ab	16.07	d	1.55	ab
3. Exp B - untreated	123	ab	33	a	2.70	ab	0.85	ab
4. Exp B - treated	919	c	78	ab	13.90	cd	1.10	ab
5. Force - untreated	124	ab	28	a	2.07	ab	0.52	a
6. Force - treated	328	b	77	ab	3.68	b	0.86	ab
7. Exp C - untreated	140	ab	76	ab	2.75	ab	1.48	ab
8. Exp C - treated	919	c	123	ab	12.10	c	1.95	ab

	Plot weight	Plant weight
p-prob	0.036	0.005
SED	128.7	1.573
LSD	265.6	3.246
df	24	24

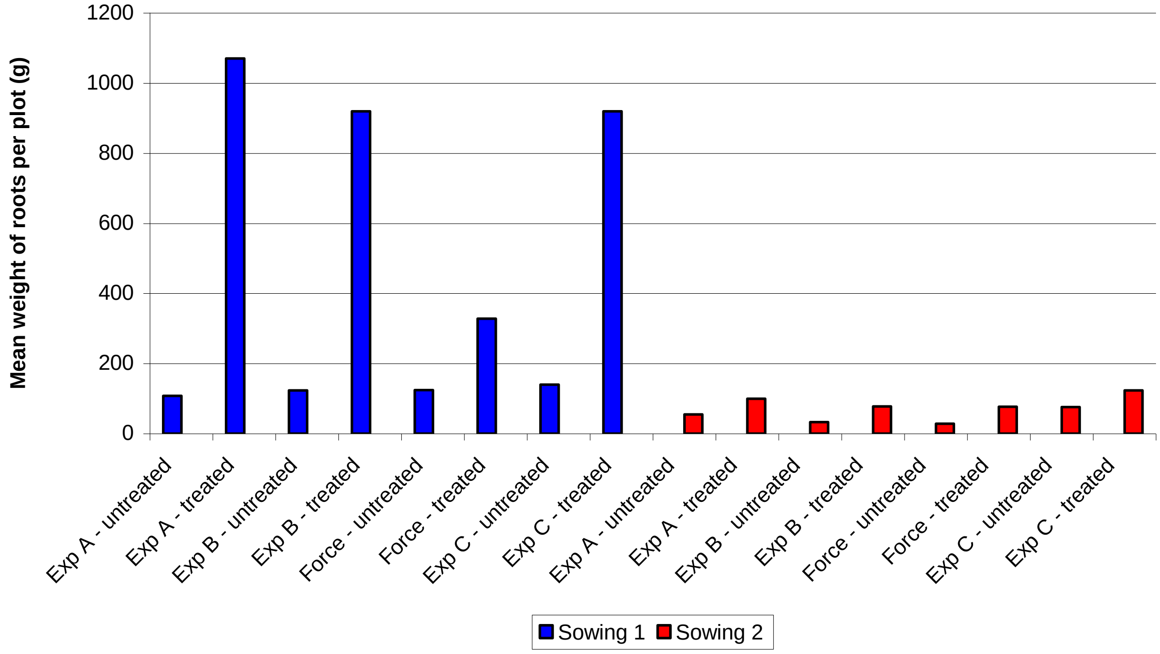

Figure 1.4: The mean weight of roots recorded per plot (1 m row) in Sowing 1 and Sowing 2 on 27 July

Table 1.6 The mean number of plants per plot (1 m row) recorded from Sowing 1 and Sowing 2 on 27 July. Statistically significant differences in the treatment means are shown by the letters next to each mean. Treatment means with a letter in common are said to be not significantly different

Sowing	**1**		**2**	
Treatment				
1. Exp A - untreated	48.2	abc	55.5	abcde
2. Exp A - treated	63.2	bcdef	62.8	bcdef
3. Exp B - untreated	41.8	ab	37.2	a
4. Exp B - treated	67.8	cdefg	71.5	defg
5. Force - untreated	44.2	ab	47.2	abc
6. Force - treated	77.0	efg	89.2	g
7. Exp C - untreated	47.5	abc	52.8	abcd
8. Exp C - treated	81.2	fg	64.0	bcdef
F-prob	0.298			
SED	9.34			
LSD	19.27			
df	24			

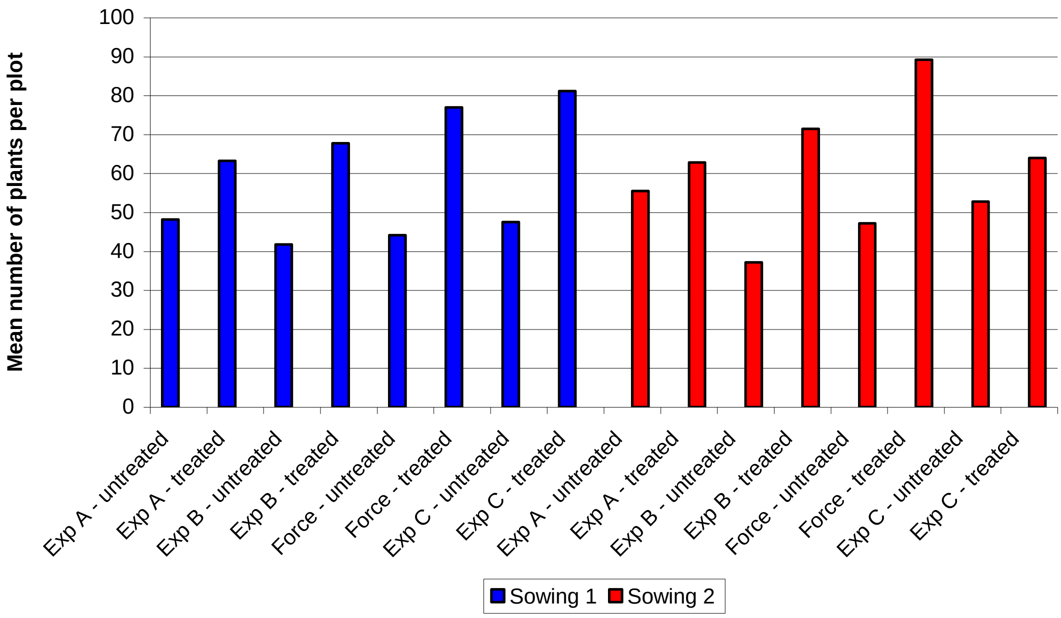

Figure 1.5: The mean number of plants recorded per plot (1 m row) in Sowing 1 and Sowing 2 on 27 July

Carrot Fly Damage

The damage categories were 0%, <5%, 5-10%, 10-25%, 25-50% and >50% of the surface are of the root damaged by carrot fly. The variables analysed were the proportion in each damage category and a mean damage score. Each damage category was given 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.

Mean carrot fly damage score

The main effects of source, and all interactions involving source, were not statistically significant ($p>0.05$). There was a highly statistically significant interaction between seed treatment and sowing ($p<0.001$) and Table 1.7 clearly shows that the untreated plants in Sowing 1 had a significantly higher mean damage score than treated plants, regardless of source. Within Sowing 2, Force ‘untreated’ had a higher mean damage score than Force treated, while all other within-source pair-wise comparisons were not statistically significant. The results are displayed in Figure 1.6.

Table 1.7: The mean carrot fly damage score recorded in Sowing 1 and Sowing 2 on 27 July. Statistically significant differences in the treatment means are shown by the letters next to each mean. Treatment means with a letter in common are said to be not significantly different

Sowing	**1**		**2**	
Treatment				
1. Exp A - untreated	2.533	f	0.350	ab
2. Exp A - treated	1.038	cd	0.012	ab
3. Exp B - untreated	3.092	f	0.424	abc
4. Exp B - treated	1.746	e	0.021	ab
5. Force - untreated	2.692	f	0.635	bc
6. Force - treated	1.577	de	0.096	a
7. Exp C - untreated	2.483	f	0.377	abc
8. Exp C - treated	1.895	e	0.055	ab
SED	0.2371			
LSD	0.4893			
df	24			

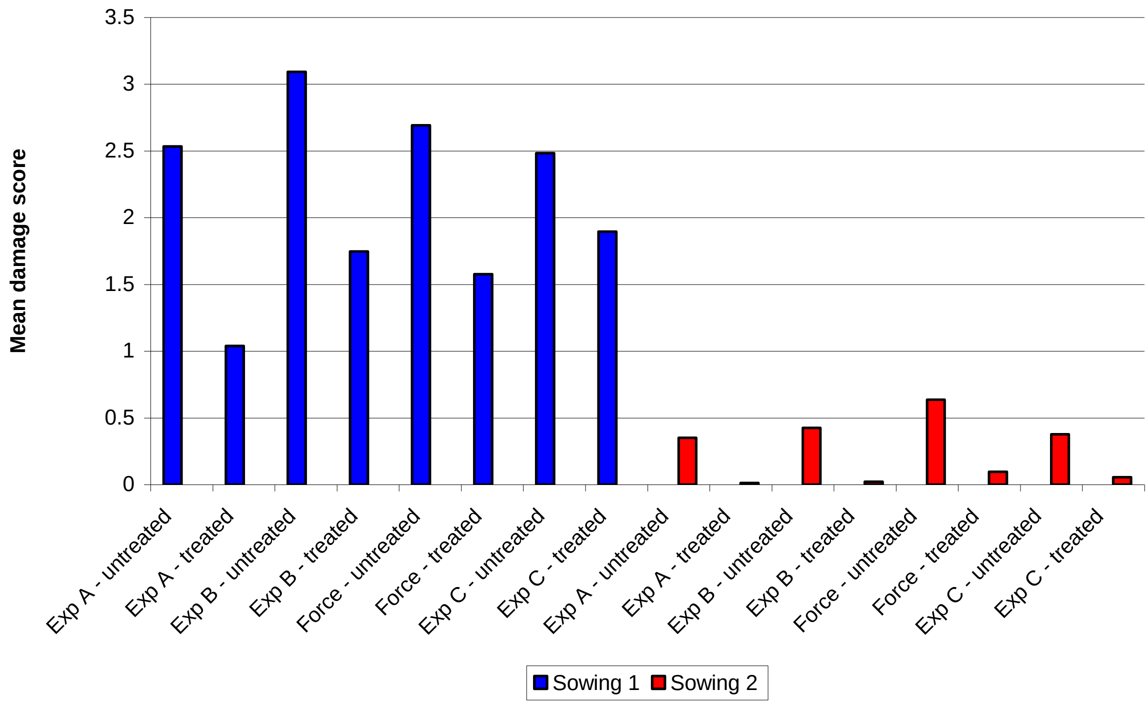

Figure 1.6: The mean carrot fly damage score of roots from Sowing 1 and Sowing 2 on 27 July

Proportion of roots with no carrot fly damage:

The main effect of seed treatment suggests that untreated plots had a lower ($p < 0.001$) proportion of roots with no damage than treated plots and that those in Sowing 2 had a higher proportion ($p < 0.001$) with no damage than those in Sowing 1 (Table 9). In Sowing 1, the treated and untreated plots were different for all sources except Exp C and in Sowing 2, there a

were statistically significant differences for all treatments.

Table 1.8: The mean proportion of roots with no carrot fly damage from Sowing 1 and Sowing 2 on 27 July. Statistically significant differences in the treatment means are shown by the letters next to each mean. Treatment means with a letter in common are said to be not significantly different

Sowing	**1**		**2**	
Treatment				
1. Exp A - untreated	0.146	abc	0.805	fgh
2. Exp A - treated	0.431	e	0.988	i
3. Exp B - untreated	0.079	ab	0.754	f
4. Exp B - treated	0.284	cde	0.982	i
5. Force - untreated	0.076	a	0.693	f
6. Force - treated	0.382	de	0.935	ghi
7. Exp C - untreated	0.242	abcd	0.776	fg
8. Exp C - treated	0.253	bcd	0.958	hi
SED	0.0808			
LSD	0.1668			
df	24			

The cumulative proportion of roots with less than 5% carrot fly damage were analysed for both sampling occasions. A summary of the results is given in Table 1.9. Overall, a higher ($p < 0.001$) proportion of treated plants showed signs of minor damage compared to untreated plants, and plants from Sowing 2 also had a higher proportion with no damage or less than 5% damage. No statistically significant differences where found between the treated and untreated plants within each source at Sowing 2. The results are displayed in Figure 1.7.

Table 1.9.: The cumulative proportion of roots with less than 5% carrot fly damage from Sowing 1 and Sowing 2 on 27 July. Statistically significant differences in the treatment means are shown by the letters next to each mean. Treatment means with a letter in common are said to be not significantly different

Sowing	**1**		**2**	
Treatment				
1. Exp A - untreated	0.319	a	0.901	d
2. Exp A - treated	0.729	c	1.000	d
3. Exp B - untreated	0.205	a	0.900	d
4. Exp B - treated	0.505	b	0.997	cd
5. Force - untreated	0.260	a	0.844	d
6. Force - treated	0.560	b	0.977	cd
7. Exp C - untreated	0.340	a	0.893	d
8. Exp C - treated	0.491	b	0.992	d
SED	0.0727			
LSD	0.1501			
df	24			

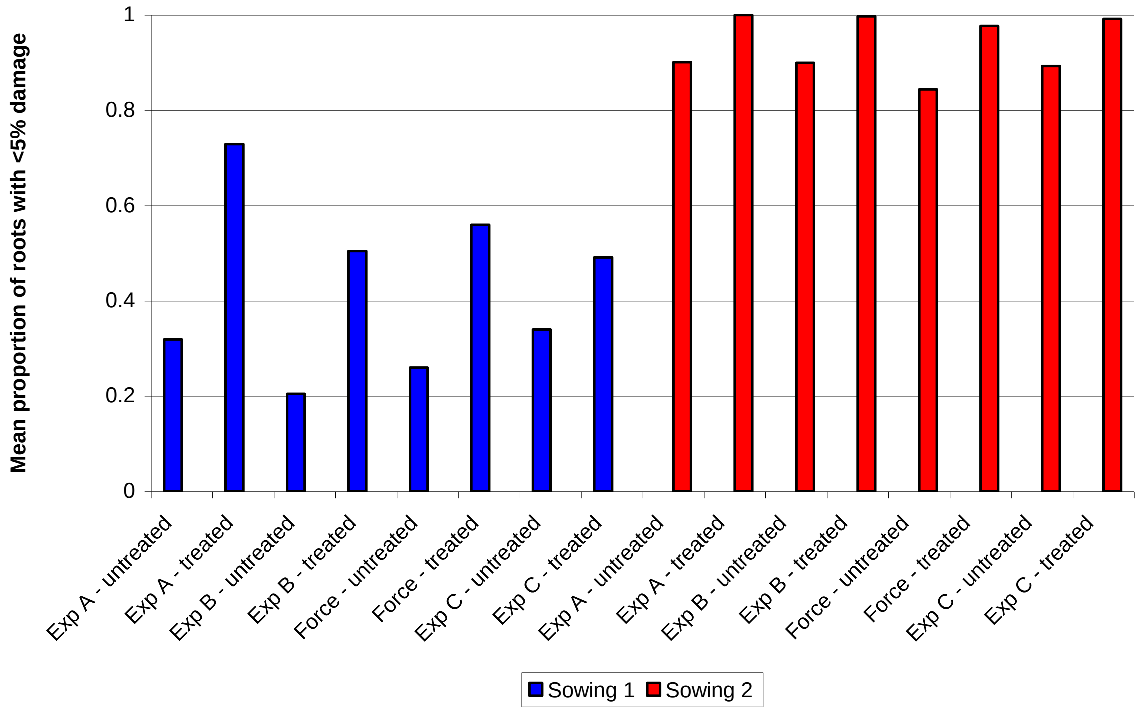

Figure 1.7: The proportion of roots with less than 5% carrot fly damage from Sowing 1 and Sowing 2 on 27 July

b) Harvest – 27 November

<u>Plant counts and weight</u>

Data were collected on the number of plants and the total weight of the roots, as well as classifying the roots into categories according to the extent of carrot fly damage. The results are presented in Table 1.10 and Figure 1.8 (weight) and Table 1.11 and Figure 1.9 (plant numbers).

Total root weight:

Statistically significant (p <0.001) differences were found within each sowing between the treated and untreated plots for each source except Force. The treated Force plots in Sowing 1 had a lower total (plot) root weight than the other treated plots in Sowing 1. Exp B treated roots from Sowing 1 had a higher total (plot) weight than those from Sowing 2, while Force treated roots from Sowing 1 had a lower total weight than Force treated roots from Sowing 2.

Mean root weight:

No statistically significant differences were found between the treated and untreated paired plots within Sowing 2, while the treated roots within Sowing 1 were heavier than the corresponding untreated roots except for Force, which showed no statistically significant difference.

Total number of roots:

The untreated plots in each sowing, except for Force at Sowing 1, had fewer plants than the corresponding treated plots. The treated Force plots at Sowing 1 had fewer plants than both the treated Exp C and treated Exp B plots from Sowing 1.

Table 1.10: The mean weight per plot (1 m row) and per plant of carrot roots recorded in Sowing 1 and Sowing 2 on 27 November. Statistically significant differences in the treatment means are shown by the letters next to each mean. Treatment means with a letter in common are said to be not significantly different

	Plot weight				Plant weight			
Sowing	1		2		1		2	
Treatment								
1. Exp A - untreated	827	a	1779	bcd	11.31	a	23.88	bc
2. Exp A - treated	3810	f	3383	ef	33.80	d	21.77	bc
3. Exp B - untreated	742	a	1062	ab	10.89	a	14.40	a
4. Exp B - treated	3523	f	2576	de	27.95	c	17.01	ab
5. Force - untreated	796	a	1412	abc	11.13	a	17.10	ab
6. Force - treated	1069	ab	2131	cd	10.84	a	14.41	a
7. Exp C - untreated	920	a	1978	cd	10.64	a	23.75	bc
8. Exp C - treated	3169	ef	3006	ef	25.83	c	22.23	bc
p-prob	0.088				0.019			
SED	393.2				3.231			
LSD	811.4				6.669			
df	24				24			

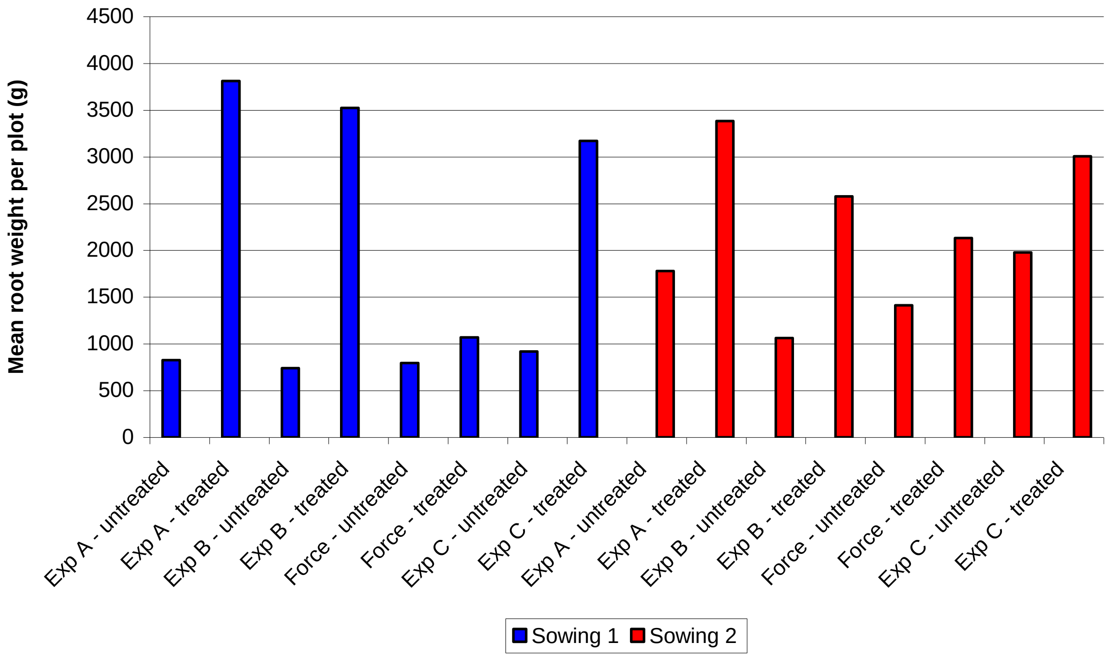

Figure 1.8: The mean weight of roots per plot (1 m row) from Sowing 1 and Sowing 2 on 27 November

Table 1.11: The mean number of plants per plot (1 m row) from Sowing 1 and Sowing 2 on 27 November. Statistically significant differences in the treatment means are shown by the letters next to each mean. Treatment means with a letter in common are said to be not significantly different

Sowing	**1**		**2**	
Treatment				
1. Exp A - untreated	65.2	a	74.5	ab
2. Exp A - treated	113.0	cd	157.5	g
3. Exp B - untreated	68.0	ab	72.5	ab
4. Exp B - treated	125.0	def	149.2	efg
5. Force - untreated	65.5	ab	76.5	ab
6. Force - treated	93.0	bc	150.8	fg
7. Exp C - untreated	83.8	ab	85.5	abc
8. Exp C - treated	122.5	de	137.0	defg
p-prob	0.594			
SED	13.48			
LSD	27.83			
df	24			

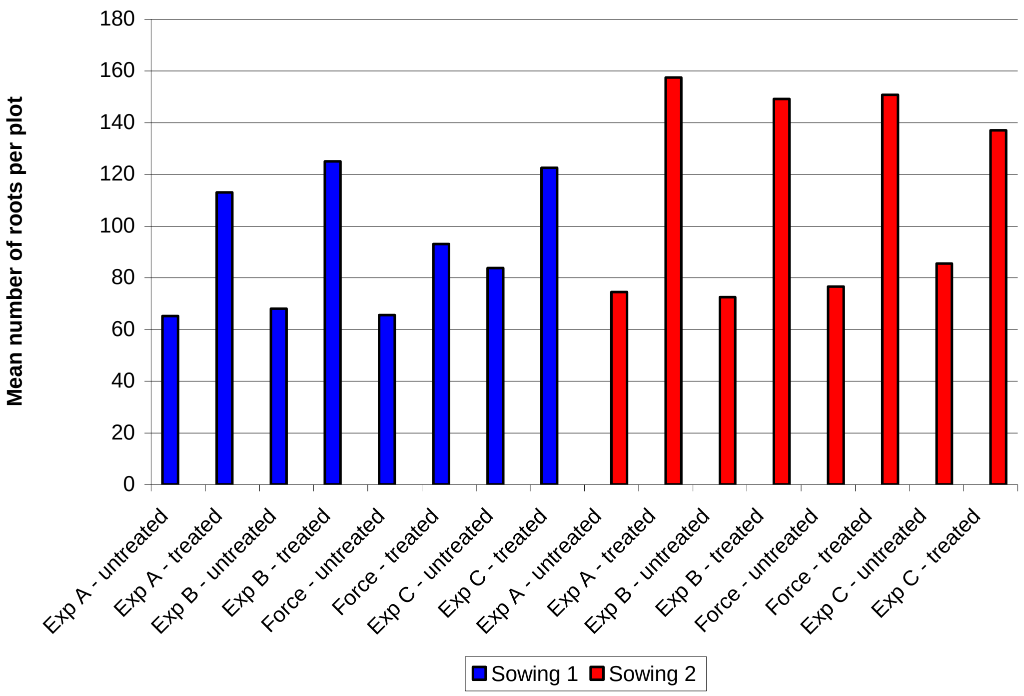

Figure 1.9: The mean number of roots per plot (1 m row) from Sowing 1 and Sowing 2 on 27 November

Carrot Fly Damage

Mean carrot fly damage score:

The main effect of seed treatment suggests that the treated plots had lower ($p < 0.001$) mean damage scores than the untreated plots. Overall, Sowing 2 had a lower ($p < 0.001$) mean damage score than Sowing 1. Treated Exp A and Force roots had less damage than the comparable untreated roots in Sowing 1. The other treatments in Sowing 1 and all treatments in Sowing 2 did not. The results are displayed in Figure 1.10 and Table 1.12.

Table 1.12: The mean carrot fly damage score in Sowing 1 and Sowing 2 on 27 November. Statistically significant differences in the treatment means are shown by the letters next to each mean. Treatment means with a letter in common are said to be not significantly different

Sowing	**1**		**2**	
Treatment				
1. Exp A - untreated	2.575	fgh	1.985	abcde
2. Exp A - treated	1.786	abc	1.668	a
3. Exp B - untreated	2.513	efg	2.361	defg
4. Exp B - treated	2.314	cdefg	1.917	abcd
5. Force - untreated	3.262	j	2.051	abcdef
6. Force - treated	2.281	bcdefg	1.745	ab
7. Exp C - untreated	2.924	hj	2.314	cdefg
8. Exp C - treated	2.613	gh	1.992	abcde
SED	0.2467			
LSD	0.5091			
df	24			

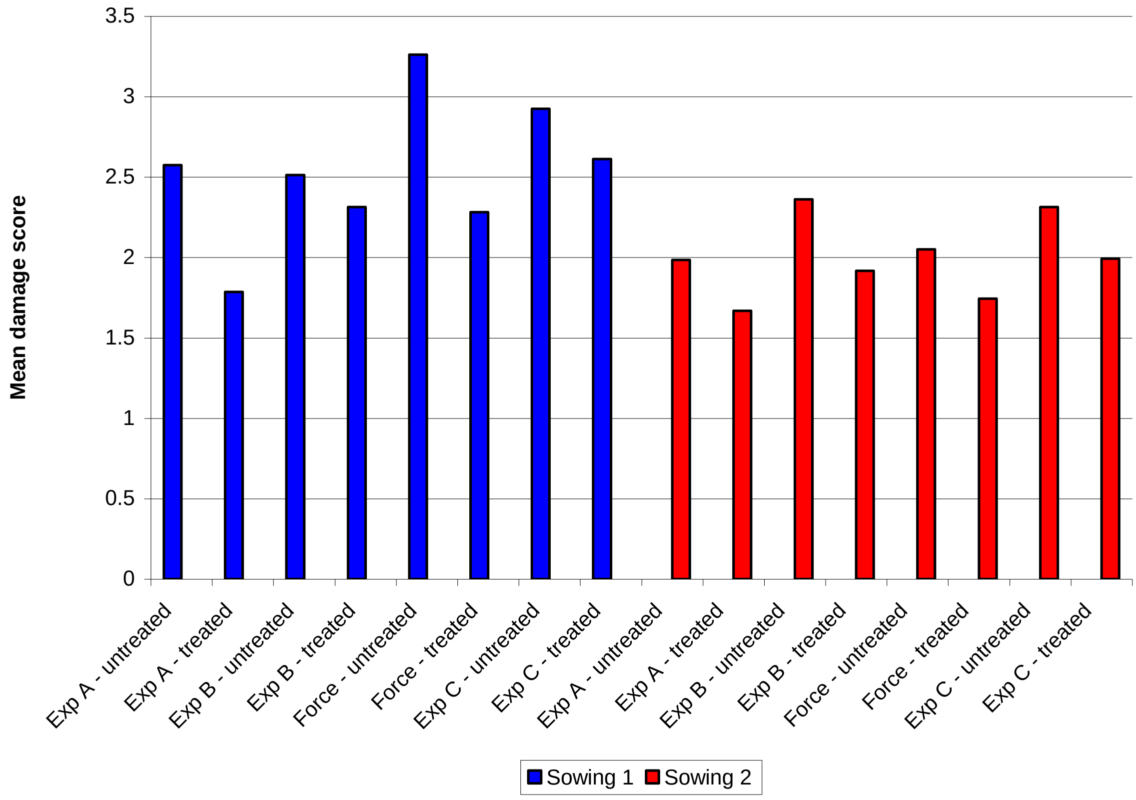

Figure 1.10: The mean carrot fly damage score of roots from Sowing 1 and Sowing 2 on 27 November

Proportion of roots with no carrot fly damage:

Within Sowing 1, only Force showed a statistically significant difference between treated and untreated plots and within Sowing 2, only Exp A showed a statistically significant difference (Table 1.13).

Table 1.13: The mean proportion of roots with no carrot fly damage from Sowing 1 and Sowing 2 on 27 November. Statistically significant differences in the treatment means are shown by the letters next to each mean. Treatment means with a letter in common are said to be not significantly different

Sowing	**1**		**2**	
Treatment				
1. Exp A - untreated	0.0812	abc	0.2204	e
2. Exp A - treated	0.1765	cdef	0.2588	f
3. Exp B - untreated	0.0742	abc	0.1054	abcd
4. Exp B - treated	0.0907	abcd	0.1911	def
5. Force - untreated	0.0203	a	0.1664	bcdef
6. Force - treated	0.1477	bcde	0.2566	f
7. Exp C - untreated	0.0687	ab	0.1422	bcde
8. Exp C - treated	0.0783	abc	0.1790	cdef
SED	0.0546			
LSD	0.1128			
df	24			

Cumulative Proportion <5% carrot fly damage:

No statistically significant differences were found between the 4 sources within Sowing 2 when considering the untreated plots and also the treated plots with no damage or less than 5% damage. Within Sowing 1, untreated Force and Exp A both had a lower proportion of roots with <5% damage than their respective treated plots. The results are displayed in Table 1.14 and Figure 1.11.

Table 1.14: The cumulative proportion of roots with less than 5% carrot fly damage from Sowing 1 and Sowing 2 on 27 November. Statistically significant differences in the treatment means are shown by the letters next to each mean. Treatment means with a letter in common are said to be not significantly different

Sowing	**1**		**2**	
Treatment				
1. Exp A - untreated	0.216	abcd	0.335	cdef
2. Exp A - treated	0.438	f	0.463	f
3. Exp B - untreated	0.241	bcde	0.249	bcd
4. Exp B - treated	0.274	bcde	0.395	ef
5. Force - untreated	0.066	a	0.344	cdef
6. Force - treated	0.317	bcdef	0.451	f
7. Exp C - untreated	0.165	ab	0.242	bc
8. Exp C - treated	0.189	abc	0.378	def
SED	0.0648			
LSD	0.1337			
df	24			

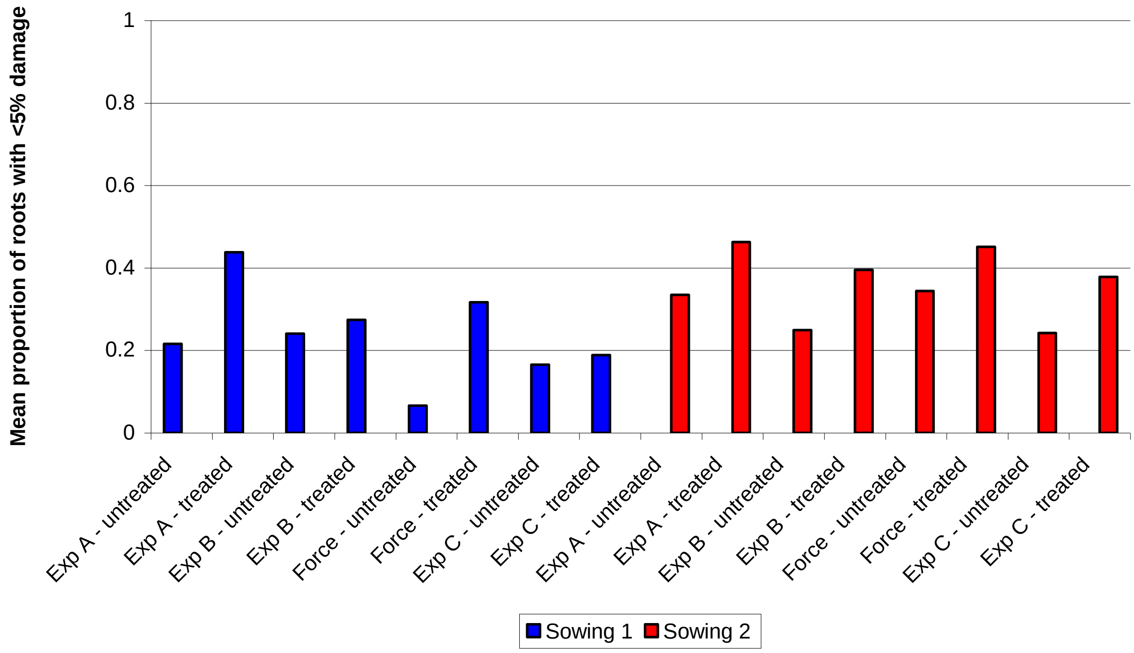

Figure 1.11: The proportion of roots with less than 5% carrot fly damage from Sowing 1 and Sowing 2 on 27 November

Experiment 1b

Materials and methods

The experiment was done within the field known as Sheep Pens at Warwick HRI, Wellesbourne. A population of carrot fly (*Psila rosae*) is maintained in an adjacent field (Long Meadow Centre).

The experiment was designed as a balanced row and column design. The field plots were 6 m x 1 bed (1.83 m each) in size and plots were separated by 1 m along beds. There were 4 replicates of each treatment and each plot consisted of two rows of insecticide-free carrots and two rows of carrots grown from insecticide-treated seed of the same carrot variety. The seed was drilled into different plots on two occasions (16 April and 22 May 2008) at a spacing of 100 seeds/m within rows and 0.38 m between rows. The treatments are listed in Table 1.15. One half (3 m) of each plot drilled on 16 April was covered with fine-mesh netting on 2 May to exclude aphids temporarily. The cover was subsequently removed on 10 June to allow aphid infestation. The purpose of this exercise was to expose the aphids to differently aged insecticide 'residues'. From July onwards, plots were treated with the 'Standard' programme for carrot fly control (Table 1.16).

Table 1.15: Seed treatments evaluated for the control of carrot fly and aphids on carrot

Code	Product code	Variety	Rate (mg a.i./seed)
1	Exp D – untreated	Nairobi	
2	Exp D – treated	Nairobi	0.5
3	Exp E – untreated	Fortuna	
4	Exp E – treated	Fortuna	0.07 + 0.023
5	Exp F – untreated	Dordogne	
6	Exp F – treated	Dordogne	0.06

Table 1.16: The spray program used to control carrot fly (H = Hallmark with Zeon Technology and D = Decis protech; Doses in ml product/ha)

Date	18 Jul	1 Aug	15 Aug	28 Aug	10 Sep	26 Sep
Treatment	H 150	H 100	H 100	H 100	D 500	D 500

To assess seedling emergence and seedling death due to feeding by carrot fly larvae, plant counts were made on a marked 0.5 m portion of each of the middle 2 rows in each plot (1 insecticide-free and 1 treated row). Assessments were made on 20 May, 13 June (first sowing) and 24 July (both sowings).

The numbers of winged, wingless and parasitized aphids were counted on the same 0.5 m portions of row on 2 June and 10 June (first sowing) and 19 June (both sowings).

On 18 July (between the first and second carrot fly generations) the 0.5 m marked areas, along with a further 0.5 m portion of row, were harvested from both sowings. The foliage was removed and the roots washed. The roots were stored in a cold store until assessment for damage due to carrot fly larvae. Further damage assessments were made on carrots taken from 1 m lengths of row on 15 December. Data were collected on the numbers of roots and the total weight of the roots per sample and the roots were classified into categories according to the extent of carrot fly damage. The damage categories were 0%, <5%, 5-10%, 10-25% and 25-50% of the surface area affected by carrot fly. These equate to damage scores of 0, 1, 2, 3, 4 and 5 respectively.

Analysis

The experiment was designed as a balanced row and column design with 4 rows and 6 columns resulting in 24 plots. All analyses were carried out using analysis of variance (ANOVA) with significant terms determined using an F probability value. Due to the structure of the design, it was not possible to evaluate all terms in a single ANOVA. To assess both the 'covering' and 'sowing' terms, two separate analyses were required.

Tables of means are shown for each analysis together with standard errors for the differences (SED) and 5% least significant differences (LSD) for pair-wise comparisons.

<u>Results</u>

Plant Counts

Plant counts were made on three occasions; 20 May, 13 June and 24 July. For the first two occasions, data were available only from the first sowing date.

20 May

No transformations of the data were required. Neither the variety nor the seed treatment main effects were significant (p = 0.631 and 0.327 respectively). The interaction term was also not significant (p = 0.944). The results of the analysis are summarised in Table 1.17 and Figure 1.12.

Table 1.17: Mean number of plants per metre length of row on 20 May 2008

	Untreated	**Treated**
Exp D	37.8	35.6
Exp E	36.3	34.6
Exp F	34.4	30.6
	Within variety	Between variety
SED	4.31	5.25
5% LSD	9.76	12.05

13 June

No transformations of the data were required. Neither the variety nor the seed treatment main effects were significant (p = 0.217 and 0.695 respectively). The interaction term was also not significant (p = 0.244). The results of the analysis are summarised in Table 1.18 and Figure 1.12.

Table 1.18: Mean number of plants per 0.5 metre length of row on 13 June 2008

	Untreated	**Treated**
Exp D	18.9	15.1
Exp E	23.0	30.7
Exp F	30.9	30.1
	Within variety	Between variety
SED	4.63	7.31
5% LSD	10.48	17.83

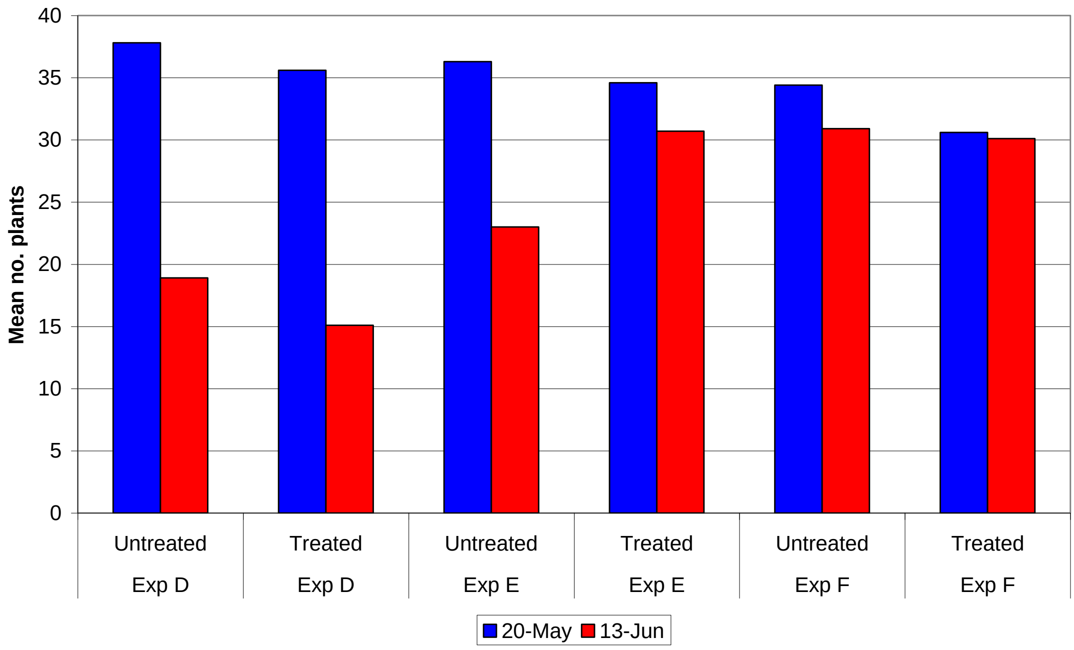

Figure 1.12: Mean number of plants per 0.5 metre length of row on 20 May and 13 June 2008

24 July

A square root transformation was used to ensure the homogeneity of variances between the treatments. Table 1.19 and Figure 1.13 summarise the results of the analysis. In particular, insecticide-treated plots in the first sowing of Exp E and Exp F had larger numbers of plants than their respective untreated controls. There were very few plants remaining in the Exp D plots (Sowing 1).

Table 1.19: Mean number of plants per 0.5 metre length of row on 24 July 2008

		Exp D	Exp E	Exp F
		Back-transformed	Back-transformed	Back-transformed
Sowing 1	Untreated	0.01	12.98	15.10
	Treated	0.02	24.98	23.25
Sowing 2	Untreated	37.77	31.19	30.45
	Treated	28.28	27.09	31.73
		Transformed	Transformed	Transformed
Sowing 1	Untreated	-0.104	3.603	3.886
	Treated	0.146	4.998	4.822
Sowing 2	Untreated	6.146	5.585	5.518
	Treated	5.318	5.205	5.633
		Within sowing	Between sowing	
	SED	0.4153	0.4279	
	5% LSD	0.8753	0.9039	

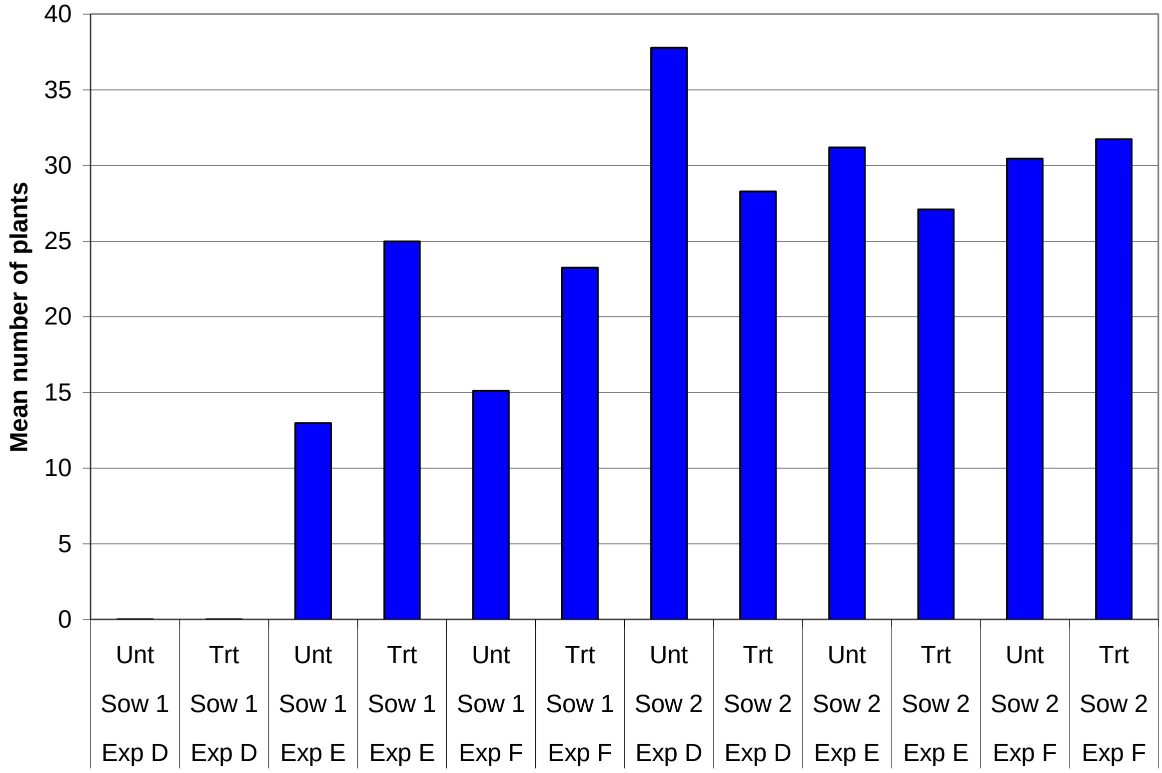

Figure 1.13: Mean number of plants per 0.5 metre length of row on 24 July 2008

Aphids

There were three assessments for aphids – on 2 June, 10 June and 19 June. Each assessment was treated independently. For all of the formal analyses using ANOVA, a square root transformation was used to ensure homogeneity between treatments.

For each assessment, data on the number of winged, wingless and parasitized aphids were analysed. For some assessments, there were insufficient non-zero data to carry out a formal analysis. In this case, simple tables displaying the totals are presented.

2 June

Winged Aphids

Neither the main effects for variety or insecticide were significant at a 5% level (p = 0.842 and 0.529 respectively). The interaction term was significant at the 10% level only (p = 0.091). The results of the analysis are summarised in Table 1.20 and Figure 1.14.

Table 1.20: Mean number of winged aphids per 0.5 metre length of row on 2 June 2008

	Exp D	**Exp E**	**Exp F**
	Back-transformed	Back-transformed	Back-transformed
Untreated	13.55	8.84	8.76
Treated	5.62	15.37	17.79
	Transformed	Transformed	Transformed
Untreated	3.682	2.973	2.96
Treated	2.37	3.92	4.218
	Within variety	Between variety	
SED	6.97	1.126	
5% LSD	1.783	2.686	

Wingless Aphids

The main effect of 'insecticide treatment' was significant (p<0.001). The main effect for variety was significant only at the 10% level (p=0.067), the interaction was not significant (p=0.146). The results of the analysis are summarised in Table 1.21 and Figure 1.14.

The insecticide-treated plants from Exp E and Exp F had fewer wingless aphids than the untreated plants. Exp D was the only variety that had substantial counts of wingless aphids on the insecticide-treated plants.

Table 1.21: Analysis of variance of mean number of wingless aphids per 0.5 metre length of row on 2 June 2008. Interaction between variety and insecticide treatment

	Exp D	**Exp E**	**Exp F**
	Back-transformed	Back-transformed	Back-transformed
Untreated	61.89	30.87	63.42
Treated	28.85	0.09	0.93
	Transformed	Transformed	Transformed
Untreated	7.867	5.556	7.964
Treated	5.371	0.308	0.966
	Within variety	Between variety	
SED	1.464	1.508	
5% LSD	3.311	3.335	

Parasitized Aphids

The main effect of insecticide treatment was significant (p<0.001). The main effects of variety and the variety and insecticide treatment interaction were not however (p=0.512, p=0.754).

There were consistently smaller numbers of parasitized aphids on the insecticide-treated plants (Exp D, E and F) (Table 1.22; Figure 1.14).

Table 1.22: Analysis of variance of mean number of parasitized aphids per 0.5 metre length of row on 2 June 2008. Interaction between variety and insecticide treatment

	Exp D	**Exp E**	**Exp F**
	Back-transformed	Back-transformed	Back-transformed
Untreated	3.043	1.982	2.831
Treated	0.248	0.02	0.001
	Transformed	Transformed	Transformed
Untreated	1.7444	1.408	1.6827
Treated	0.4983	0.143	0.0377
	Within variety	Between variety	
SED	0.497	0.461	
5% LSD	1.125	1.001	

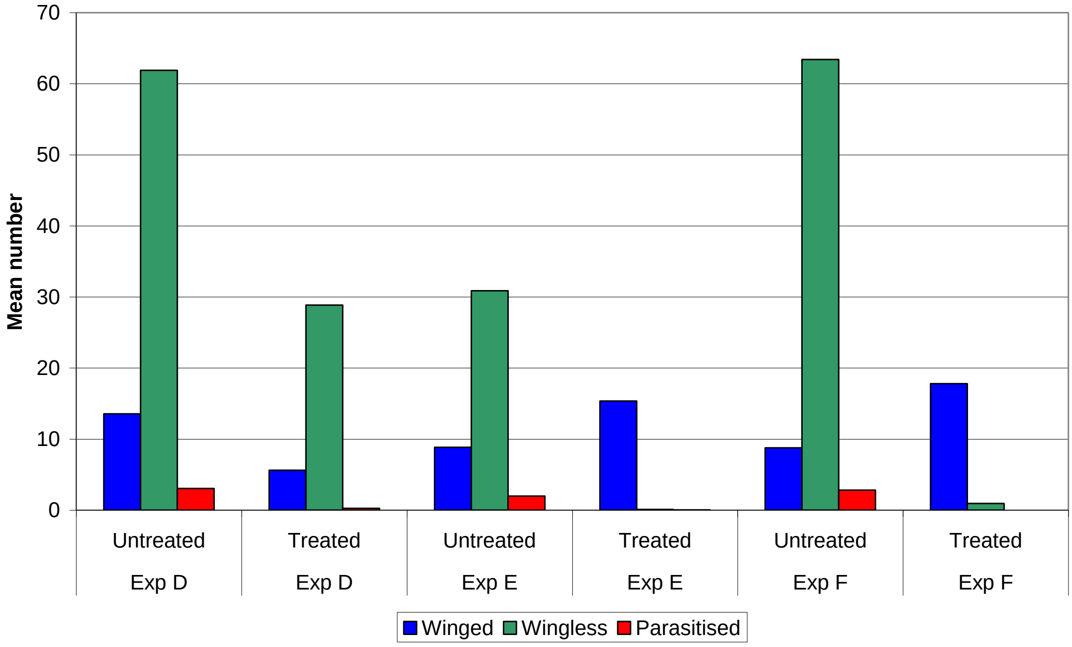

Figure 1.14: Mean number of aphids per 0.5 metre length of row on 2 June 2008

10 June

Winged Aphids

Neither the main effects for variety or insecticide treatment were significant (p=0.525; p=0.695). The interaction was also non-significant (p=0.202). The results of the analysis are summarised in Table 1.23 and Figure 1.15.

Table 1.23: Mean number of winged aphids per 0.5 metre length of row on 10 June 2008

	Exp D	**Exp E**	**Exp F**
	Back-transformed	Back-transformed	Back-transformed
Untreated	3.964	2.708	0.85
Treated	1.676	4.273	2.432
	Transformed	Transformed	Transformed
Untreated	-1.991	-1.646	-0.922
Treated	-1.295	-2.067	-1.56
	Within variety	Between variety	
SED	0.516	0.625	
5% LSD	1.168	1.433	

Wingless Aphids

No formal analysis was carried out due to a large number of zero counts within the data. There was a large number of wingless aphids on the untreated plants from Exp D relative to all other treatments (Table 1.24; Figure 1.15).

Table 1.24: Mean number of wingless aphids per 0.5 metre length of row on 10 June 2008

Insecticide	**Untreated**	**Treated**
Exp D	1	7
Exp E	0	0
Exp F	1	0

Parasitized Aphids

The main effect for insecticide treatment was significant at the 5% level (p=0.003) but no other terms were. There were statistically significant differences between the untreated and treated plants of Exp E and Exp F, with more parasitized aphids on the untreated plants (Table 1.25; Figure 1.15).

Table 1.25: Mean number of parasitized aphids per 0.5 metre length of row on 10 June 2008.

	Exp D	**Exp E**	**Exp F**
	Back-transformed	Back-transformed	Back-transformed
Untreated	6.637	4.419	15.03

Treated	3.225	0.007	0.024
	Transformed	Transformed	Transformed
Untreated	2.576	2.102	3.877
Treated	1.796	0.086	0.154
	Within variety	Between variety	
SED	0.928	0.843	
5% LSD	2.1	1.827	

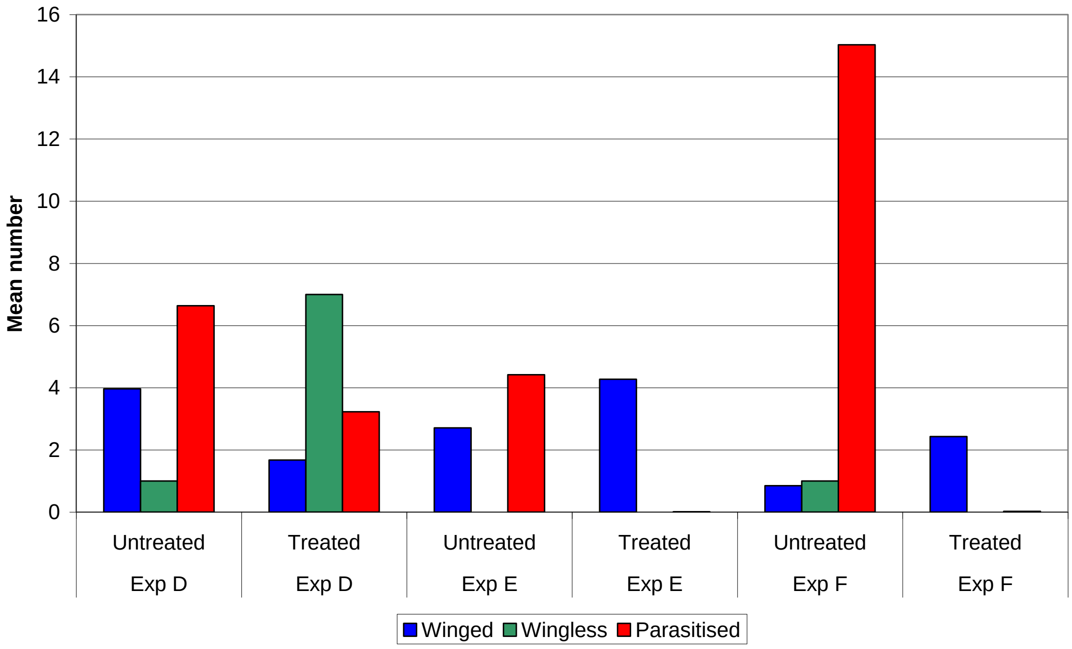

Figure 1.15: Mean number of aphids per 0.5 metre length of row on 10 June 2008

19 June

Two sets of analyses were carried out. The first analysis used the data from the uncovered areas in Sowings 1 and 2. Here the differences between sowing dates, as well as the differences between variety and seed treatments, were assessed. The second analysis compared the covered and uncovered plots from the first sowing date. Here the difference due to covering was assessed, as well as the difference between the variety and seed treatments.

Data from the uncovered areas in Sowings 1 and 2

Only the data for the wingless aphids are presented in this report.

Wingless Aphids

Table 1.26 and Figure 1.16 summarise the analysis. In particular, there were fewer wingless aphids on the insecticide-treated plants of Exp E and Exp F from Sowing 2 than on their respective untreated controls.

Table 1.26: Mean number of wingless aphids on 19 June 2008 – comparison of Sowing 1 and Sowing 2

		Exp D	Exp E	Exp F
Sowing		Back-transformed	Back-transformed	Back-transformed
1	Untreated	0.255	0.179	0.169
	Treated	0.925	0.033	0.008
2	Untreated	2.737	9.191	4.789
	Treated	5.483	0.028	0.002
		Transformed	Transformed	Transformed
1	Untreated	0.5046	0.4230	0.4106
	Treated	0.9618	-0.1806	-0.0894
2	Untreated	1.6545	3.0317	2.1883
	Treated	2.3415	0.1660	-0.0401
		Within sowing	Between sowing	
	SED	0.465	0.473	
	5% LSD	0.953	0.971	

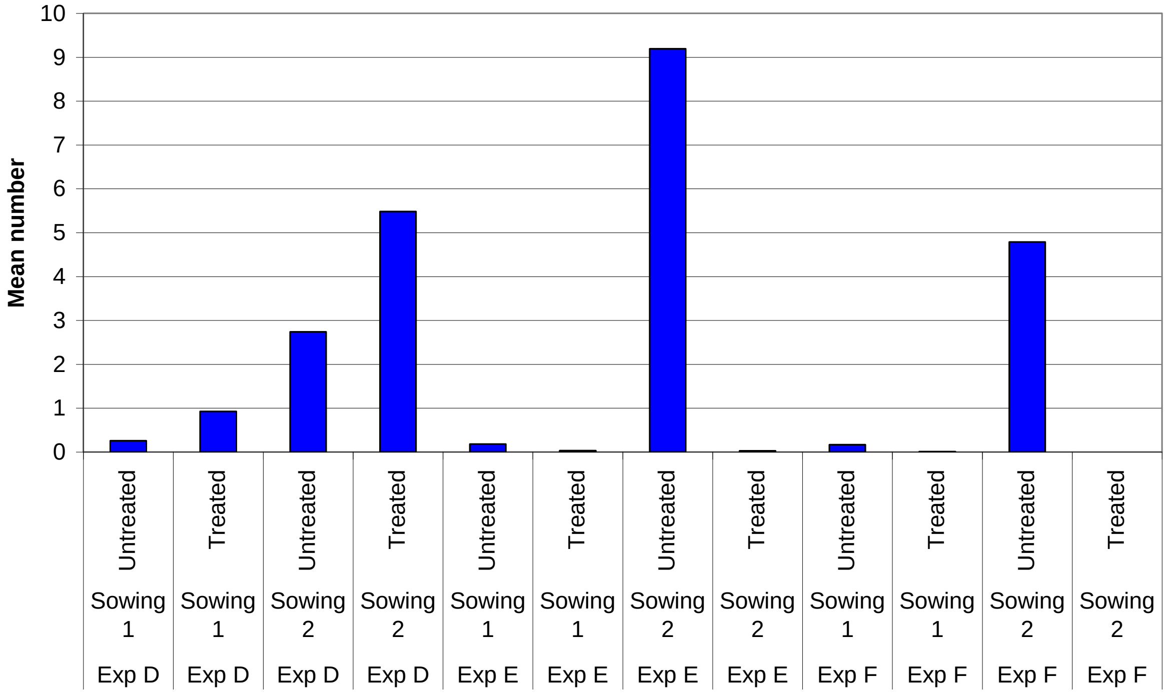

Figure 1.16: Mean number of wingless aphids on 19 June 2008 – comparison of Sowing 1 and Sowing 2

Data from the covered and uncovered areas – Sowing 1

Table 1.27 and Figure 1.17 summarise the analysis. There were more aphids on the untreated covered plots than on the untreated uncovered plots and this difference was statistically significant for Exp D. The insecticide applied to Exp E was still providing statistically-significant aphid control.

Table 1.27: Mean number of wingless aphids on 19 June 2008 – comparison of covered and uncovered plots

		Exp D	**Exp E**	**Exp F**
		Back-transformed	Back-transformed	Back-transformed
Covered	Untreated	3.8598	2.9538	1.1852
	Treated	1.4997	0.0049	0.2354
Uncovered	Untreated	0.2542	0.4533	0.1816
	Treated	0.924	0.0049	0.0055
		Transformed	Transformed	Transformed
Covered	Untreated	1.9646	1.7187	1.0887
	Treated	1.2246	0.0697	0.4851
Uncovered	Untreated	0.5042	0.6733	0.4261
	Treated	0.9613	0.0697	-0.0739
		Within covering	Between covering	
	SED	0.528	0.613	
	5% LSD	1.084	1.295	

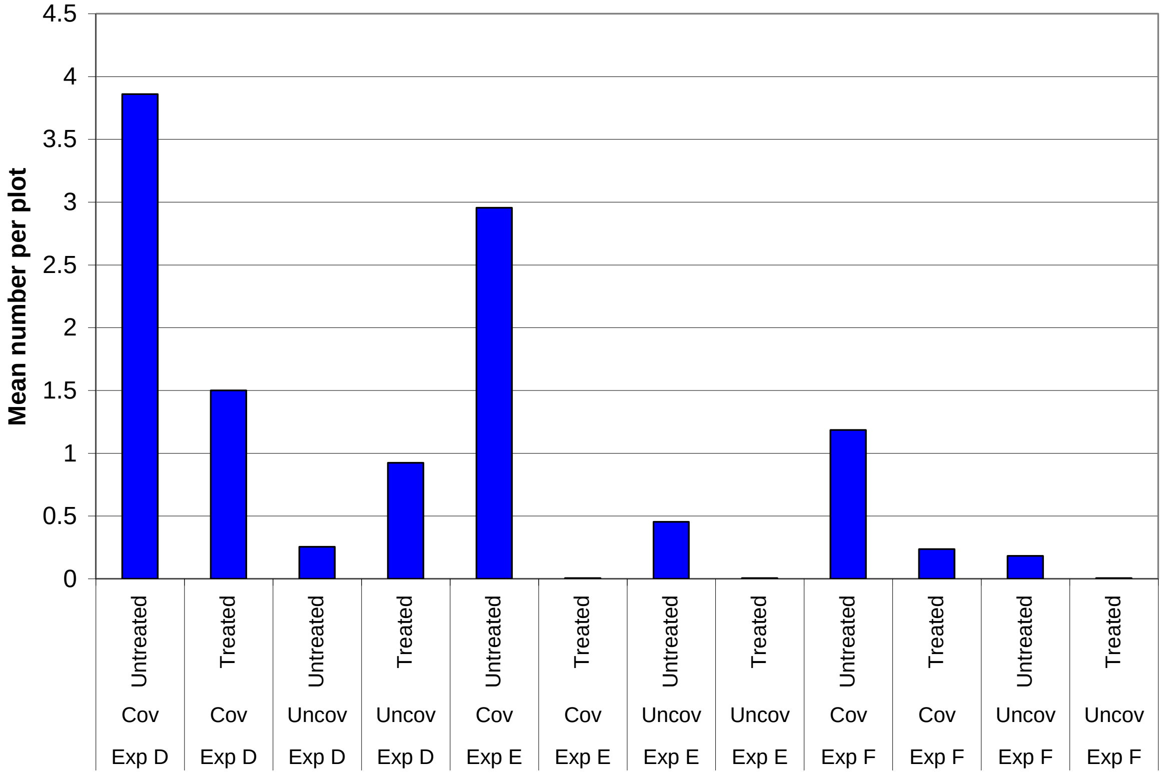

Figure 1.17 Mean number of wingless aphids on 19 June 2008 – comparison of covered and uncovered plots

Carrot Fly Damage

Assessments on carrot fly damage were carried out on 18 July and 15 December 2008. Only data from the uncovered plots were analysed.

18 July

Proportion undamaged roots

Table 1.28 and Figure 1.18 summarise the analysis. The insecticide treatment applied to Exp F reduced carrot fly damage in Sowing 1 plots.

Table 1.28: Proportion of undamaged roots on 18 July

	Sowing 1		Sowing 2	
Product	Treated	Untreated	Treated	Untreated
Exp D	0.568	0.697	0.996	0.995
Exp E	0.819	0.700	0.978	0.915
Exp F	0.852	0.547	1.005	1.007
		Within sowing	Between sowing	
	SED	0.1066	0.1085	
	5% LSD	0.2189	0.2232	

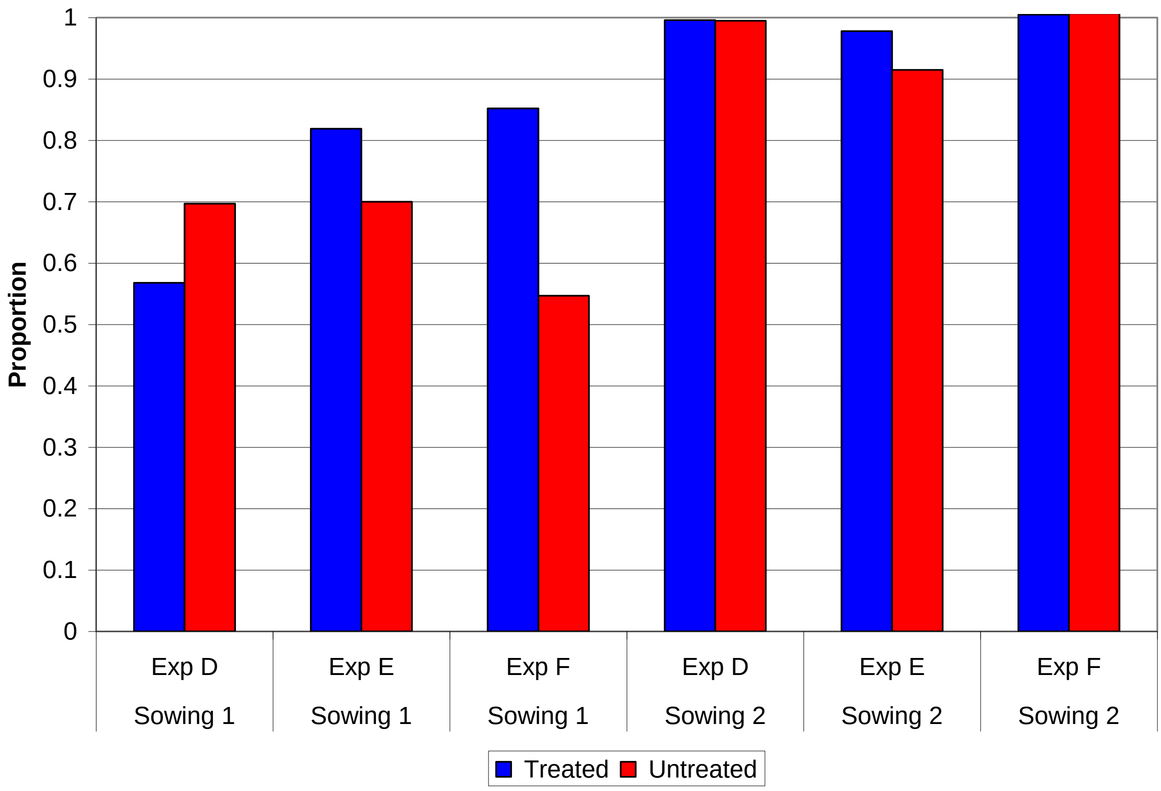

Figure 1.18: Proportion of undamaged roots on 18 July

Proportion of roots showing <5% carrot fly damage

Table 1.29 and Figure 1.19 summarise the analysis. The roots from the insecticide-treated plots of Exp D were more damaged than those from the untreated plots.

Table 1.29: Proportion of roots showing <5% carrot fly damage on 18 July

	Sowing 1		Sowing 2	
Product	Treated	Untreated	Treated	Untreated
Exp D	0.611	0.906	0.991	0.991
Exp E	0.941	0.794	1.003	0.990
Exp F	0.969	0.789	1.018	1.018
		Within sowing	Between sowing	
	SED	0.1084	0.1098	
	5% LSD	0.2227	0.2254	

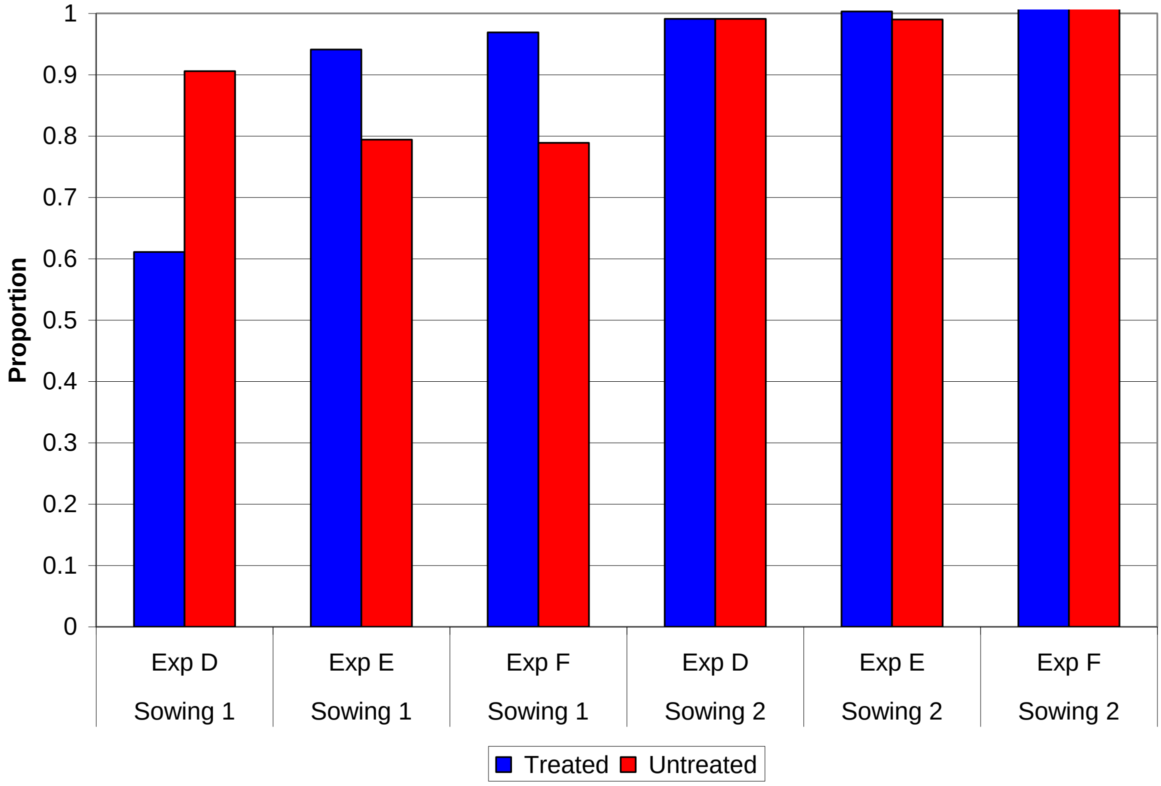

Figure 1.19: Proportion of roots showing <5% carrot fly damage on 18 July 2008

Mean carrot fly damage score

Table 1.30 and Figure 1.20 summarise the analysis. There were no statistically significant differences in the mean damage score.

Table 1.30: Mean carrot fly damage score on 18 July 2008

	Sowing 1		Sowing 2	
Product	Treated	Untreated	Treated	Untreated
Exp D	1.327	0.552	0.015	0.016
Exp E	0.259	0.899	-0.003	0.074
Exp F	0.216	0.861	-0.033	-0.035
		Within sowing	Between sowing	
	SED	0.4124	0.4192	
	5% LSD	0.8463	0.8606	

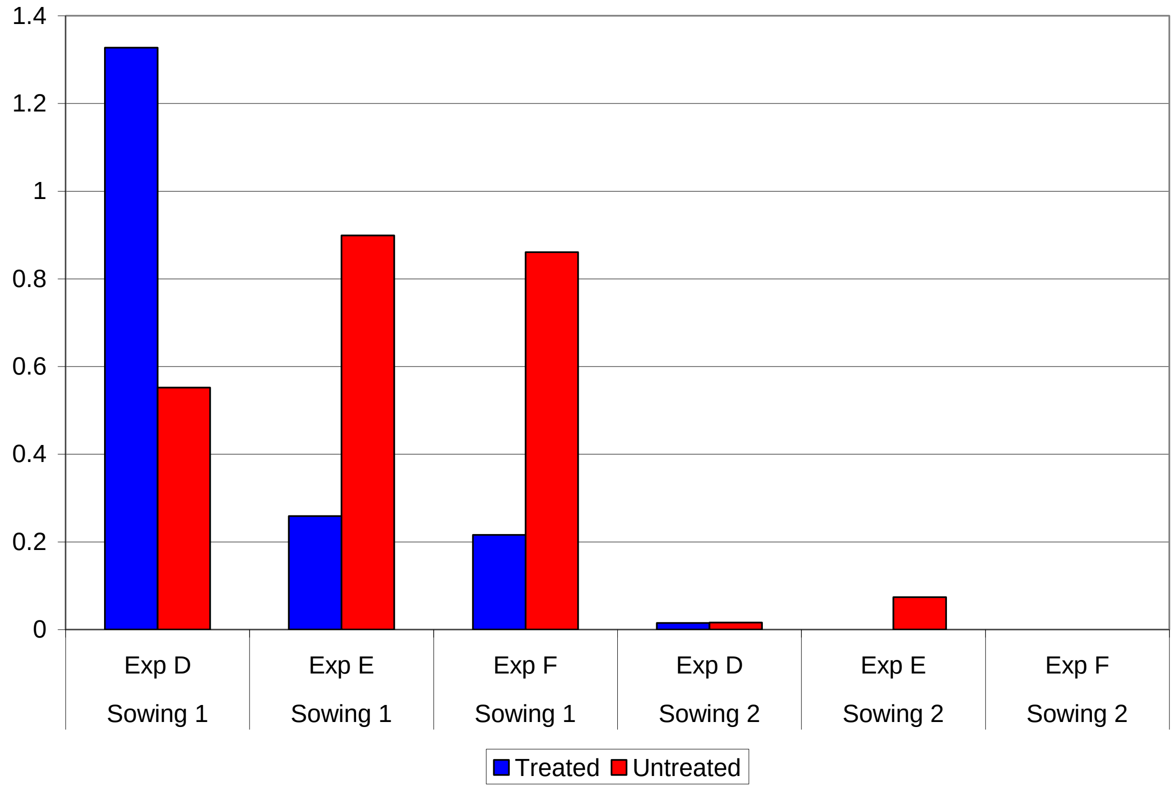

Figure 1.20: Mean carrot fly damage score on 18 July 2008

Mean Weight

Considering the variety and insecticide treatment interaction, the untreated samples had the smallest means; although the differences between untreated and treated samples were only significant for Exp E and Exp F (Table 1.31; Figure 1.21).

Table 1.31: Mean weight of roots per sample on 18 July

	Sowing 1		Sowing 2	
	Treated	Untreated	Treated	Untreated
Exp D	1.36	1.17	6.45	6.63
Exp E	13.68	3.29	12.32	9.55
Exp F	22.09	4.36	8.85	7.27
	Within sowing	Within variety Sowing	Within sowing insecticide	Between varieties
SED	2.548	2.165	2.548	2.615
5% LSD	5.304	4.568	5.304	5.455

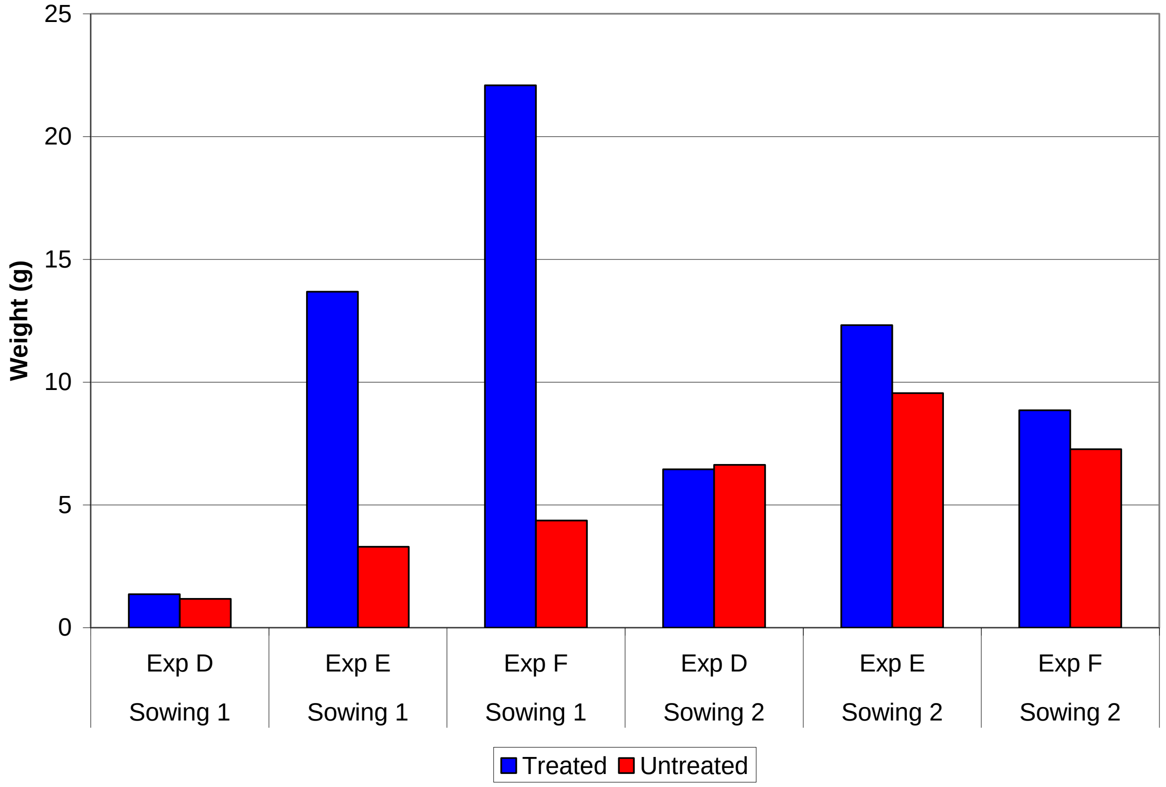

Figure 1.21: Mean weight of roots per sample on 18 July

15 December

Proportion of undamaged roots

No transformations of the data were required. Table 1.32 and Figure 1.22 show the proportion of undamaged roots on 15 December 2008. The insecticides applied to Exp E and Exp F increased the proportion of undamaged roots on Sowings 1 and 2 (Exp E) and Sowing 1 only (Exp F).

Table 1.32: Proportion undamaged roots on 15 December 2008

	Sowing 1		**Sowing 2**	
Product	Untreated	Treated	Untreated	Treated
Exp D	0.25	0.224	0.487	0.542
Exp E	0.325	0.524	0.428	0.623
Exp F	0.332	0.535	0.483	0.641
		Within sowing	Between sowing	
	SED	0.0817	0.0834	
	5% LSD	0.1636	0.1671	

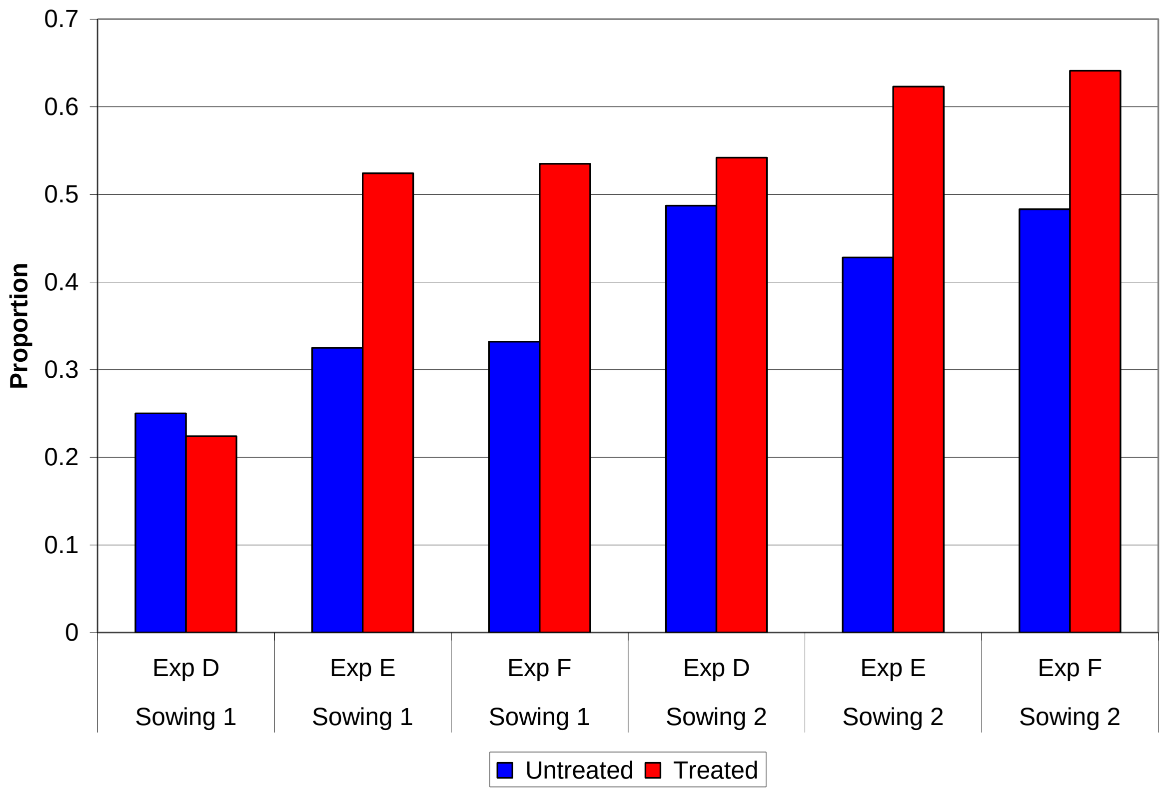

Figure 1.22: Proportion undamaged on 15 December 2008

Proportion of roots with <5% carrot fly damage

No transformations of the data were required. Table 1.33 and Figure 1.23 show the proportion of roots with <5% damage on 15 December 2008. The insecticides applied to Exp E and Exp F increased the proportion of roots with <5% damage in Sowing 2.

Table 1.33: Proportion of roots with <5% carrot fly damage on 15 December 2008

	Sowing 1		**Sowing 2**	
Product	Untreated	Treated	Untreated	Treated
Exp D	0.367	0.440	0.686	0.749
Exp E	0.546	0.673	0.597	0.805
Exp F	0.572	0.722	0.669	0.851
		Within sowing	Between sowing	
	SED	0.0827	0.0845	
	5% LSD	0.1657	0.1693	

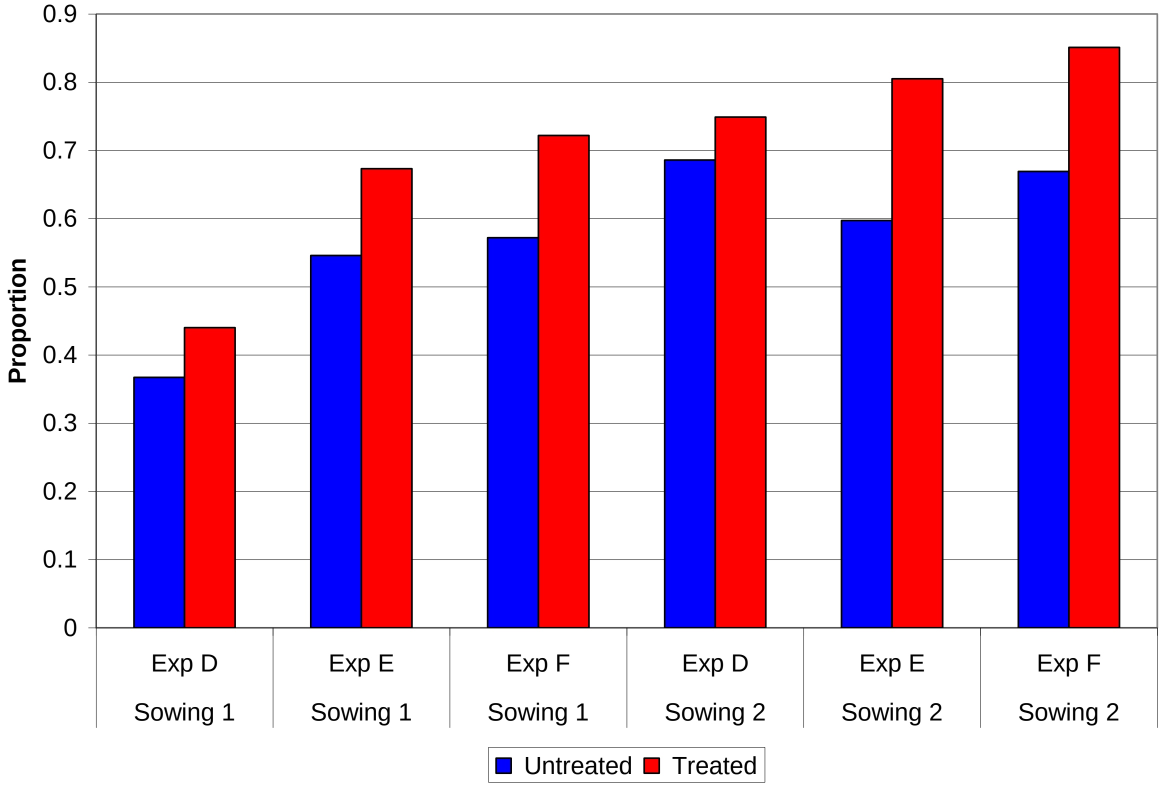

Figure 1.23: Proportion of roots with <5% carrot fly damage on 15 December 2008

Mean carrot fly damage score

No transformations of the data were required. Table 1.34 and Figure 1.24 show the proportion of roots with <5% damage on 15 December 2008. The insecticide applied to Exp E reduced the mean damage score in Sowings 1 and 2.

Table 1.34: Mean carrot fly damage score on 15 December 2008

	Sowing 1		Sowing 2	
Product	Untreated	Treated	Untreated	Treated
Exp D	2.009	1.820	1.061	0.879
Exp E	1.508	0.981	1.219	0.634
Exp F	1.321	0.913	1.033	0.606
		Within sowing	Between sowing	
	SED	0.2305	0.2354	
	5% LSD	0.4618	0.4716	

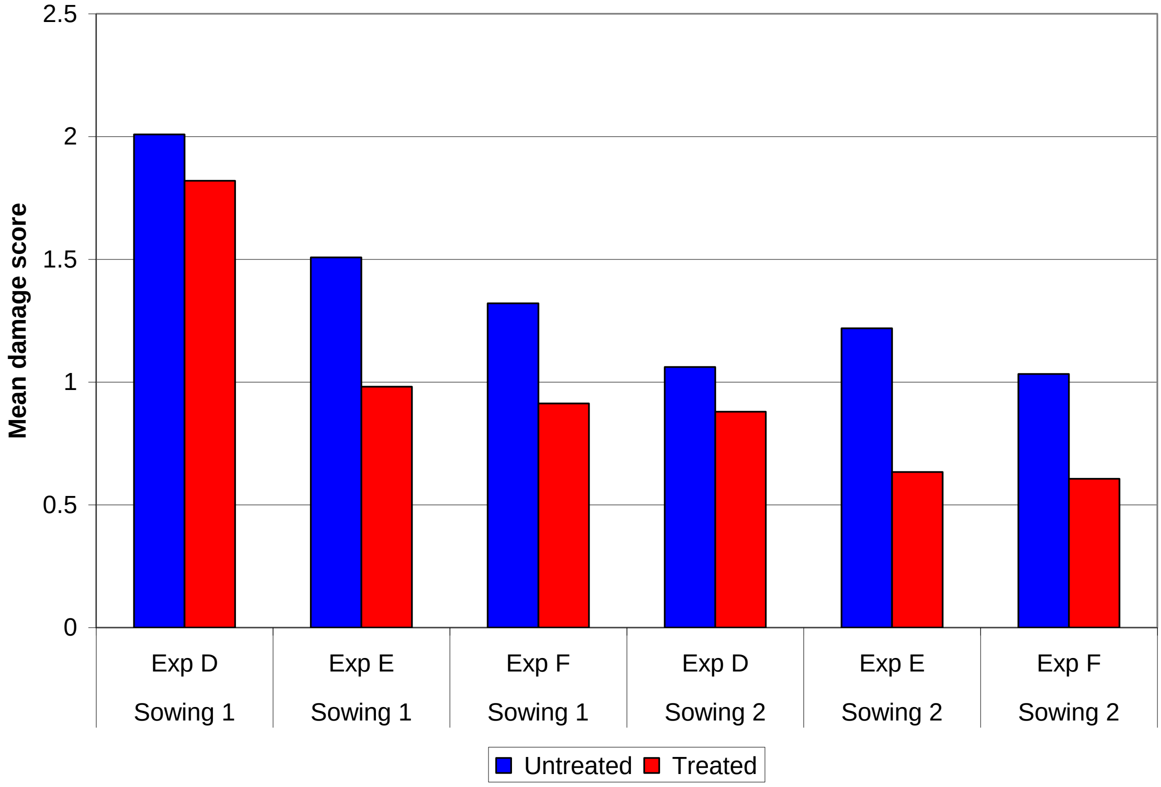

Figure 1.24: Mean carrot fly damage score on 15 December 2008

Mean weight of roots

For Sowing 1, the yield from Exp E and Exp F grown from insecticide-treated seed was considerably larger than the respective untreated controls (Table 1.35; Figure 1.25). There were no other differences between insecticide-treated and untreated plots.

Table 1.35 The mean weight of carrots grown from insecticide-treated and insecticide-free seed on 15 December 2008

	Sowing 1		**Sowing 2**	
Product	Untreated	Treated	Untreated	Treated
Exp D	27.4	39.1	52.1	50.1
Exp E	25.1	47.8	48.1	58.8
Exp F	36.4	60.1	55.5	67.2
		Within sowing	Between sowing	
	SED	7.08	7.23	
	5% LSD	14.18	14.49	

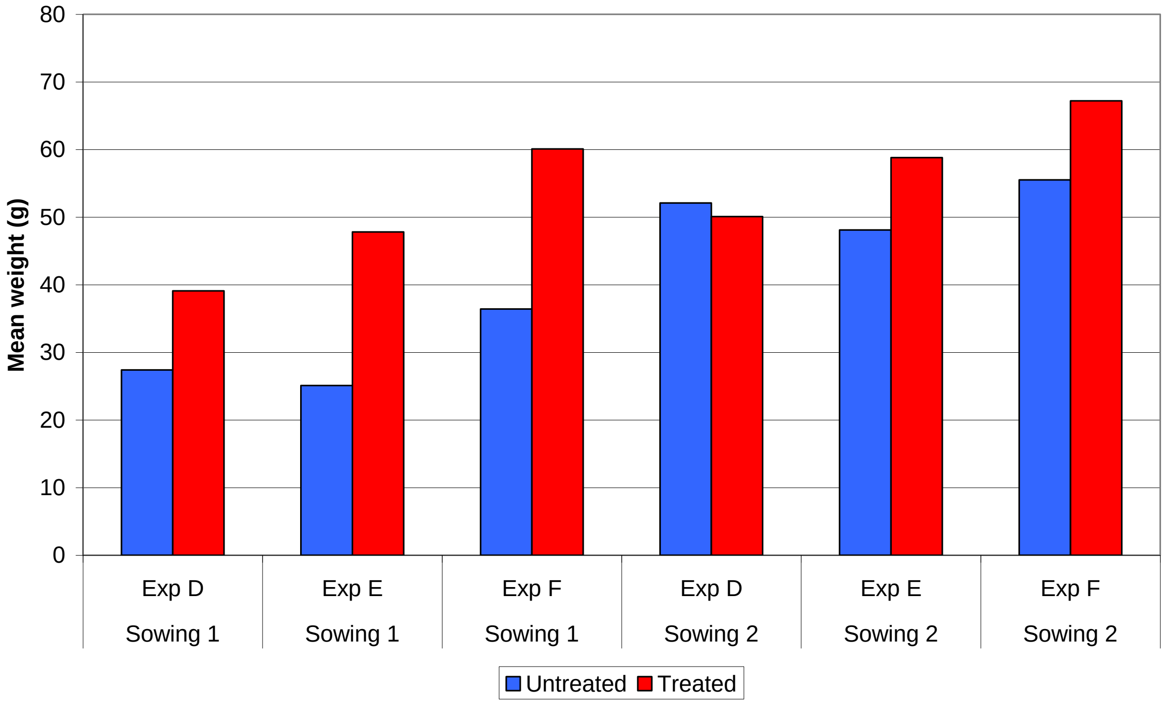

Figure 1.25: The mean weight of carrots grown from insecticide-treated and insecticide-free seed on 15 December 2008

Novel spray treatments to control carrot fly on carrot

Experiment 2a

Materials and methods

The experiment was done within the field known as Sheep Pens at Warwick HRI, Wellesbourne which is adjacent to the field (Long Meadow Centre) where the population of carrot fly is maintained.

The experiment was originally designed as a Trojan Square for 12 treatments each replicated 4 times. The experiment actually comprised 10 treatments replicated 4 times and an insecticide-free control treatment replicated 8 times. The field plots were 6 m x 1 bed (1.83 m each) in size and plots were separated by 1 m along beds. Seed (cv Nairobi) was drilled on 23 May 2007 at a spacing of 100 seeds/m within rows and 0.38 m between rows. Spraying commenced on 19 July (timed according to the Warwick HRI/HDC carrot fly forecast) and spray programmes were followed as described in Table 2.2 using the products specified in Table 2.1.

Root samples were taken on 22 November and assessed for carrot fly damage and further samples were taken in spring 2008 to determine the effects of the treatments on damage development during the winter.

Table 2.1: The products used in the spray programmes to control carrot fly

Spray code	Product or code	Active Ingredient	Rate (product/ha)
H 100	Hallmark with Zeon Technology	Lambda-cyhalothrin	100 ml
H 150	Hallmark with Zeon Technology	Lambda-cyhalothrin	150 ml
D 500	Decis Protech	Deltamethrin	500 ml
B 400	Biscaya	Thiacloprid	400 ml
S 500	Exp S		500 g
S 750	Exp S		750 g
T 400	Exp T		400 g

Table 2.2: Spray programmes for carrot fly control in carrots

	Date	18 Jul	1 Aug	15 Aug	29 Aug	12 Sept	26 Sept	10 Oct
	Days	**0**	**14**	**28**	**42**	**56**	**70**	**84**
1	Untreated	Insecticide-free	Insecticide-free	Insecticide-free	Insecticide-free	Insecticide-free	Insecticide-free	Insecticide-free
2	Hall 100 x 4; Decis x 2	H 100	H 100	H 100	H 100	D 500	D 500	
3	Hall 150; Hall 100 x 3; Decis x 2	H 150	H 100	H 100	H 100	D 500	D 500	
4	Exp S 500 x 4; Decis x 2	S 500	S 500	S 500	S 500	D 500	D 500	
5	Exp S 750 x 4; Decis x 2	S 750	S 750	S750	S 750	D 500	D 500	
6	Biscaya x 4; Decis x 2	B 400	B 400	B 400	B 400	D 500	D 500	
7	Hall 150 x 3; Exp T 400 x 2; Decis x 1	H 150	H 150	H 150	T 400	T 400	D 500	
8	Exp T 400 x 2; Hall 150 x 3; Decis X 1	T 400	T 400	H 150	H 150	H 150	D 500	
9	Hall 150 x 3; Exp T 400 x 2; Decis x 2	H 150	H 150	H 150	T 400	T 400	D 500	D 500
10	Hall 150; Hall 100 x 3; Exp T 400 x 2	H 150	H 100	H 100	H 100	T 400	T 400	
11	Decis x 6	D 500	D 500	D 500	D 500	D 500	D 500	

Analysis

In order to use the full design structure in the analysis Residual Maximum Likelihood (REML) rather than Analysis of Variance (ANOVA) was used.

Results

Data were collected on the number of plants (roots) and the total weight of the roots 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%. Only two plots (both untreated) recorded damage > 50% and therefore this category was not analysed. The variables analysed were the total weight and number of roots, the mean weight of roots, the proportion of roots in each damage category and a mean damage score. The mean damage score was calculated for each plot 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

There were some statistically significant treatment differences in the total weight of roots (Table 2.3) but not in the plant count. The untreated plots had a higher mean damage score than all of the other treatments (Table 2.3; Figure 2.1) and the programme beginning with 4 sprays of Biscaya was the least effective. Programmes beginning with Exp T or Decis also appeared to be less effective than some of the other programmes. Two SEDs and corresponding 95% LSD were calculated due to the extra replication of the untreated control.

Table 2.3: The total weight of carrot roots in 1 metre of row, the mean weight of individual roots, the mean damage score and the total number of plants sampled on 22 November 2007. Statistically significant differences in the treatment means are shown by the letters next to each mean. Treatment means with a letter in common are said to be not significantly different

	Treatment	Total weight		Mean weight	Mean damage score		Total plant (root) count
1	Untreated	5552	a	53.60	1.48	d	104.9
2	Hall 100 x 4; Decis x 2	5369	a	54.29	0.51	a	107.3
3	Hall 150; Hall 100 x 3; Decis x 2	5752	ab	58.36	0.39	a	98.7
4	Exp S 500 x 4; Decis x 2	6714	c	65.36	0.56	ab	103.7
5	Exp S 750 x 4; Decis x 2	6605	bc	64.29	0.56	ab	104.9
6	Biscaya x 4; Decis x 2	6049	abc	63.77	1.08	c	96.9
7	Hall 150 x 3; Exp T 400 x 2; Decis x 1	6039	abc	57.04	0.41	a	106.4
8	Exp T 400 x 2; Hall 150 x 3; Decis X 1	6700	c	64.71	0.97	bc	106.4
9	Hall 150 x 3; Exp T 400 x 2; Decis x 2	5882	abc	53.76	0.51	a	114.0
10	Hall 150; Hall 100 x 3; Exp T 400 x 2	6257	abc	58.91	0.36	a	108.8
11	Decis x 6	6057	abc	57.03	0.93	bc	107.1
	Wald	2.14		1.03	8.72		0.27
	p-value	0.019		0.413	<0.001		0.987
	SED (Tmt v Control)	378.4		5.88	0.177		10.9
	SED (Tmt v Tmt)	436.9		6.82	0.205		12.6
	LSD (Tmt v Control)	770.0		11.97	0.360		22.2
	LSD (Tmt v Tmt)	889.1		13.88	0.417		25.6
	df	10		10	10		10

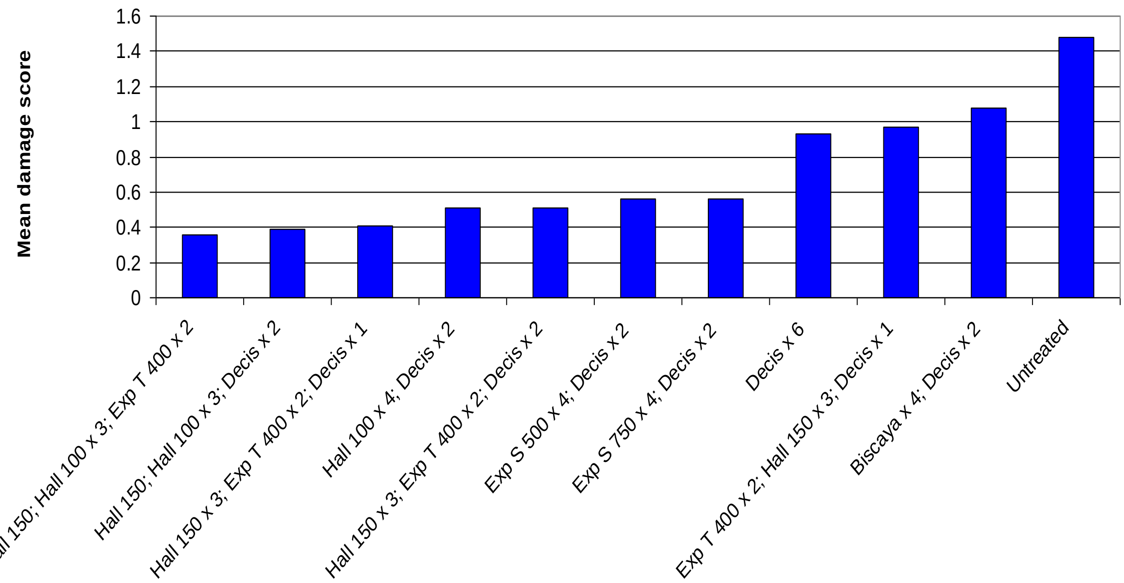

Figure 2.1: The mean damage score of carrot roots sampled on 22 November 2007

The proportions of roots with no damage are shown in Table 2.4. The untreated plots had the lowest proportion of undamaged roots (31%), whereas 74% roots were undamaged as a result of the most effective spray programme. The analysis confirmed that the programmes beginning with Biscaya, Exp T and Decis were the least effective.

Table 2.4: The proportion of carrot roots sampled on 22 November 2007 with no carrot fly damage. Statistically significant differences in the treatment means are shown by the letters next to each mean. Treatment means with a letter in common are said to be not significantly different

	Treatment	Proportion with no damage	
1	Untreated	0.315	a
2	Hall 100 x 4; Decis x 2	0.678	c
3	Hall 150; Hall 100 x 3; Decis x 2	0.741	c
4	Exp S 500 x 4; Decis x 2	0.651	c
5	Exp S 750 x 4; Decis x 2	0.667	c
6	Biscaya x 4; Decis x 2	0.410	ab
7	Hall 150 x 3; Exp T 400 x 2; Decis x 1	0.718	c
8	Exp T 400 x 2; Hall 150 x 3; Decis X 1	0.464	b
9	Hall 150 x 3; Exp T 400 x 2; Decis x 2	0.670	c
10	Hall 150; Hall 100 x 3; Exp T 400 x 2	0.737	c
11	Decis x 6	0.486	b
	Wald	13.23	
	p-value	<0.001	
	SED (Tmt v Control)	0.0572	
	SED (Tmt v Tmt)	0.0662	
	LSD (Tmt v Control)	0.1164	
	LSD (Tmt v Tmt)	0.1347	
	df	10	

The proportions of roots with less than 5% carrot fly damage were analysed. An arcsin transformation was needed to improve the underlying assumptions of the analysis. The transformed and back-transformed means (in italics) are given in Table 2.5. Figures 2.2 and 2.3 show the proportion of carrot roots with <5% damage due to carrot fly on 22 November 2007 and 6 February 2008 respectively.

Table 2.5: The cumulative proportion of carrot roots sampled on 22 November 2007 with <5% carrot fly damage. Statistically significant differences in the treatment means are shown by the letters next to each mean. Treatment means with a letter in common are said to be not significantly different. Back-transformed means are shown in italics

	Treatment	<5% damage		
1	Untreated	0.551	a	*0.523*
2	Hall 100 x 4; Decis x 2	1.046	de	*0.865*
3	Hall 150; Hall 100 x 3; Decis x 2	1.140	de	*0.909*
4	Exp S 500 x 4; Decis x 2	1.000	cd	*0.841*
5	Exp S 750 x 4; Decis x 2	1.064	de	*0.874*
6	Biscaya x 4; Decis x 2	0.687	ab	*0.634*
7	Hall 150 x 3; Exp T 400 x 2; Decis x 1	1.111	de	*0.896*
8	Exp T 400 x 2; Hall 150 x 3; Decis X 1	0.820	bc	*0.731*
9	Hall 150 x 3; Exp T 400 x 2; Decis x 2	1.082	de	*0.883*
10	Hall 150; Hall 100 x 3; Exp T 400 x 2	1.196	e	*0.931*
11	Decis x 6	0.785	b	*0.707*
	Wald	13.43		
	p-value	<0.001		
	SED (Tmt v Control)	0.0809		
	SED (Tmt v Tmt)	0.0935		
	LSD (Tmt v Control)	0.1646		
	LSD (Tmt v Tmt)	0.1903		
	df	10		

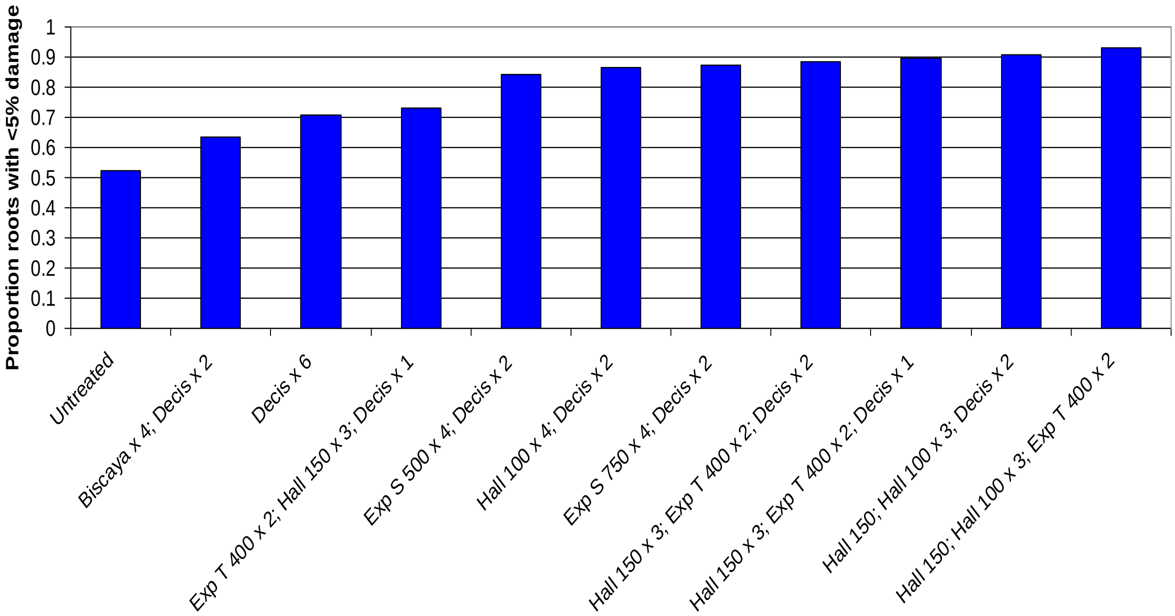

Figure 2.2: The proportions of carrot roots with <5% damage due to carrot fly on 22 November 2007

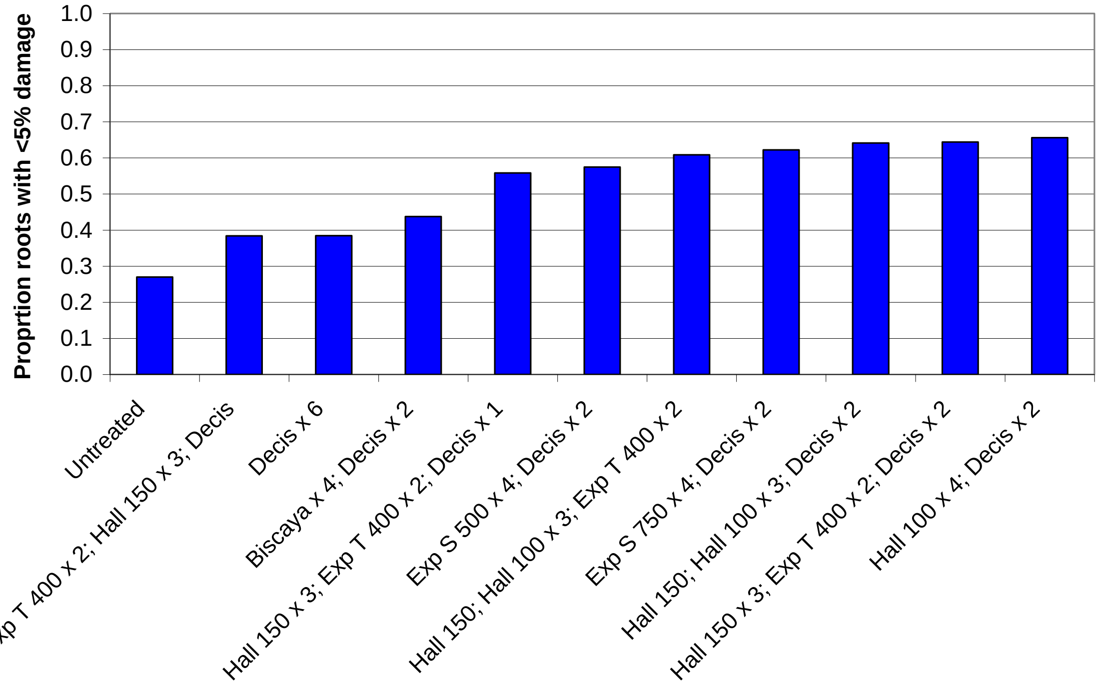

Figure 2.3: The proportions of carrot roots with <5% damage due to carrot fly on 6 February 2008

Experiment 2b

<u>Materials and methods</u>

The experiment was done within the field known as Long Meadow Centre at Warwick HRI, Wellesbourne, which is where the population of carrot fly is maintained.

The experiment was designed using a balanced row and column design with 4 rows and 10 columns. Including an untreated control, there were 10 treatments within the experiment (1 replicate within each row). The field plots were 5.5 m x 1 bed (1.83 m each) in size and plots were separated by 1 m along beds. Seed (cv Nairobi) was drilled on 5 June at a spacing of 100 seeds/m within rows and 0.38 m between rows. Herbicide was applied to the plot areas only, avoiding the inter-plot spaces. These 1 m areas were left to develop weeds to provide oviposition sites for the turnip moth (cutworm). To encourage the dispersal of any cutworm, the resulting weeds were rotavated-in on 4 August. Spraying commenced on 18 July (timed according to the Warwick HRI/HDC carrot fly forecast) and spray programmes were followed as described in Table 2.7 using the products specified in Table 2.6. All sprays were applied in 300l water/ha using a knapsack sprayer fitted with 02F110 nozzles.

Root samples were taken on 1 December 2008 and 15 January 2009 and assessed for carrot fly damage.

Table 2.6: The products used in the spray programmes to control carrot fly in 2008

Spray code	Product or code	Active Ingredient	Rate (product/ha)
H 100	Hallmark with Zeon Technology	Lambda-cyhalothrin	100 ml
H 150	Hallmark with Zeon Technology	Lambda-cyhalothrin	150 ml
D 500	Decis Protech	Deltamethrin	500 ml
X1	Exp X1		1500 ml
X2	Coragen	DuPont™ Rynaxypyr® (active ingredient chlorantraniliprole)	175 ml
A 400	Actara	Thiamethoxam	400 g
T 200	Tracer	Spinosad	200 ml
P	Exp P		2400 ml
N	Exp N		1000 ml
Untreated			

Table 2.7: Spray programmes for carrot fly control in 2008

		18 Jul	1 Aug	15 Aug	28 Aug	10 Sep	26 Sep
1	Standard programme	H 150	H 100	H 100	H 100	D 500	D 500
2	Tracer	T 200	T 200	H 150	H 100	H 100	H 100
3	Exp X1 - first	X1	X1	H 150	H 100	H 100	H 100
4	Coragen - first	X2	X2	H 150	H 100	H 100	H 100
5	Actara	H 150	Actara	H 100	Actara	H 100	H 100
6	Exp X1 - second	H 150	X1	H 100	X1	H 100	H 100
7	Coragen - second	H 150	X2	H 100	X2	H 100	H 100
8	Exp P	P	P	P	P	P	P
9	Exp N	N	N	N	N	N	N
10	Untreated						

Results

Analysis was carried out using analysis of variance (ANOVA). No transformations of the data were required to ensure homogeneity of the variances between treatments.

1 December 2008

Table 2.8 shows the mean damage score, the proportions of undamaged plants and of plants showing <5% damage as well as the total number of roots assessed and the total weight of roots. The treatment factor for the mean damage score was significant at a 5% level. The untreated control had the largest mean damage score. This was significantly larger than the mean for all other treatments. Only treatments Exp X1 - first, Coragen - first, Exp X1 - second and Coragen - second had means significantly smaller than the industry standard. The treatment factor for the proportion of undamaged roots was significant at a 5% level. The Standard programme, Exp X1 - first, Coragen - first, Actara, Exp X1 - second, and Coragen - second had more undamaged roots than the untreated control. Treatments Exp X1 - first, Coragen - first, Exp X1 - second and Coragen - second had more undamaged roots than the industry standard.

The treatment factor for the proportion of plants showing <5% damage was significant at a 5% level. All treatments had a larger proportion of roots with <5% damage than the untreated control. The proportions of plants with <5% damage from treatments Exp X1 - first, Coragen - first, Exp X1 - second and Coragen - second were significantly larger than the industry standard. The treatment factors for the total number or total weight of roots were not significant at a 5% level.

Table 2.8: Assessments on roots harvested on 1 December 2008

	Treatment	**Mean root damage score**	**Proportion of roots with no damage**	**Proportion of roots with <5 % damage**	**Total number of roots assessed**	**Total weight of roots assessed**
1 – Standard	Standard programme	1.561	0.301	0.502	106.3	5924
2	Tracer	2.018	0.187	0.372	91.5	4928
3	Exp X1 - first	0.063	0.940	0.991	98.9	7020
4	Coragen - first	0.504	0.669	0.875	94.3	5995
5	Actara	1.219	0.383	0.612	67.1	6277
6	Exp X1 - second	0.206	0.863	0.964	64.3	6038
7	Coragen - second	0.497	0.688	0.857	97.0	6145
8	Exp P	1.796	0.258	0.415	86.1	5488
9	Exp N	1.93	0.204	0.372	131.3	6177
10 - Control	Untreated	2.704	0.068	0.168	85.9	4758
F-Value		17.63	22.660	19.730	2.110	2.250
P-Value		<.001	<.001	<.001	0.072	0.056
SED		0.304	0.0925	0.0935	18.640	632.0
5% LSD		0.6288	0.1913	0.1933	38.570	1307.4
df		23	23	23	23	23

<u>15 January 2009</u>

Table 2.9 shows the mean damage score and the proportions of undamaged plants and of plants showing <5% damage as well as the total number of roots assessed and the total weight of roots.

The treatment factor for the mean damage score was significant at a 5% level. All treatments had mean scores that were significantly smaller than the untreated control. Only treatments Exp X1 - first, Coragen - first, Exp X1 - second and Coragen - second had means significantly smaller than the industry standard.

The treatment factor was significant at a 5% level for the proportion of undamaged plants. Pair-wise comparisons show that Treatments Exp X1 - first, Coragen - first, Actara, Exp X1 - second and Coragen - second had means significantly larger than the untreated control. Only Treatments Coragen - first, Exp X1 - second and Coragen - second had means that were larger than the industry standard.

The treatment factor was significant at a 5% level for the cumulative proportion of plants showing less than 5% damage. The mean for the untreated control was smaller than that for the Standard programme, Tracer, Exp X1 - first, Coragen - first, Actara, Exp X1 - second and Coragen - second. The mean for the industry standard was smaller than that for Treatments Exp X1 - first, Coragen - first, Exp X1 - second and Coragen - second. The treatment factors for the total number or total weight of roots were not significant at a 5% level.

Figures 2.4-2.8 show the results graphically.

Table 2.9: Assessments on roots harvested on 15 January 2009

	Treatment	Mean damage score	Proportion of roots with no damage	Proportion of roots with <5 % damage	Total number of roots assessed	Total weight of roots assessed
1 – Standard	Standard programme	1.614	0.253	0.468	106.0	5954
2	Tracer	1.885	0.230	0.394	112.2	5870
3	Exp X1 - first	0.217	0.803	0.984	137.1	5896
4	Coragen - first	0.457	0.674	0.908	128.1	6991
5	Actara	1.258	0.345	0.605	92.3	6435
6	Exp X1 - second	0.305	0.731	0.972	85.7	5702
7	Coragen - second	0.523	0.585	0.877	119.9	6024
8	Exp P	2.106	0.161	0.348	116.4	6272
9	Exp N	2.107	0.146	0.324	104.6	6748
10- Control	Untreated	2.621	0.105	0.199	88.6	6142
F-Value		26.52	73.570	33.150	2.18	0.610
P-Value		<.001	<.001	<.001	0.064	0.775
SED		0.2444	0.0446	0.0749	16.2	737.5

5% LSD		0.5055	0.0923	0.1550	33.52	1525.5
df		23	23	23	23	23

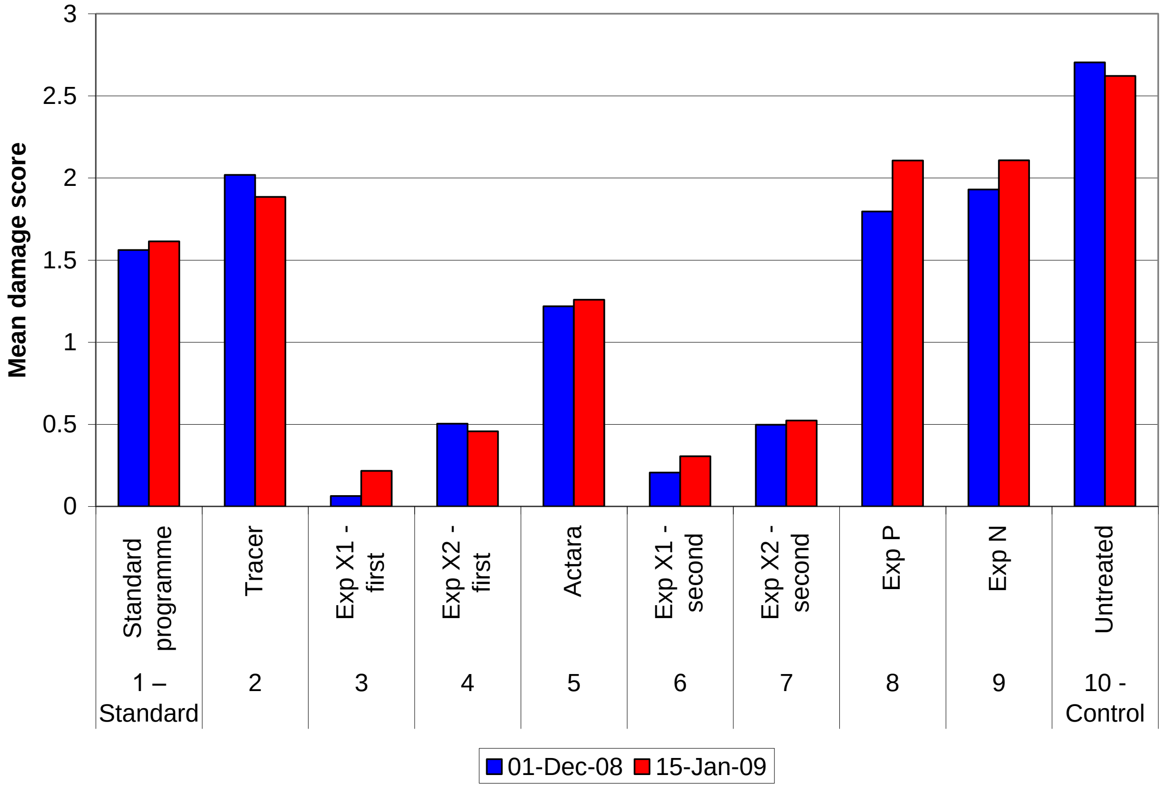

Figure 2.4: Mean damage score on 1 December 2008 and 15 January 2009

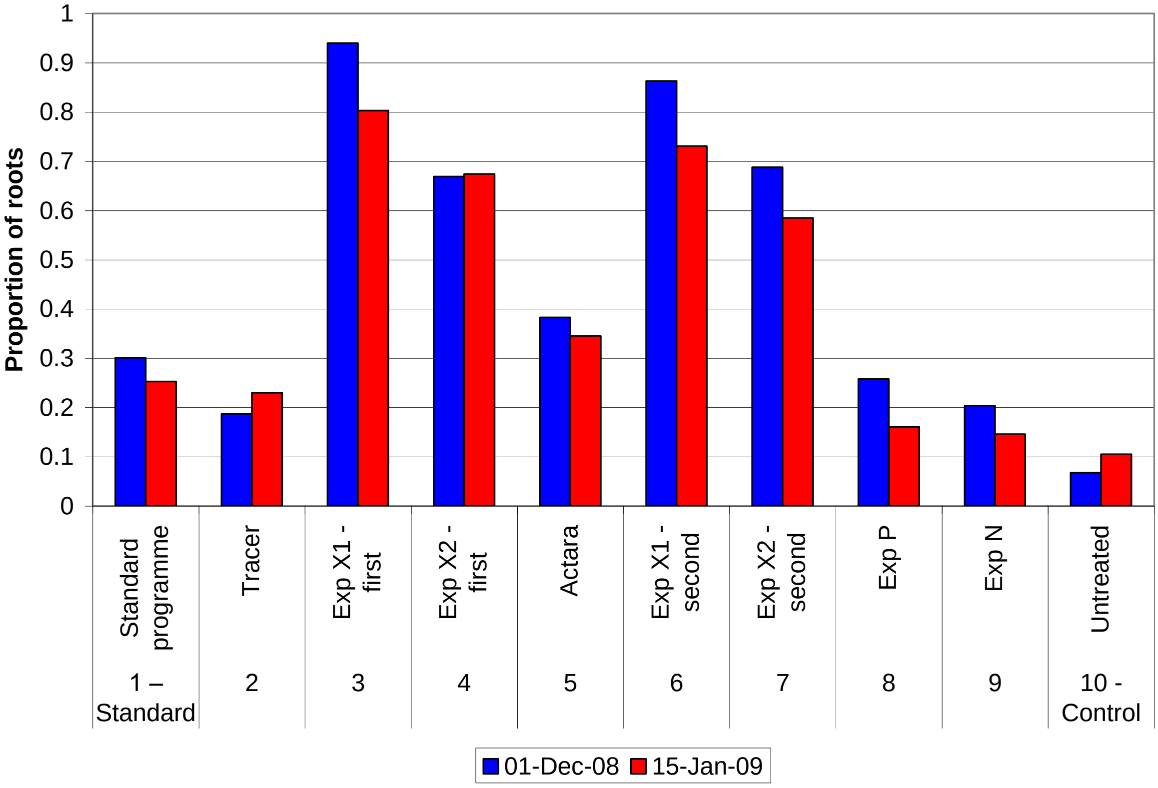

Figure 2.5: Proportion of undamaged roots on 1 December 2008 and 15 January 2009

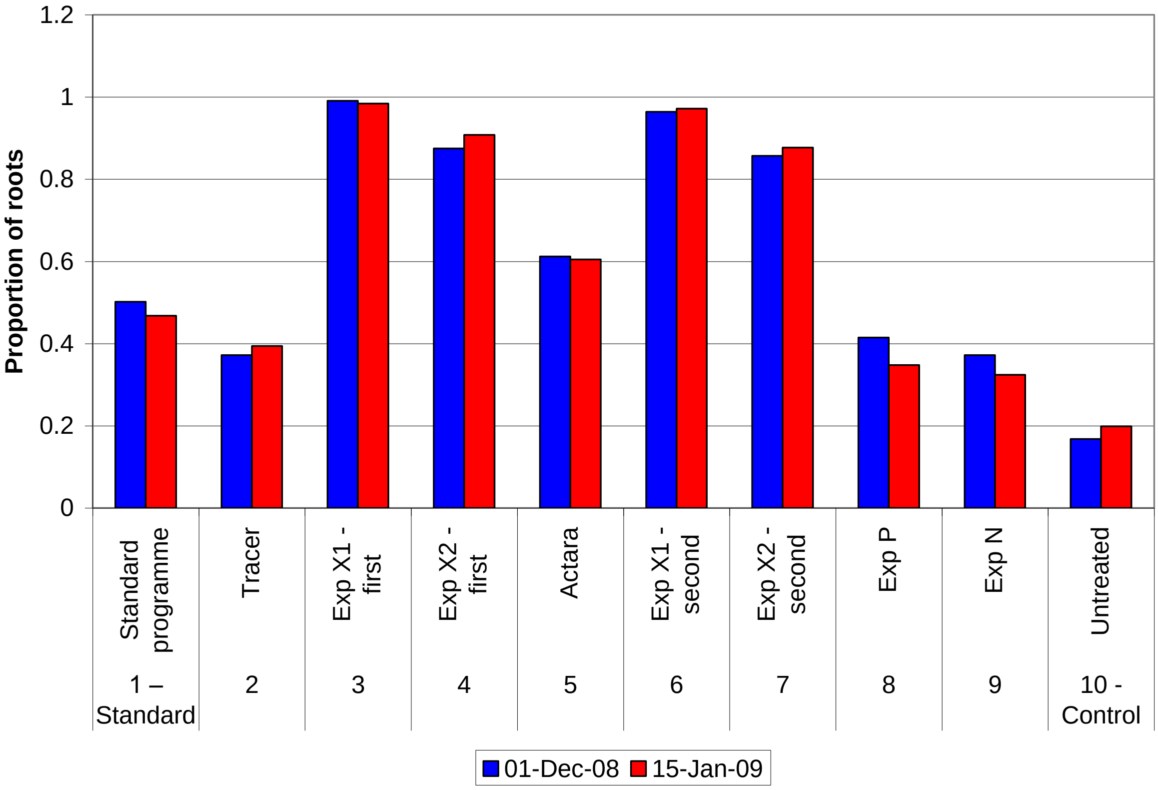

Figure 2.6: Proportion of roots with <5% damage on 1 December 2008 and 15 January 2009

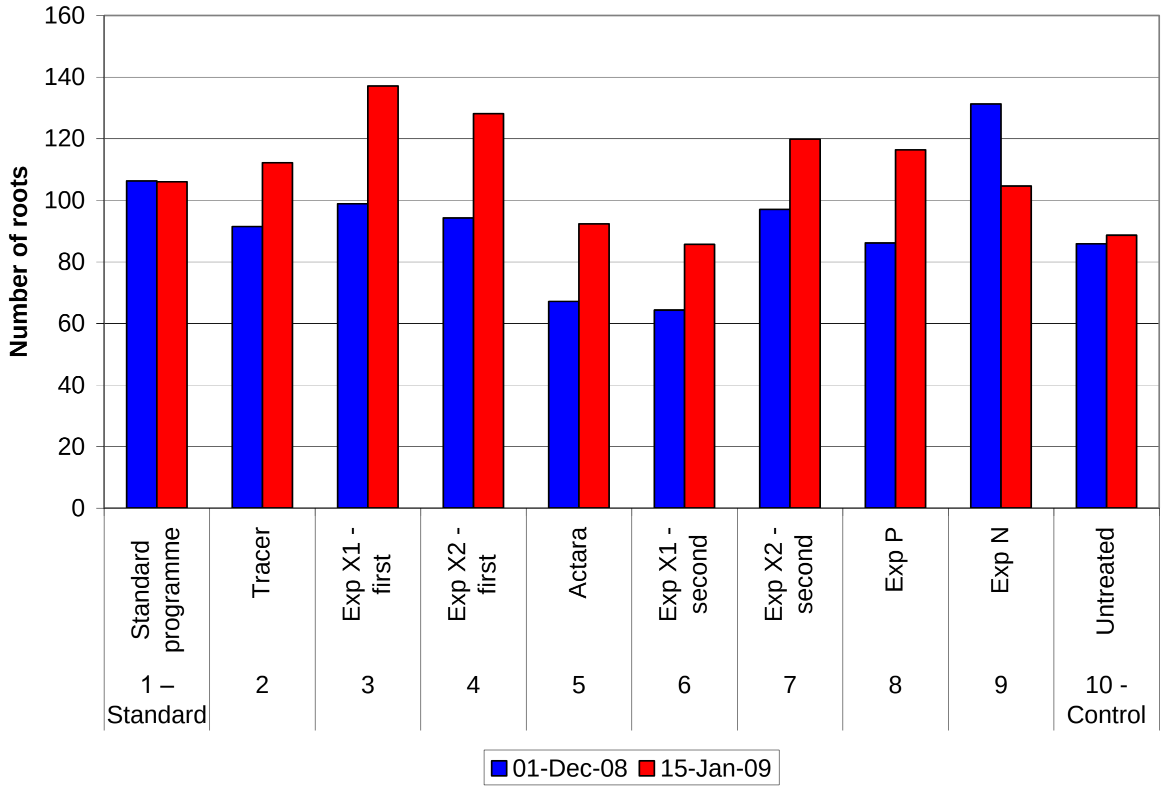

Figure 2.7: Number of roots assessed on 1 December 2008 and 15 January 2009

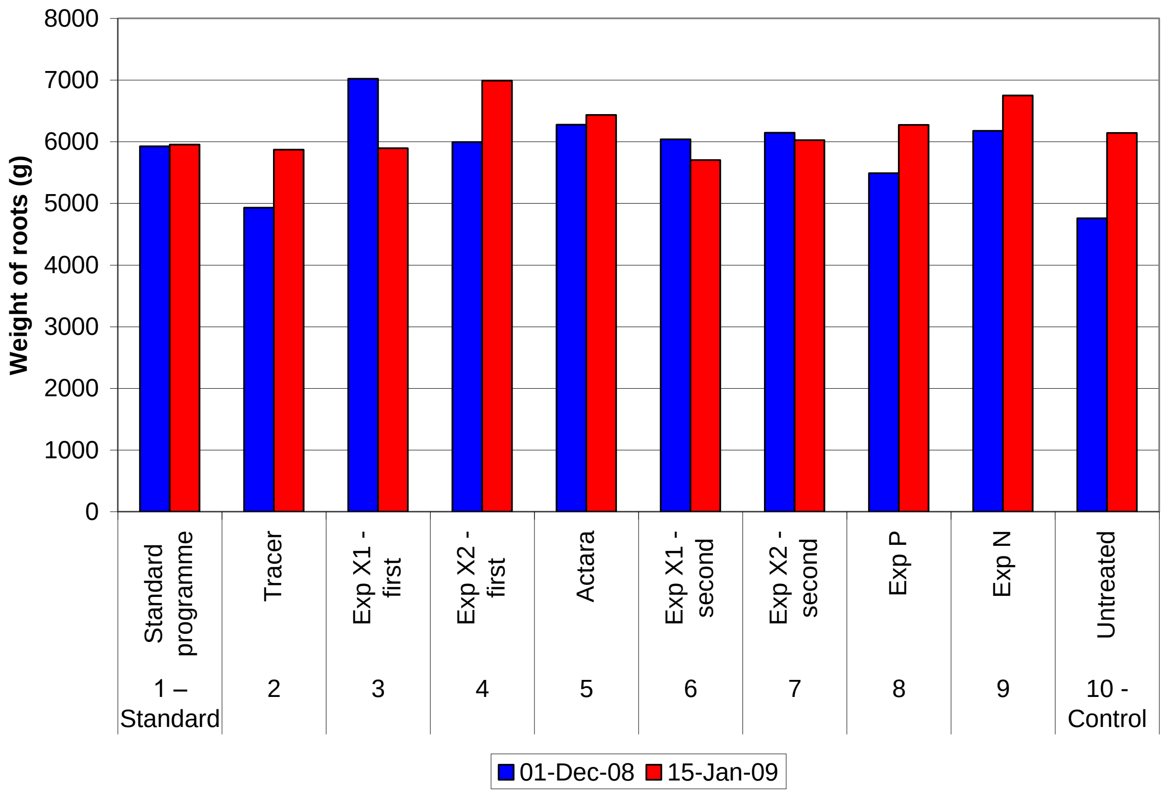

Figure 2.8: Weight of roots assessed on 1 December 2008 and 15 January 2009

Experiment 3

Are there novel spray treatments to control aphids on carrot?

Materials and methods

The experiment was done within the field known as Sheep Pens at Warwick HRI, Wellesbourne, which is adjacent to the field where the population of carrot fly is maintained.

The experiment was designed as a balanced row and column design with 5 columns and 4 rows. Including the untreated control, there were 5 treatments (Table 3.1). The field plots were 4 m x 1 bed (1.83 m each) in size and plots were separated by 1 m along beds. Seed (cv Nairobi) was drilled on 15 April 2008 at a spacing of 100 seeds/m within rows and 0.38 m between rows. All plots were sown with Force treated seed (2 rows) and insecticide-free seed (2 rows). Sprays were applied on 22 May using the products specified in Table 3.1 and a second set of sprays was applied on 5 June. All sprays were applied in 300l water/ha using a knapsack sprayer fitted with 02F110 nozzles. From July onwards, plots were treated with the 'Standard' programme for carrot fly control (Table 3.2).

Plant counts were made on 20 May and 13 June and aphid assessments were made on 2 and 9 June (0.5 m of middle 2 rows – 1 untreated row and 1 Force treated row). Root samples were taken on 8 December and assessed for carrot fly damage.

Table 3.1: The products used in the spray programmes to control aphids

Code	Product	Active ingredient	Rate (Product/ha)
1	Control	Untreated	
2	Aphox	Pirimicarb	280 g
3	Exp U	Exp U	480 ml
4	Plenum	Pymetrozine	400 g
5	Biscaya	Thiacloprid	400 ml

Table 3.2: The spray program use to control carrot fly (H = Hallmark with Zeon Technology and D = Decis protech – Doses in ml product/ha)

Date	18 Jul	1 Aug	15 Aug	28 Aug	10 Sep	26 Sep
Treatment	H 150	H 100	H 100	H 100	D 500	D 500

Results

Analysis was carried out using analysis of variance (ANOVA). No transformations of the data were required.

Aphids

Aphid counts were made on 2 and 9 June, after the first and second sprays respectively. Analyses were carried out on the counts of winged, wingless and parasitized aphids. Where it was considered there were insufficient non-zero data for formal analysis using ANOVA, simple treatment means were printed instead.

2 June

As there was no evidence of aphid control due to the Force seed treatment, the data from the untreated seed rows and the Force treated seed rows was combined. Formal analyses were carried out for the total counts of winged and wingless aphids per plot. For both, the treatment factor was significant at the 5% level. For winged aphids, Biscaya had a mean significantly larger than the untreated control. For wingless aphids, the untreated control had the largest mean. This was significantly larger than the means for treatments Aphox, Exp U and Plenum. No formal analysis was carried out for the counts of parasitized aphids. The results of the analysis are summarised in Table 3.3 and Figure 3.1.

Table 3.3: The mean numbers of aphids per metre length of row on 2 June 2008

Treatment		**Winged aphids**	**Wingless aphids**	**Parasitized aphids**
1	Untreated control	25.1	61.65	1.25
2	Aphox	22.77	19.92	0.25
3	Exp U	18.23	8.12	0
4	Plenum	11.43	4.58	0.25
5	Biscaya	69.97	41.98	0.75
F-Value		2.93	9.99	
P-Value		0.091	0.003	
SED		19.17	10.81	
5% LSD		44.2	24.93	
df		8	8	

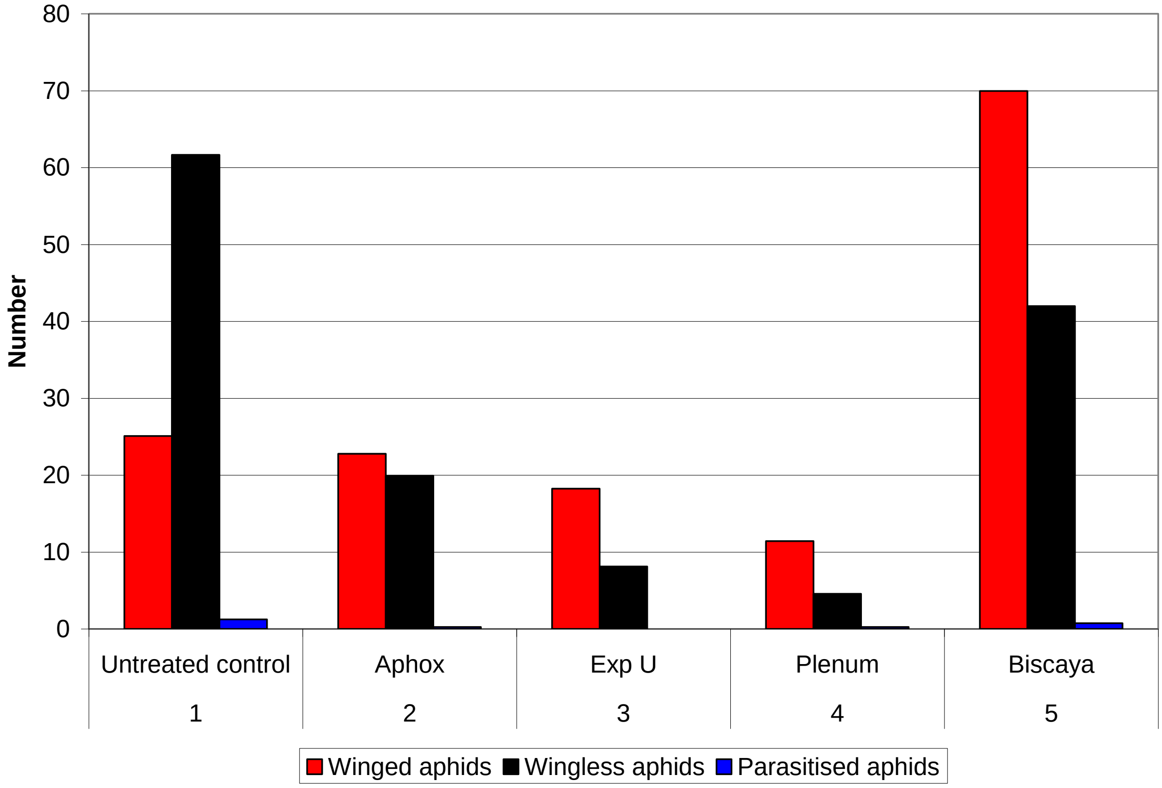

Figure 3.1: Mean numbers of aphids on 2 June 2008

9 June

Formal analysis was carried out only for the number of winged aphids. The treatment factor was not significant at the 5% level and there were no significant pair-wise comparisons. Although no formal analyses were carried out on the numbers of wingless or parasitized aphids, the largest counts were obtained for the untreated control for both of these categories (Table 3.4; Figure 3.2).

Table 3.4: The mean numbers of aphids per metre length of row on 9 June 2008

Treatment		Winged	Wingless	Parasitized
1	Untreated control	3.933	2.75	10.75
2	Aphox	2.533	0.25	0
3	Exp U	3.200	0.25	0
4	Plenum	2.067	0.25	1
5	Biscaya	1.267	0	0
F-Value		0.91		
P-Value		0.501		
SED		1.517		
5% LSD		3.499		
df		8		

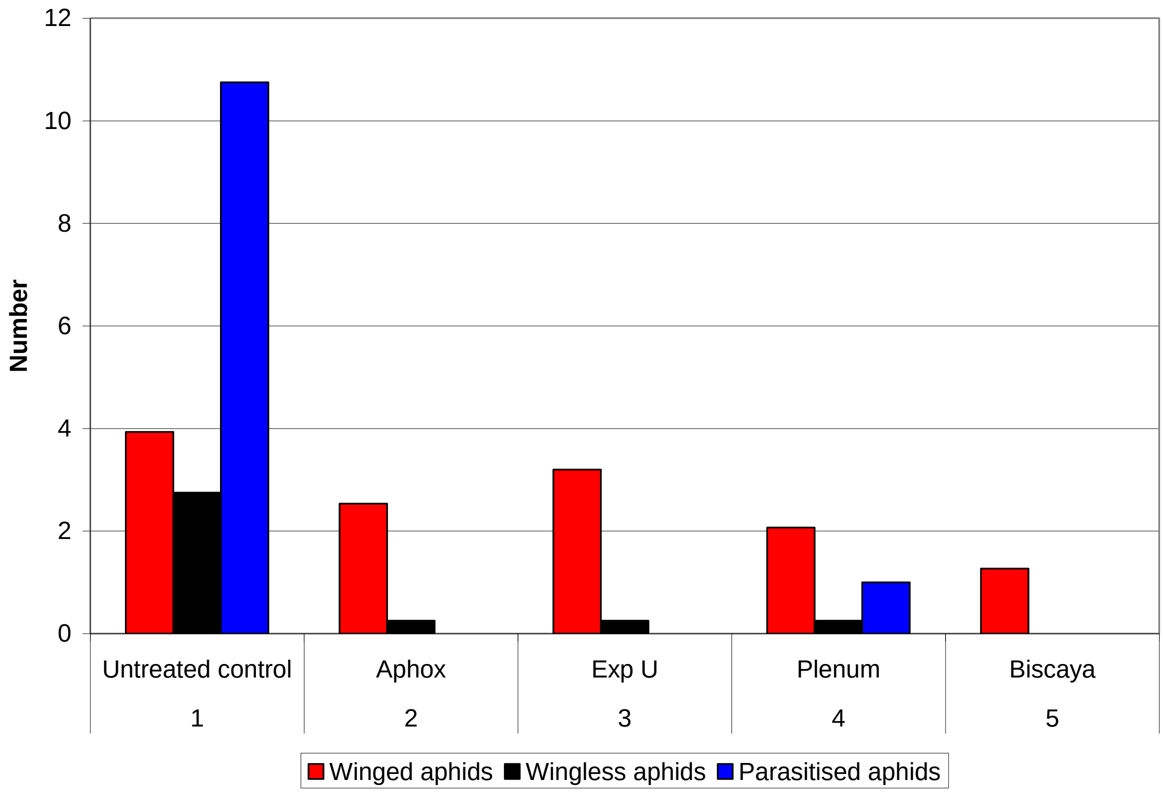

Figure 3.2: Mean numbers of aphids on 9 June 2008

Carrot Fly Damage

Mean damage score

Table 3.5 and Figure 3.3 show the mean damage score on 8 December 2008. There were no significant differences between the insecticide-treated and untreated samples for any of the seed treatments. Considering only the seed-treated samples, the Plenum treatment had a mean damage score significantly smaller than the untreated control.

Table 3.5: Mean damage score on 8 December 2008

	Seed treatment	**Untreated**
Untreated control	1.506	1.492
Aphox	1.150	1.313
Exp U	1.295	1.579
Plenum	1.101	1.244
Biscaya	1.422	1.513
	Within seed	Between seed
SED	0.1784	0.1815
5% LSD	0.3803	0.378

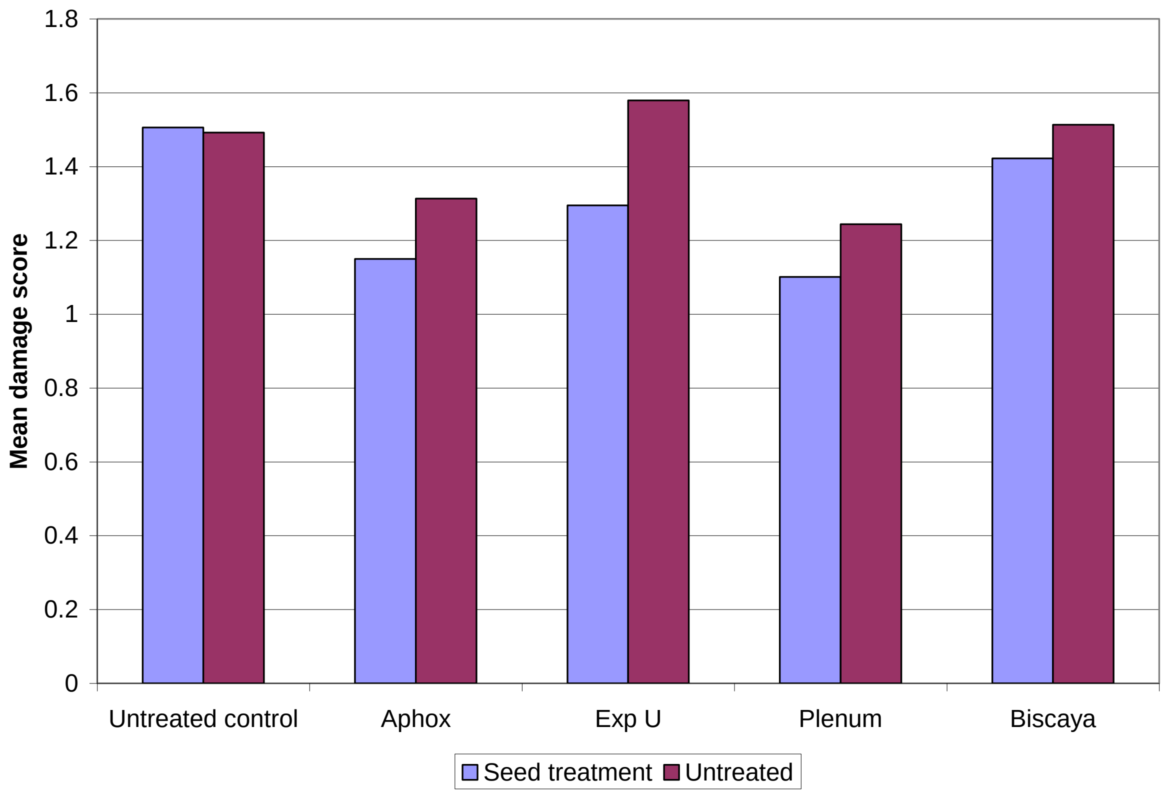

Figure 3.3: Mean damage score on 8 December 2008

Proportion of undamaged roots

Table 3.6 and Figure 3.4 show the proportion of undamaged roots on 8 December 2008. The presence of the insecticide seed treatment did not reduce the proportion of undamaged roots. However, the plots grown from insecticide-treated seed and then sprayed with either Aphox or Plenum had a higher proportion of undamaged roots than the plots grown from insecticide-treated seed that had not been sprayed.

Table 3.6: The proportion of undamaged roots on 8 December 2008

	Seed treatment	**Untreated**
Untreated control	0.2822	0.3720
Aphox	0.4401	0.3297
Exp U	0.3492	0.3149
Plenum	0.4426	0.3973
Biscaya	0.3709	0.3294
	Between Spray	Within Spray
SED	0.0602	0.0552
5% LSD	0.1262	0.1176

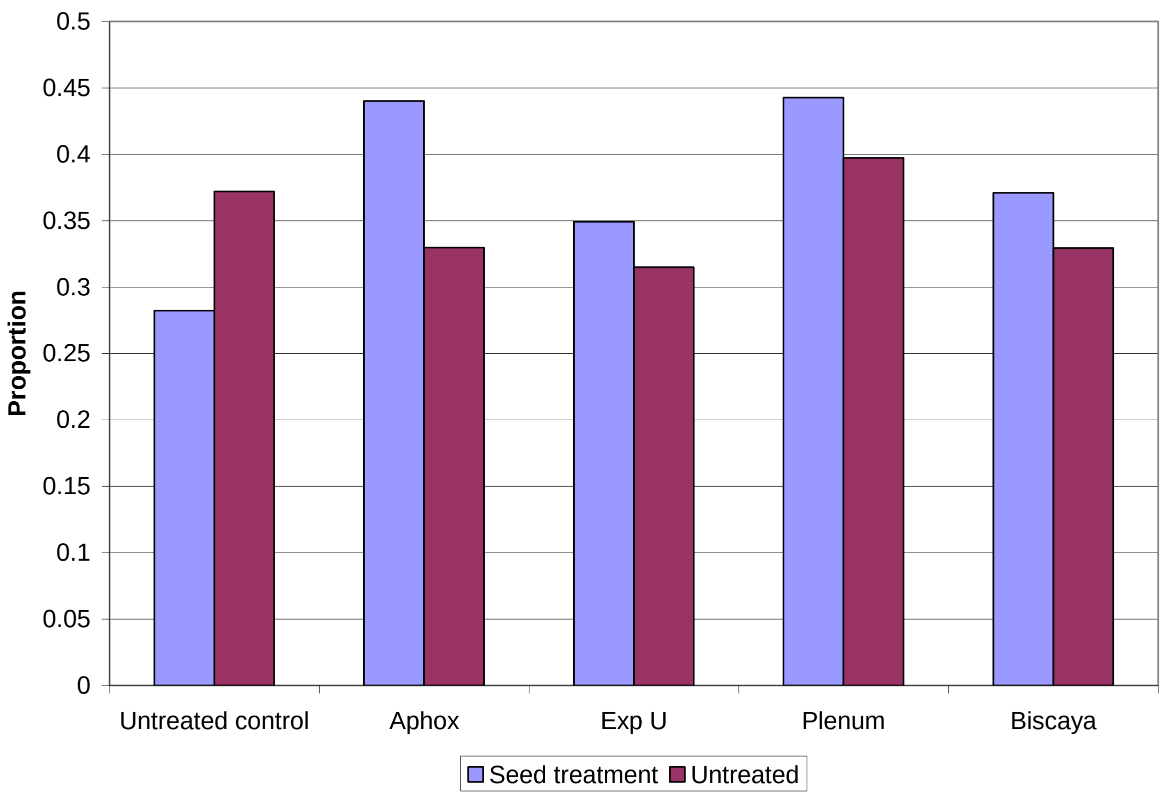

Figure 3.4: The proportion of undamaged roots on 8 December 2008

Proportion of roots with <5% damage

For the cumulative proportion of plants showing less than 5% damage, the Plenum treatment had a significantly larger proportion of roots with <5% damage than the untreated control for the seed-treated samples only (Table 3.7; Figure 3.5).

Table 3.7: The proportion of roots with <5% damage on 8 December 2008

	Seed treatment	**Untreated**
Untreated control	0.5185	0.5543
Aphox	0.6521	0.5883
Exp U	0.5853	0.4949
Plenum	0.6669	0.6140
Biscaya	0.5441	0.5631
	Between Spray	Within Spray
SED	0.0589	0.0611
5% LSD	0.1222	0.1302

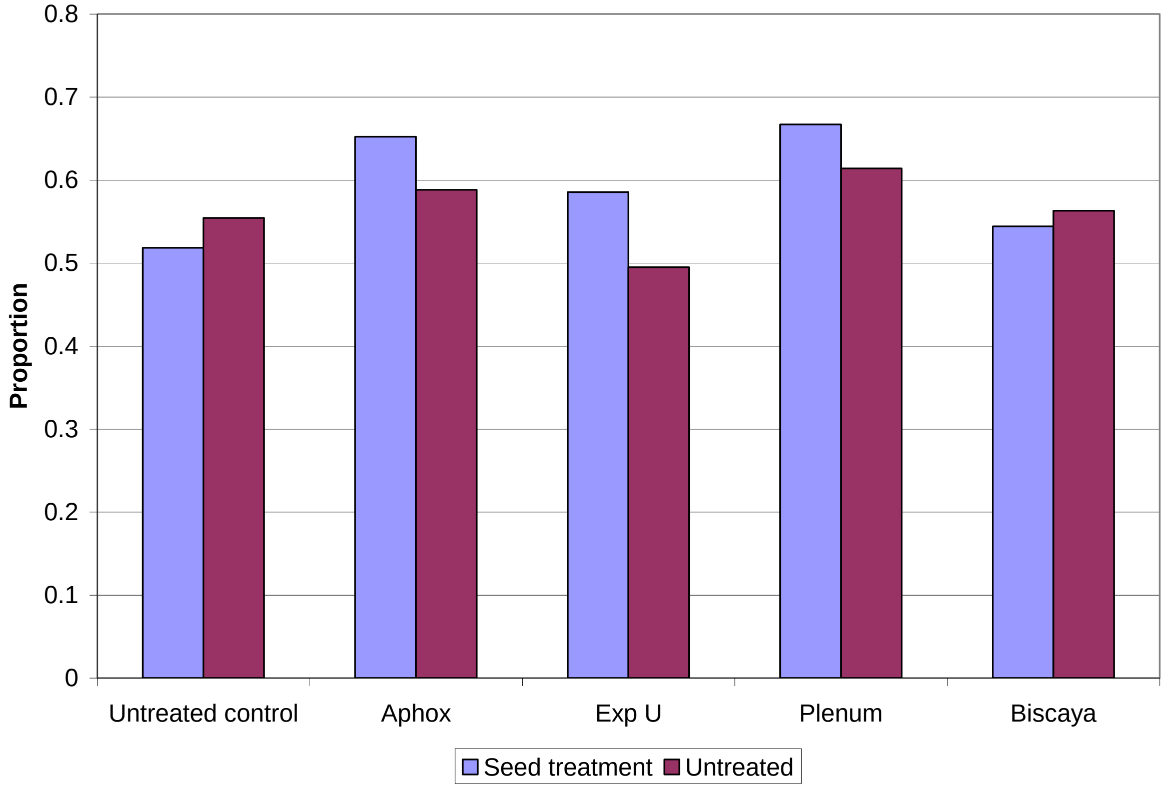

Figure 3.5: The proportion of roots with <5% damage on 8 December 2008

Total weight of roots

For the weight of roots assessed, there was an overall difference between the seed-treated and untreated samples, with the treated samples producing the larger means (Table 3.8; Figure 3.6). Considering the interaction table, this difference was significant for the Exp U and Plenum treatments as well as for the unsprayed control. Considering only the samples which did not receive seed treatment, the Aphox and Plenum treatments both had means significantly larger than the untreated control.

Table 3.8: Weight of roots assessed on 8 December 2008

	Seed treatment	Untreated
Untreated	3970	2782
Aphox	3851	3586
Exp U	4551	3240
Plenum	4625	3611
Biscaya	3683	3132
	Between Spray	Within Spray
SED	374.7	330.5
5% LSD	788.3	704.5

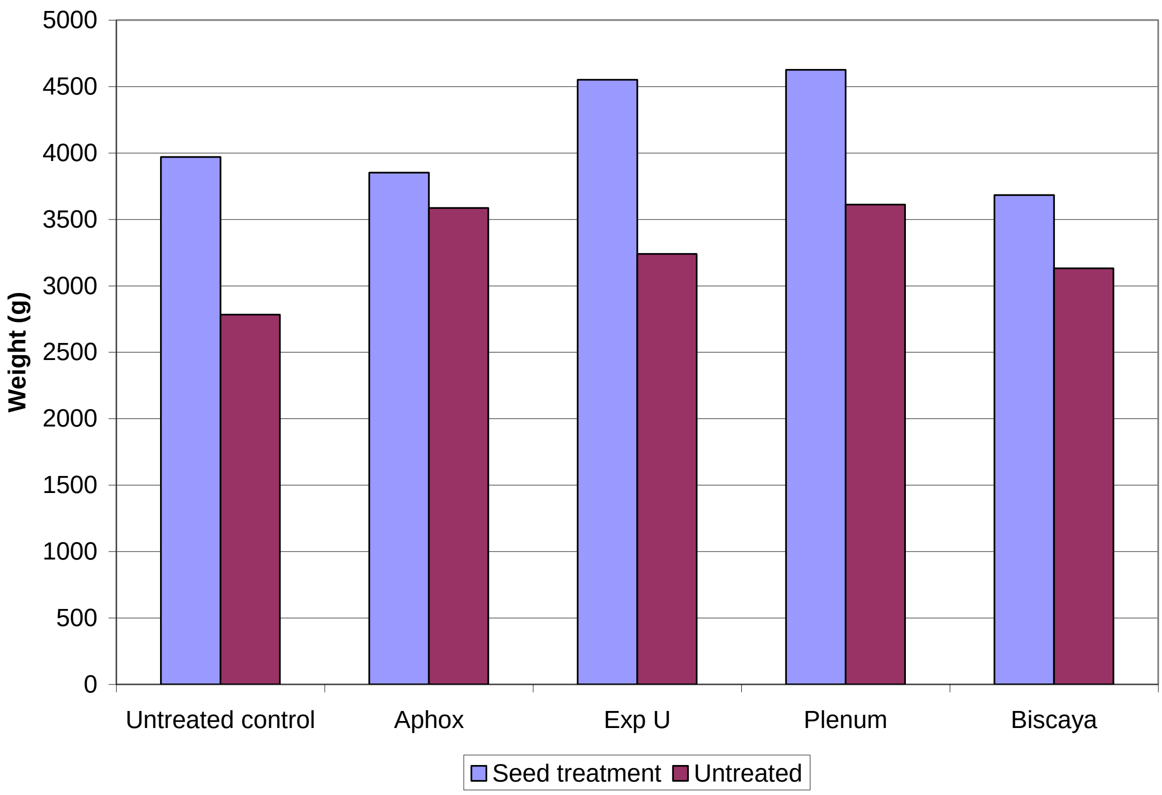

Figure 3.6: Weight of roots assessed on 8 December 2008

Experiment 4

Fences to exclude carrot fly from carrot crops

Materials and methods

During the spring and summer of 2007, fences made of fine mesh netting were tested in small-scale experiments at Wellesbourne. There were two plots, and both were near the source of carrot fly, but one was in a large open field (Sheep Pens) whilst the other was in a small field enclosed by hawthorn hedges that were generally taller than the fence (Long Meadow Centre).

On 29 March (Long Meadow Centre) and 30 March (Sheep pens), carrot seed (cv Nairobi) was drilled at a spacing of 100 seeds/m within rows and 0.38 m between rows. Four rows were drilled into each of 8 adjacent beds in each field such that there were 2 areas separated by 6 m of bare ground. One area was 12 m in length and the other was 10 m in length. On 11 April (before the seedling carrots emerged), four 1.7 m fences made from fine-mesh netting supported on a wooden frame were erected to enclose an area of 6 beds wide by 10 m in length within the 12 m area of each field. The fences had a 0.4 m external overhang (at 45^{o} to the vertical) (Figure 4.1). A border of 1 bed along the sides and 1 m at either end of the fences was left exposed. The 10 m lengths were left unfenced as a control.

To ensure that the effects of the fences could be monitored over two carrot fly generations, half of the beds of carrot within the fences were covered in fine-mesh netting to exclude any carrot fly that entered the area. The covers remained in place until mid July, between the two fly generations. The covers were then removed and placed over the beds that had been exposed during the first generation, to ensure that any flies that emerged from these beds were 'trapped' inside the covers. This meant that any second generation flies recovered inside the fences had come from outside. In addition to the plots enclosed by the fences, the beds in the two open 'control' plots were covered with fine-mesh netting in a similar manner.

Adult carrot fly numbers within all plots were recorded using sticky traps (3 per plot) and root samples taken on 3-7 August and 29 November were assessed for carrot fly damage.

Figure 4.1: One of the fences. Half of the beds inside the fence are enclosed in fine mesh netting to exclude carrot fly

Results

The fences were inspected at the time that first generation carrot flies were most numerous and they, and considerable numbers of other insect species, were observed inside the overhang. During the first and second generations, the numbers of flies captured on sticky traps inside the fences were approximately 15% of those captured outside, so the effect was consistent throughout the summer (Figure 4.2). There were relatively more flies inside the fences at the time of the third generation (October) because the progeny of second generation flies that entered the enclosed area were free to emerge from the exposed carrots.

When the carrot roots were assessed in early August, damage to the carrots within the fences was less than to those in the open plots (Table 4.1). However, whilst the ratios of flies and damage in the fenced versus open plots were similar at the time of the first generation (all approximately 15%), damage was relatively greater after the second generation.

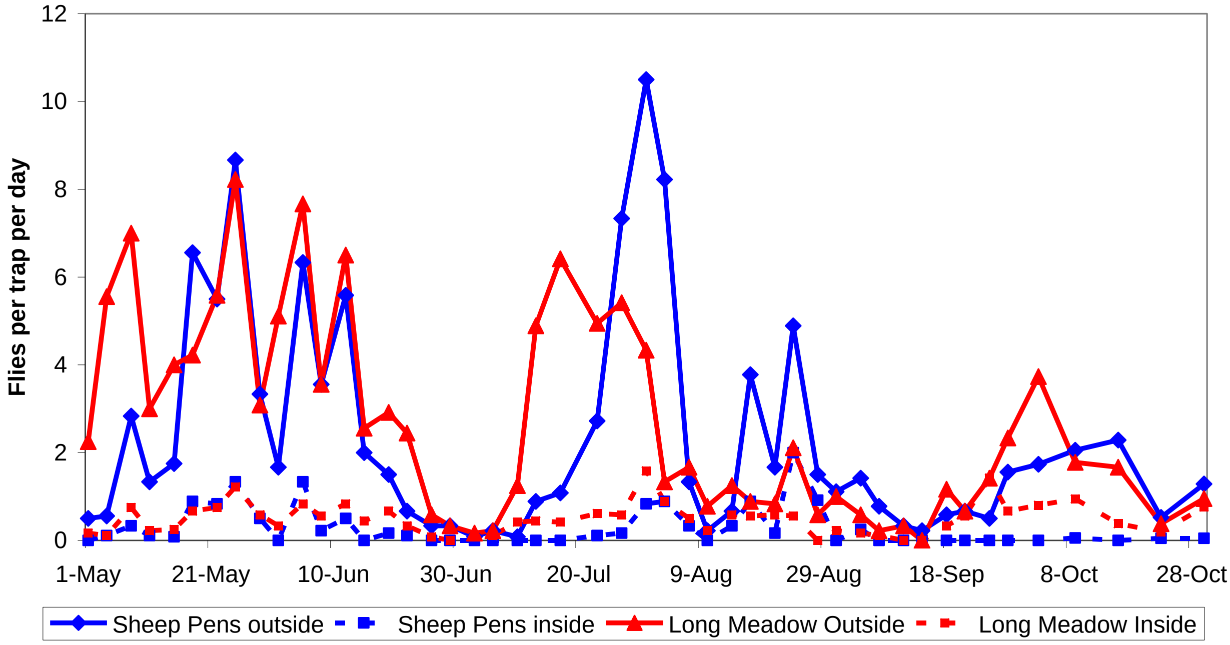

Figure 4.2: The numbers of carrot flies captured per trap per day on sticky traps placed within and outside the areas enclosed by fences. Long Meadow is closer to the site where the carrot flies spent the winter and is surrounded by hedges

Table 4.1: Percentage of carrot roots with >5% damage due to carrot fly when sampled after the first generation (3-7 August) and second generation (29 November)

Location and generation	Inside fence	Outside fence	Damage inside as a percentage of damage outside
Sheep Pens Gen 1	5	30	15
Long Meadow Gen 1	10	68	15
Sheep Pens Gen 2	20	39	51
Long Meadow Gen 2	35	56	62

<u>Discussion</u>

The aim of this project was to evaluate novel insecticides, application methods and spray programmes for the control of carrot fly, aphids and cutworms on carrot crops and the use of fences to eliminate the need for chemical control of carrot fly.

There was an expectation that cutworms (caterpillars of the turnip moth, *Agrotis segetum*) would cause significant problems in 2007. In summer 2006, the weather was so warm that some of turnip moth population was able to complete a second generation. This is usually a sign that moth numbers will be high in the following spring. Indeed the numbers captured in pheromone traps at Wellesbourne in 2007 were relatively high and the adult population was active several weeks earlier than in 2006, as a result of the warm spring. However, by the time large numbers of cutworm eggs started to hatch, the period of rain had started. This reduced the risk of cutworm damage considerably as mortality of young caterpillars is very high if it is wet. Indeed, the ADAS cutworm forecast bulletins published on the HDC Pest Bulletin web site indicated that there was no need to treat for cutworms in any part of the UK and cutworms were not observed in either experiment at Wellesbourne.

Whilst the expectation of cutworm damage in 2008 was not so high, relatively large numbers of moths were captured in pheromone traps in June, activity being later than in 2007. However, as in 2007, summer rainfall was considerable and as a result there was no significant damage to carrot crops at Wellesbourne.

Seed treatments

In 2007, the plant count in the plots treated with Force was higher than in the other plots (Figure 4) (although this difference was not always statistically significant (Table 2)), supporting the assertion that this treatment benefits seedling establishment.

Winged willow-carrot aphids were captured during April - June in the Rothamsted suction trap located at Wellesbourne. The aphid migration (from its winter host – willow) was relatively early in 2007 because of the exceptionally warm spring. As soon as the migration started, winged and wingless aphids were found on the insecticide-free carrots. W inged and wingless aphids were also present on the plants treated with Force and with one of the coded products tested in 2008. However, very few wingless aphids were found on the plots treated with the other coded products, indicating that the winged aphids that colonised these plants had been unable to produce young. After a few weeks, and in both years, most of the aphids were parasitized by a small wasp.

Adult carrot flies were captured on sticky traps at Wellesbourne from late April and numbers had declined by mid June. When they were harvested in mid-July, the carrots sown towards the end of the first generation had suffered considerably less carrot fly damage than those sown in early April.

Of the carrots sown in early April 2007, the insecticide-free carrots suffered the most damage and none of the insecticide-treated roots were damage-free (approximately 73% of roots from the best treatment, Exp A, suffered <5% damage, compared with 32% of the roots from the appropriate untreated plots). However, all of the insecticide seed treatments increased the proportion of roots with <5% damage compared with the untreated control plots. One of the most striking treatment effects on the April 2007 sowing was on 'yield'. The carrots recovered from the plots treated with the coded insecticides were considerably heavier than those recovered from the insecticide-free plots and those treated with Force. This was mainly a reflection of the increased weight of individual roots in the treated plots, but also, in most cases, of higher plant numbers. This effect persisted until harvest on 27 November and was then apparent in both sowings. The reduced weight of carrots in the untreated plots was at least in part a reflection of the aphid infestation. Again in 2008, two of the experimental treatments had a positive effect on the mean weight of roots per sample in mid July and again when more roots were harvested in mid December, but in this case only for Sowing 1.

Whilst the effects were not so pronounced in 2008, one of the coded products again reduced carrot fly damage mid-season. At harvest, in early winter 2008, two of the coded treatments reduced carrot fly damage in early winter and the effects were apparent in both sowings.

Spray treatments

Previous studies have shown that foliar sprays of pyrethroid insecticides kill adult carrot flies rather than carrot fly larvae in the soil. Because it is impossible to assess fly mortality (knockdown) in plot experiments, the efficacy of treatments was compared by assessing damage to the roots caused by carrot fly larvae. There is therefore a 'lag' between treatment application and damage assessment. Consequently, it is sensible to compare spray 'programmes', but to keep some of the treatments 'constant' so that certain components of the programme can be compared. This was the aim in the present experiments, since all of the sprays were applied at fortnightly intervals and most consisted of a total of 6 sprays.

The experiment in 2007 confirmed the efficacy of Hallmark Zeon as a spray treatment to control carrot fly and also confirmed that it is best to use the most effective treatments at the beginning of a spray programme against second generation carrot fly. In 6-spray programmes where the last two sprays consisted of Decis, Biscaya was the least effective insecticide, followed by Decis (Figure 5.1). Exp S (2 both rates) and Hallmark Zeon (4 x 100 ml or 1 x 150 ml and 3 x 100 ml) appeared to be equally effective.

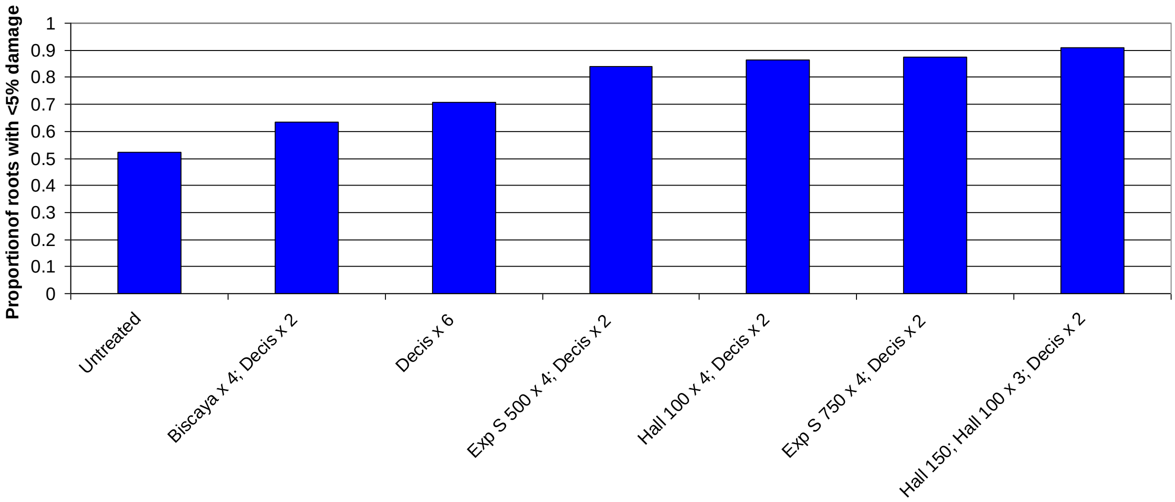

Figure 5.1: The proportion of carrot roots with <5% damage from treatments where the last two sprays of a 6-spray programme consisted of Decis

Exp T was tested in various 'positions' in spray programmes with Hallmark Zeon and Decis. It appeared to be less effective than Hallmark Zeon (Figure 5.2), so probably should not be applied 'first', but was comparable to Decis as a treatment at the end of a programme.

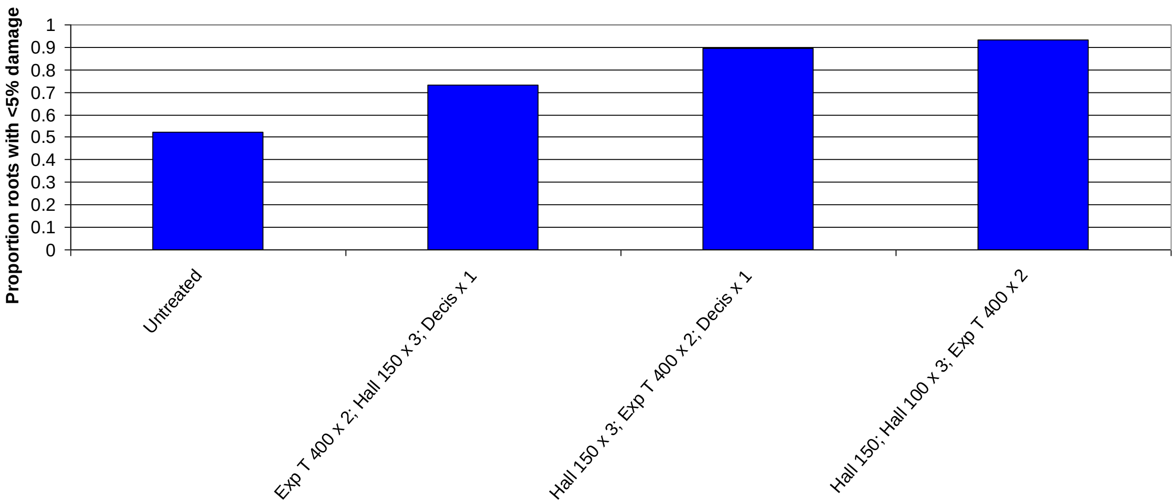

Figure 5.2: The proportion of carrot roots with <5% damage from treatments where Exp T formed part of a 6-spray programme

There was only one 7-spray programme (in 2007) (Hall 150 x 3; Exp T 400 x 2; Decis x 2), however, this did not improve control compared with the similar programme where the last Decis spray (10 October) was omitted (Hall 150 x 3; Exp T 400 x 2; Decis x 1). The programmes evaluated in this experiment did not indicate whether it would have been possible to omit a further one or two sprays at the end of the 6-spray programmes.

In 2008, damage to the insecticide-free control plots was heavier (93% roots damaged versus 68% in 2007). Probably as a consequence, the ‘standard’ 6-spray programme (1 x Hallmark 150 ml, 3 x Hallmark 100 ml, 2 x Decis) appeared to be less effective (70% versus 26% damaged roots). However, the ‘standard’ programme was surpassed by programmes containing two sprays of either of two experimental products (X1 and X2) in combination with 4 Hallmark sprays (1 x 150 ml and 3 x 100 ml). In addition to synthetic pesticides, two ‘natural’ products were also evaluated. Both reduced carrot fly damage compared with the insecticide-free control treatment, but were not as effective as the ‘standard’ programme.

Foliar sprays to control aphids

Four aphicides (Plenum (pymetrozine), Biscaya (thiacloprid), Aphox (pirimicarb) and a coded product were applied once aphids were present on the plants. Aphox, Plenum and the coded product all reduced aphid numbers compared with the insecticide-free control treatment. Surprisingly, Biscaya did not reduce aphid numbers.

Exclusion fences

The results from the experiment with the fences suggest that there is a basis for using this technique on a field scale. However, the experiments were done on a very small scale and the approach may not be so effective when ‘scaled up’. Factors to consider include the area cropped compared with the height of fence, the presence of trees or shrubs on the field boundary (since carrot flies have been found at considerable heights in shrubs and trees) and the use of ‘trap crops’, plants susceptible to carrot fly, outside the fence, to arrest potential colonizers.

Similar fences were evaluated on a field scale by several organic growers and some basic data were collected as part of FV 312. The experiences of these growers highlighted some of the practical difficulties of using such an approach on a field scale. These include making sure that the fences are in place before either the crop emerges or carrot flies start to disperse in the spring and ensuring that the gateway used by farm machinery is closed at all other times to prevent the ingress of carrot flies.

TECHNOLOGY TRANSFER

Date	Description
November 2007	Carrot conference - presentation
March 2008	Fence and defence for carrots. HDC News March 2008, 20-21.
19 March 2009	HDC/BCGA Technical Seminar
March 2009	Article for HDC News – spring 2009

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