ANNUAL REPORT

To:
Horticultural Development Council
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Integrated control of carrot pests

FV 312

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Commercial - In Confidence

Grower Summary

FV 312

Integrated control of carrot pests

Annual report 2007-2008

Project title: Integrated control of carrot pests

Project number: FV 312

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Signed on behalf of: **Warwick HRI**

Simon Bright *01 April 2008*
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CONTENTS

GROWER SUMMARY

SCIENCE SECTION

FV 312 : Integrated control of carrot pests

Headline

Field trials on carrot have confirmed the efficacy of current methods of carrot fly control, highlighted some experimental seed treatments that control aphids and give partial control of 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 be providing a background level of carrot fly control in some crops.

Since carrot fly was last investigated in detail in the UK, several new active ingredients have become available and some of these are approved on other crops in the UK. There is the potential to apply insecticide treatments as seed treatments, granules or foliar sprays. However, no appropriate granule treatments are available at present. Seed treatments are unlikely to persist throughout the life of the crop, but might be expected to give useful control of aphids and first generation carrot fly. Work in the Netherlands indicates that either Clothianidin or Thiamethoxam might be effective against carrot fly when applied to carrot seed and both insecticides have activity against aphids when used on other crops. In 2006, a single field trial was done at Wellesbourne to address the then recent reduction in the number of Hallmark Zeon spray applications (FV 13f). The trial investigated various strategies for using Hallmark Zeon and Decis (Deltamethrin) in line with the new Hallmark Zeon approval, as well as one 'novel' insecticide treatment. 'Novel' foliar spray treatments would be very valuable additions to the armoury, particularly if they were effective against more than one pest.

Previous research (FV 13d) showed that most damage to overwintering carrots results from larvae that hatch from eggs laid in late July/early August at the beginning of the second fly generation. Unless good control is achieved at this time, it is impossible to prevent damage to carrot crops increasing during the winter months. Usually, the damage done to overwintering crops is caused by larvae that hatch from eggs laid no later than the end of September and damage by the third generation is relatively minor. However, in very warm years, there may be a risk of some third generation egg hatch and larval development in crops grown in the south of the country. Climate change may increase this risk. The HDC/HRI carrot fly forecast can be used to indicate the risk of damage due to third generation flies.

At present, apart from new insecticides, the 'novel' treatment for carrot fly that would appear to be most interesting is the use of fences to prevent carrot fly colonising susceptible crops. This technique has been evaluated previously in Canada, Switzerland and Germany, with variable results.

The aim of this project is 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 (fences) to eliminate the need for chemical control.

The expected deliverables from this work include:

- 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 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

Three experiments were done in 2007 using eight insecticides: Hallmark with Zeon Technology (Lambda-cyhalothrin), Decis Protech (Deltamethrin), Biscaya (Thiacloprid), Force (Tefluthrin) and 5 experimental treatments (Exp A, Exp B, Exp C, Exp S and Exp T).

Experiments were done to answer the following questions:

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

Experiment summaries and main conclusions

1. Novel seed treatments to control carrot fly and aphids on carrot

The experiment was designed to assess novel insecticides as seed treatments for the control of carrot fly (*Psila rosae*) and aphids (willow-carrot aphid, *Cavariella aegopodii*). Four insecticides (Force, Exp A, Exp B and Exp C) were assessed as seed treatments for the control of both pests. The carrots were sown on two occasions (5 April and 23 May) in order to expose them to different 'pressures' from first generation carrot fly and willow-carrot aphid. Regular assessments were made of the numbers of seedlings/plants and the numbers of aphids infesting the plants, and samples of roots were taken on 18 July (between the first and second generations of carrot fly) and 27 November to assess carrot fly damage and yield (number and weight of roots).

Results and conclusions

- The seedling 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.
- Winged willow-carrot aphids were captured from early May until the end of June in the Rothamsted suction trap located at Wellesbourne. The aphid migration (from its winter host – willow) was relatively early because of the exceptionally warm spring. Peak numbers of winged aphids were found when the carrot plants were assessed

on 2 May and the highest numbers of wingless aphids were recorded on 2-10 May. Aphid numbers then declined and few aphids were found when plants of the second sowing were assessed on 18 June.

- Aphids were relatively abundant on the insecticide-free carrots and those treated with Force, but very few aphids were found on the plots treated with the three coded products.
- 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 on 23 May (towards the end of the first generation) had suffered considerably less carrot fly damage than those sown on 5 April.
- Of the carrots sown on 5 April, the insecticide-free carrots suffered the most damage and none of the insecticide-treated roots were damage-free. 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 5 April 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.
- At harvest, on 27 November, none of insecticide treatments appeared to reduce carrot fly damage in sowing 2 compared with the untreated control. Within sowing 1, untreated Force and Exp A both had a lower proportion of roots with <5% damage than their respective treated plots.
- The effects of the coded treatments on 'yield' persisted until harvest on 27 November and these effects were apparent in both sowings.

2. Novel spray treatments to control carrot fly on carrot

The second trial was sown on 23 May 2007 towards the end of the first generation of carrot fly and was concerned principally with foliar spray treatments against the second generation. Five insecticides (Table 1) were assessed as foliar spray treatments for the control of carrot fly. There were 11 treatment programmes and sprays were applied at fortnightly intervals between mid July and early October. Root samples were taken on 22 November and assessed for carrot fly damage and further samples will be taken in spring 2008 to determine the effects of the treatments on damage development during the winter.

Table 1. The products used in the spray programmes to control carrot fly

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

Results and conclusions

- All of the spray programs reduced carrot fly damage compared with the untreated control.
- All of the programmes which started with Hallmark Zeon were very effective and not significantly different from each other. The trial confirmed the efficacy of Hallmark Zeon as a spray treatment to control carrot fly.
- In 6-spray 'standard' programmes (where the last two sprays consisted of Decis), Biscaya was the least effective insecticide, followed by Decis. Exp S (both rates) and Hallmark Zeon (4 x 100 ml or 1 x 150 ml and 3 x 100 ml) appeared to be equally effective.
- Exp T was tested in various 'positions' in spray programmes with Hallmark Zeon and Decis. It appeared to be less effective than Hallmark Zeon, so probably should not be applied 'first', but was comparable to Decis as a treatment at the end of a programme.
- There was only one 7-spray programme (Hallmark 150 ml x 3; Exp T 400 g 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 ml x 3; Exp T 400 g x 2; Decis x 1).
- The programmes evaluated in this trial do not indicate whether it would have been possible to omit a further one or two sprays at the end of the 6-spray programmes.

3. *Fences to exclude carrot fly from carrot crops*

During the spring and summer of 2007, fences were tested in small-scale trials 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 (Figure 1). 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.

Figure 1. One of the fences. Half of the beds inside the fence are enclosed in fine mesh netting to exclude carrot fly.

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 trials 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 trials 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 carrot fly 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 work is the first year of 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:

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

The test chemicals are shown as the active ingredients (with the product used in parenthesis) as certain chemicals are available under a range of different product names.

The actual active ingredients tested, together with the product used (shown in parenthesis), were: Lambda-cyhalothrin (Hallmark with Zeon Technology), Deltamethrin (Decis Protech), Thiacloprid (Biscaya), Tefluthrin (Force) and 5 experimental treatments (Exp A, Exp B, Exp C, Exp S and Exp T).

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 trial using two pheromone traps (Agralan).

Figure 2 shows the number of adult carrot flies (*Psila rosae*) captured on sticky traps in Long Meadow Centre and Figure 3 shows the number of willow-carrot aphids (*Cavariellla aegopodii*) captured in the suction trap at Wellesbourne. Figure 4 shows the numbers of male turnip moth (*Agrotis segetum*) captured in two pheromone traps. All three species were active relatively early in the year because of the warm spring.

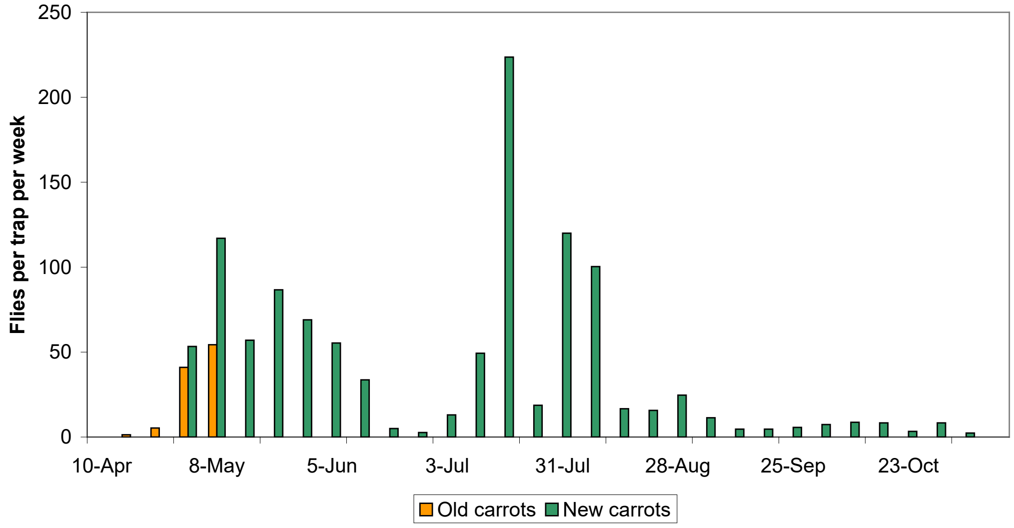

Figure 2. The mean numbers of adult carrot fly (*Psila* rosae) captured on sticky traps (3) at Warwick HRI, Wellesbourne in 2007. Old carrots = overwintered crop; new carrots = drilled early April 2007.

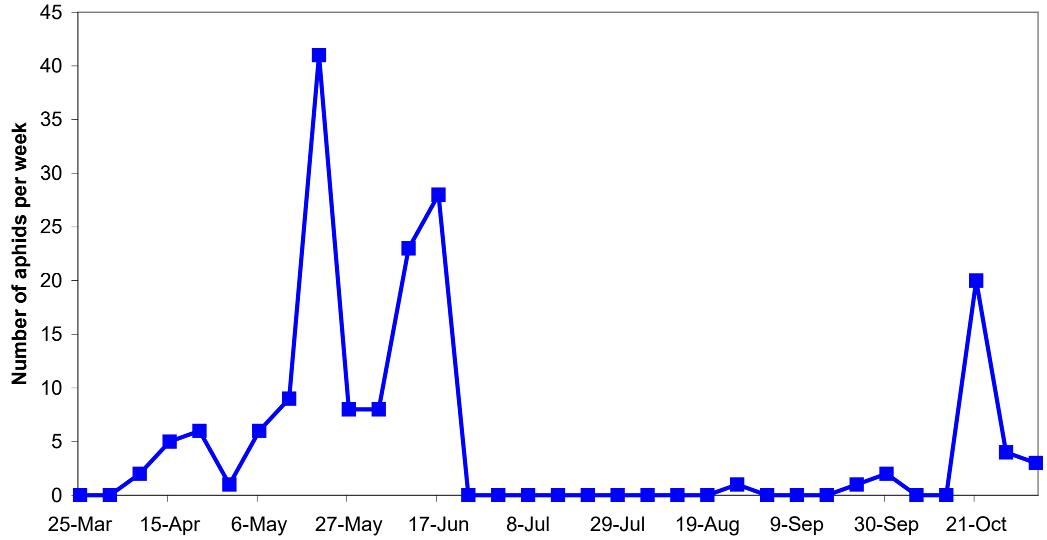

Figure 3. The numbers of willow-carrot aphid (*Cavariella aegopodii*) captured in the Rothamsted suction trap at Warwick HRI, Wellesbourne in 2007.

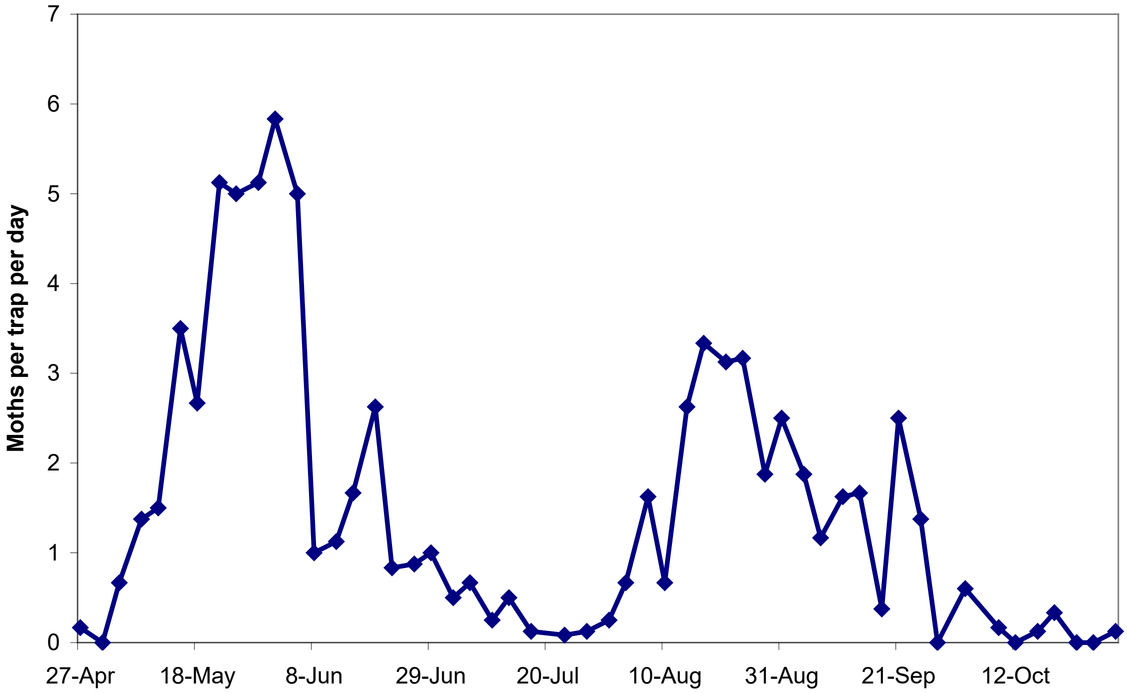

Figure 4. The numbers of male turnip moth (*Agrotis segetum)* captured in pheromone traps at Warwick HRI, Wellesbourne in 2007.

Experiment 1

Novel seed treatments to control carrot fly and aphids on carrot

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 trial 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 2.

Table 2. 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 *			
4	Exp B – treated		Nairobi	0.07 + 0.023 mg/seed
5	Force – untreated *		Nairobi	
6	Force – treated	Tefluthrin	Namdal	Commercial rate
7	Exp C – untreated		Namdal	
8	Exp C – treated		Nairobi	

* 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 drilling) and 18 June and 28 June (second drilling).

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 drilling) and 18 June (second drilling).

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 drillings. 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.

Seedling counts

Seedling 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 seedling counts for each plot on each occasion were analysed separately and are summarized in Table 3 and Figure 5. 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 seedling 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 seedling counts than treated seed subplots (p = 0.003). The Exp B and Force untreated seed subplots had a lower seedling count than their respective treated seed subplots.

Table 3. The total number of seedlings 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	

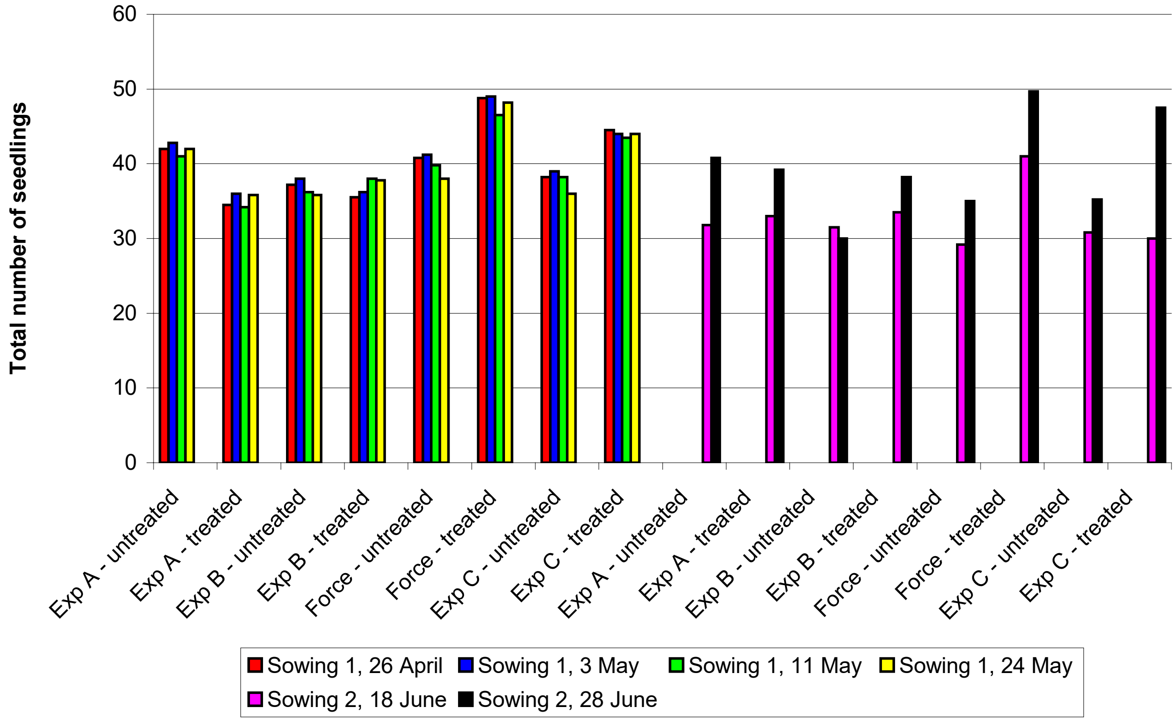

Figure 5. The total number of seedlings per plot (0.5 m of row) recorded in sowing 1 (26 April, 3 May, 11 May and 24 May) and sowing 2 (18 and 28 June).

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 4 and Figure 6). 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 5 and Figure 7), 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 5) 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 4. 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

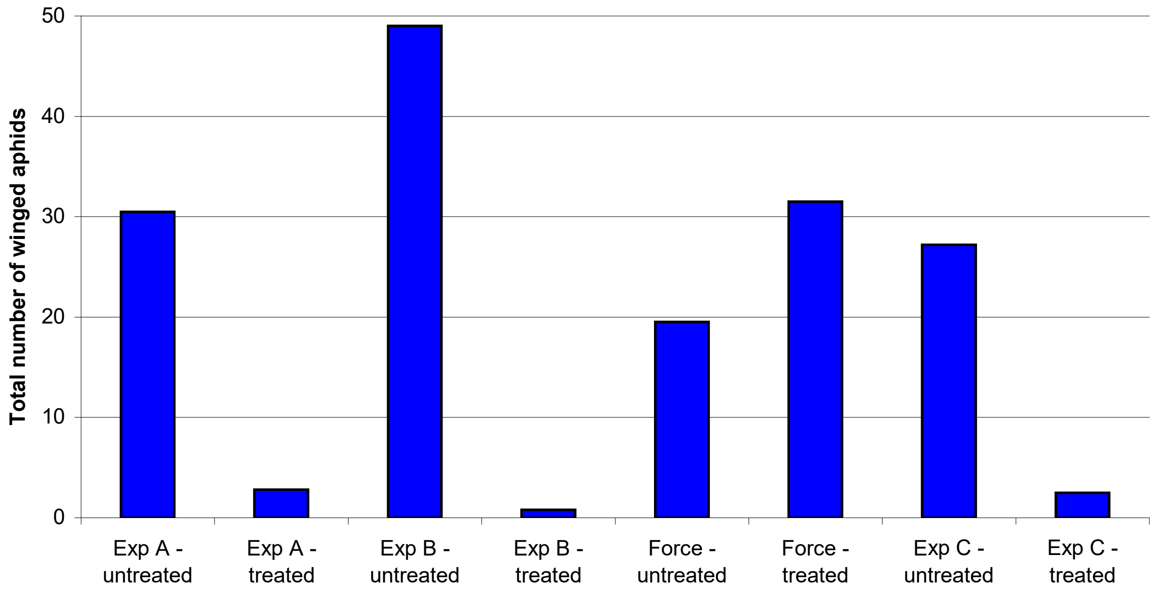

Figure 6. The total number of winged aphids per plot recorded in sowing 1 on 2 May.

Table 5. The total number of wingless aphids and parasitised 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**				**Parasitised 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

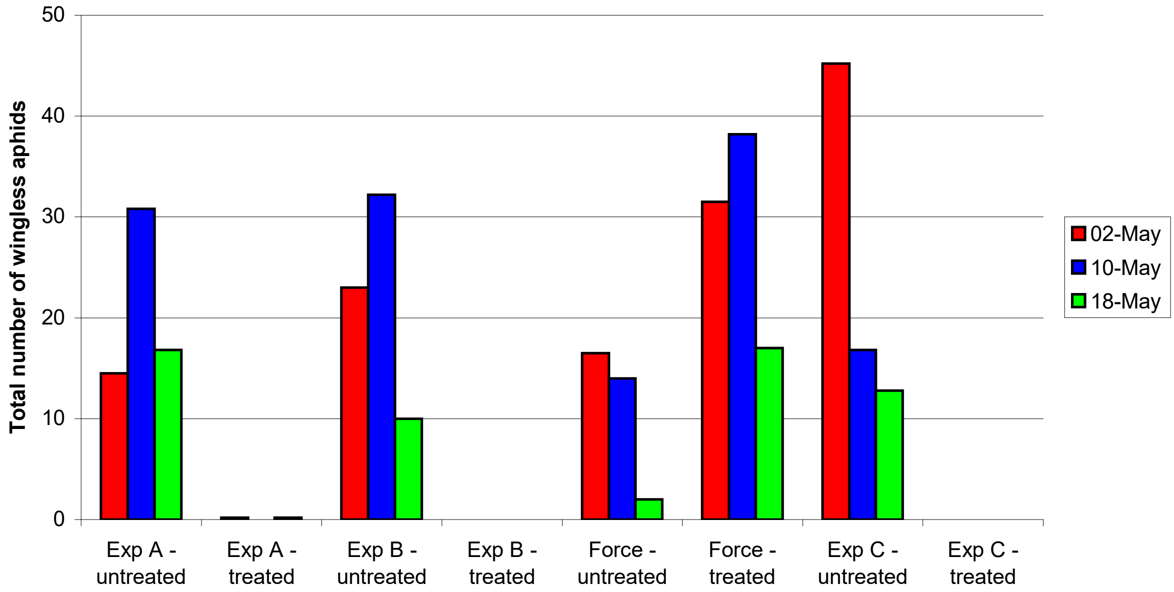

Figure 7. The total number of wingless aphids recorded per plot in sowing 1 on 2, 10 and 18 May

Carrot Fly Assessments

a) Mid-season – 27 July

Plant counts and weight

Data were collected on the number of plants and the total weight of the roots, as well as classifying the seedlings into categories according to the extent of carrot fly damage. The results for the analysis of total seedling weight, mean seedling weight and the total number of seedlings are presented in Table 6 and Figure 8 (weight) and Table 7 and Figure 9 (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 6. 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
p-prob	0.036				0.005			
SED	128.7				1.573			
LSD	265.6				3.246			
df	24				24			

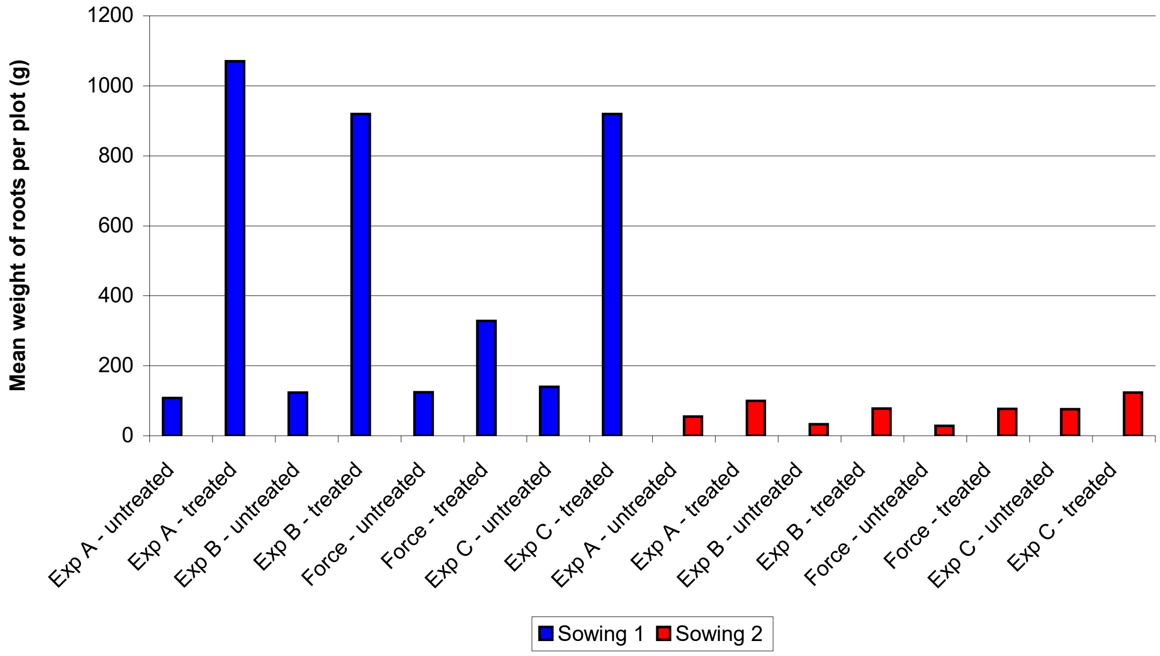

Figure 8. The mean weight of roots recorded per plot (1 m row) in sowing 1 and sowing 2 on 27 July

Table 7. 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			

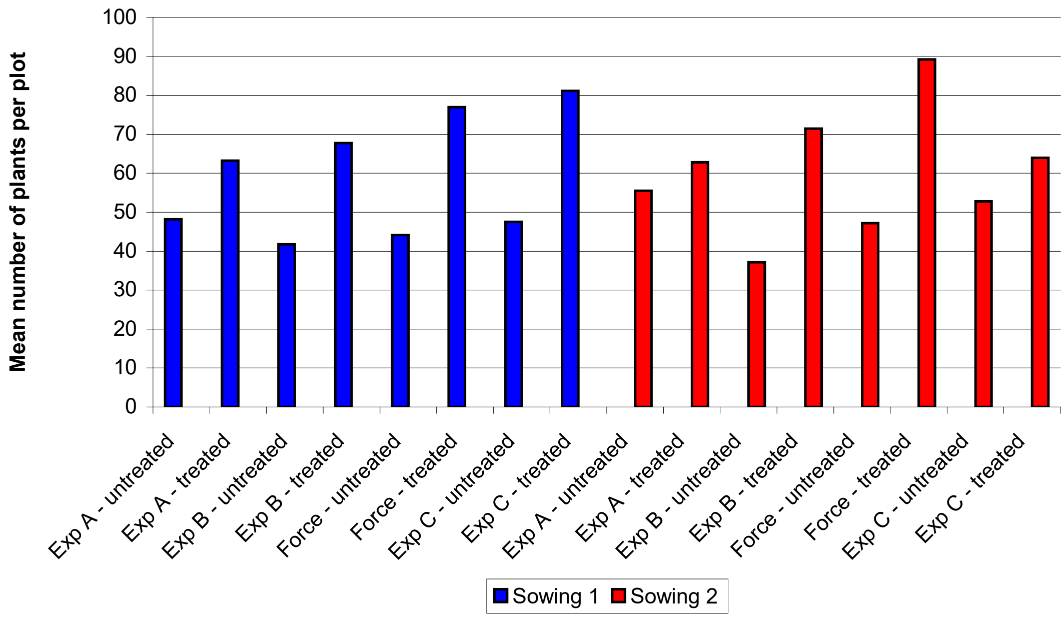

Figure 9. The mean number of plants recorded per plot (1 m row) in sowing 1 and sowing 2 on 27 July.

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 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 8 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 10.

The results for the individual damage categories are summarized in Tables 9 – 11.

No 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. 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.

Less than 5% damage:

Statistically significant differences ($p < 0.001$) were evident between sowing 1 and sowing 2 and within each sowing there were statistically significant differences between the treated and untreated paired plots. In sowing 1, the treated and untreated plots were different for all sources except Force and in sowing 2, there were statistically significant differences for Bayer B and Force only.

5-10% damage:

The only statistically significant difference within sowing 2 was between the overall plot means for treated and untreated plants. Within sowing 1, the proportion of roots with 5-10% damage in Exp A untreated was higher than Exp A treated, Exp C untreated and Exp B untreated.

10-25% damage:

At sowing 1, Exp A had a lower proportion of roots with between 10 and 25% damage ($p = 0.041$) but this difference between sources was not evident at sowing 2. No statistically significant differences were found between the treated and untreated roots within sowing 2, but for sowing 1, untreated Exp C, Exp B and Force plots had higher proportions in this damage category than their treated counterparts.

25-50% damage:

Again, no statistically significant differences were found between seed and source treatments within sowing 2 and overall there was a lower proportion with 25-50% damage in sowing 2 than sowing 1. In sowing 1, untreated Exp A and Exp B had a higher proportion in this damage category than the corresponding treated plots.

More than 50% damage:

Sowing 1 had more ($p <0.001$) carrots with severe damage than sowing 2, and the untreated plots within sowing 1 had a higher proportion in this category than the treated plots. Only Force had plants with severe damage in the treated plots at sowing 2, and only Force and Exp B had plants with severe damage in the untreated plots at sowing 2.

Table 8. The mean 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			

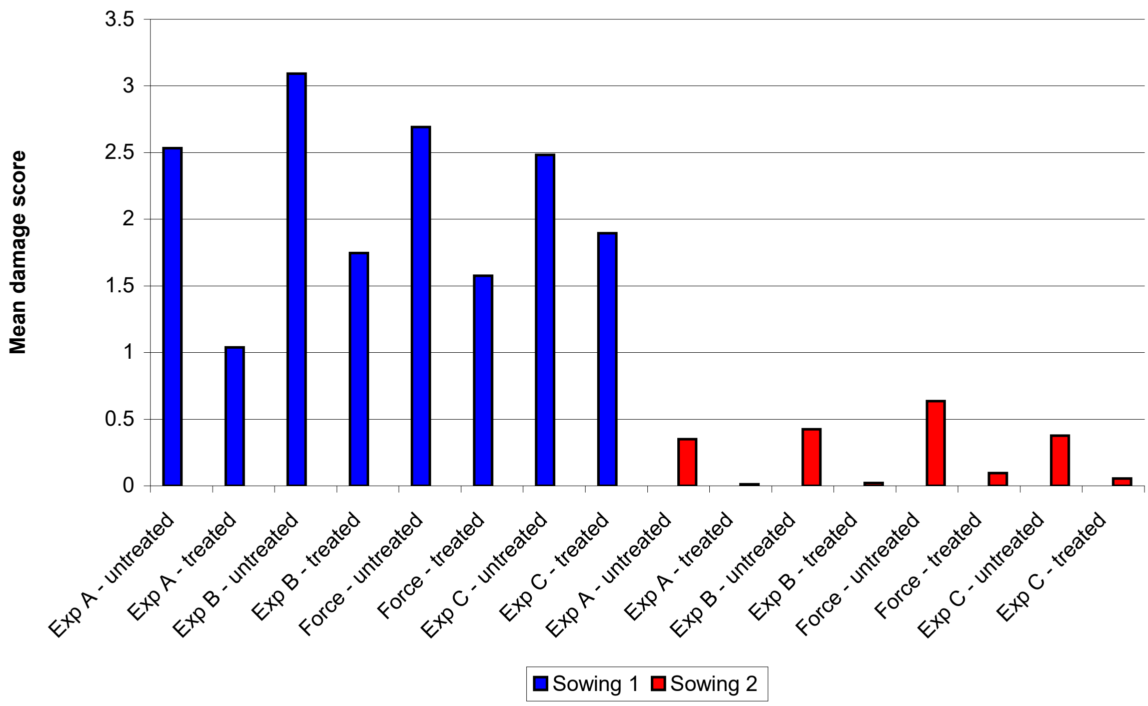

Figure 10. The mean damage score of roots from sowing 1 and sowing 2 on 27 July.

Table 9. The mean proportion of roots with no damage and < 5% 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.

Damage	0%				<5%			
Sowing	1		2		1		2	
Treatment								
1. Exp A - untreated	0.146	abc	0.805	fgh	0.1732	cdef	0.0957	abc
2. Exp A - treated	0.431	e	0.988	i	0.2977	g	0.0118	a
3. Exp B - untreated	0.079	ab	0.754	f	0.1258	cd	0.1458	cde
4. Exp B - treated	0.284	cde	0.982	i	0.2213	efg	0.0149	a
5. Force - untreated	0.076	a	0.693	f	0.1841	def	0.1513	cde
6. Force - treated	0.382	de	0.935	ghi	0.1777	cdef	0.0419	ab
7. Exp C - untreated	0.242	abcd	0.776	fg	0.0988	bc	0.1173	bcd
8. Exp C - treated	0.253	bcd	0.958	hi	0.2385	fg	0.0340	ab
SED	0.0808				0.0418			
LSD	0.1668				0.0863			
df	24				24			

Table 10. The mean proportion of roots with 5 – 10 and 10 – 25% 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.

Damage	5-10%				10-25%			
Sowing	1		2		1		2	
Treatment								
1. Exp A - untreated	0.2144	f	0.0538	ab	0.1127	bc	0.0351	a
2. Exp A - treated	0.1323	cde	0	a	0.1015	bc	0	a
3. Exp B - untreated	0.1136	bcde	0.0607	abc	0.2121	d	0.0106	a
4. Exp B - treated	0.1789	def	0.0032	a	0.1490	c	0	a
5. Force - untreated	0.1854	ef	0.0513	ab	0.2313	d	0.0529	ab
6. Force - treated	0.1609	def	0.0199	a	0.1027	c	0	a
7. Exp C - untreated	0.1062	bcd	0.0662	abc	0.2188	d	0.0351	a
8. Exp C - treated	0.1712	def	0.0030	a	0.1301	c	0.0048	a
SED	0.0397				0.0331			
LSD	0.0819				0.0683			
df	24				24			

Table 11. The mean proportion of roots with 25 – 50 and >50% 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.

Damage	25-50%				>50%			
Sowing	1		2		1		2	
Treatment								
1. Exp A - untreated	0.1773	de	0.0103	a	0.1767	e	0	a
2. Exp A - treated	0.0144	a	0	a	0.0227	abc	0	a
3. Exp B - untreated	0.2447	e	0.0192	ab	0.2248	e	0.0096	a
4. Exp B - treated	0.1152	bcd	0	a	0.0518	abc	0	a
5. Force - untreated	0.1720	cde	0.0348	ab	0.1510	de	0.0167	a
6. Force - treated	0.0788	abc	0	a	0.0800	bc	0.0028	a
7. Exp C - untreated	0.1577	cde	0.0056	a	0.1769	e	0	a
8. Exp C - treated	0.1129	bcd	0	a	0.0945	cd	0	a
F-prob	0.433				0.150			
SED	0.0373				0.0267			
LSD	0.0770				0.0550			
df	24				24			

The cumulative proportion of roots with less than 5% carrot fly damage, less than 10%, less than 25% and less than 50% carrot fly damage were analysed for both sampling occasions. A summary of the results is given in Tables 12 and 13.

Cumulative proportion <5% damage:

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 11.

Cumulative proportion <10% damage

No statistically significant differences were found for the cumulative proportion with less than 10% damage at sowing 2, but within each seed source at sowing 1, the untreated plots had a lower proportion in this cumulative damage category compared with the corresponding treated plots.

Cumulative proportion <25% damage:

As with the previous cumulative analysis, no statistically significant differences were found within sowing 2 and overall, sowing 1 had fewer ($p < 0.001$) seedlings in this cumulative damage category than sowing 2. Within each seed source at sowing 1, the untreated plots had a lower proportion in this cumulative damage category compared with the corresponding treated plots.

Cumulative Proportion <50% damage:

The untreated plots in sowing 1 had a lower ($p < 0.001$) proportion in this cumulative damage category compared with the treated plots in sowing 1. Within each seed source at sowing 1, the untreated plots had a lower proportion in this cumulative damage category compared with the corresponding treated plots.

Table 12. The cumulative proportion of roots with less than 5% and less than 10% 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.

Damage	<5%				<10%			
Sowing	1		2		1		2	
Treatment								
1. Exp A - untreated	0.319	a	0.901	d	0.533	bc	0.955	f
2. Exp A - treated	0.729	c	1.000	d	0.861	ef	1.000	f
3. Exp B - untreated	0.205	a	0.900	d	0.318	a	0.961	f
4. Exp B - treated	0.505	b	0.997	cd	0.684	cd	1.000	f
5. Force - untreated	0.260	a	0.844	d	0.446	ab	0.896	f
6. Force - treated	0.560	b	0.977	cd	0.721	de	0.997	f
7. Exp C - untreated	0.340	a	0.893	d	0.447	ab	0.959	f
8. Exp C - treated	0.491	b	0.992	d	0.662	cd	0.995	f
SED	0.0727				0.0594			
LSD	0.1501				0.1225			
df	24				24			

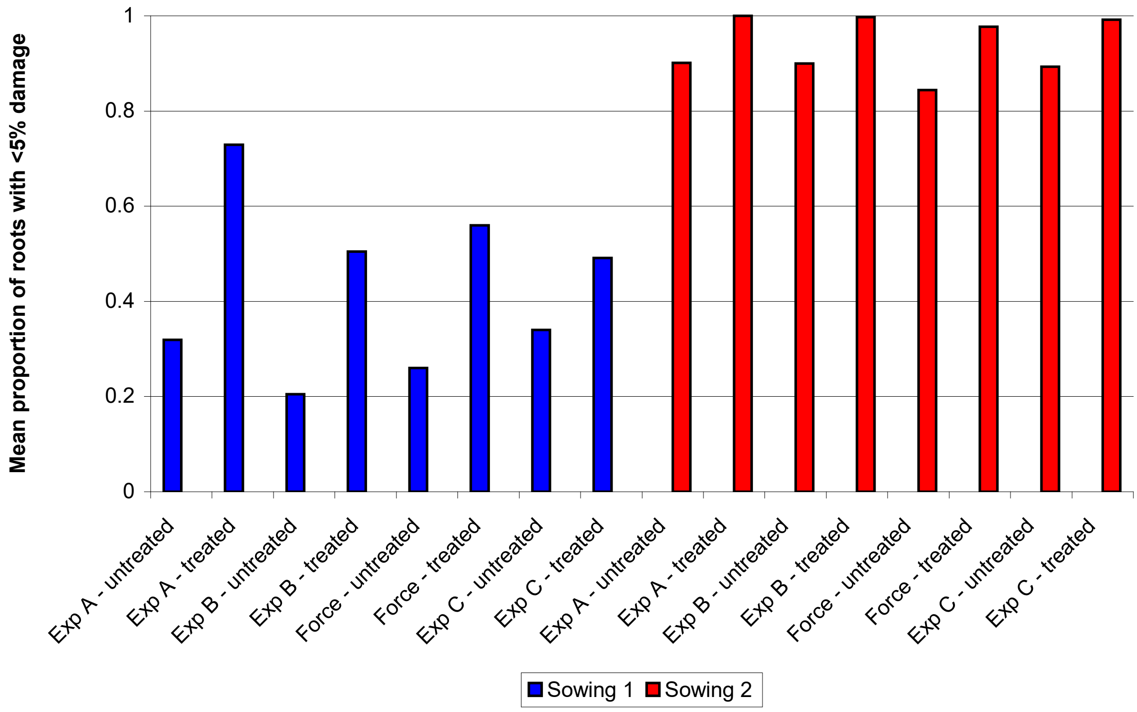

Figure 11. The cumulative proportion of roots with less than 5% damage from sowing 1 and sowing 2 on 27 July

Table 13. The cumulative proportion of roots with less than 25% and less than 50% 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.

Damage	<25%				<50%			
Sowing	1		2		1		2	
Treatment								
1. Exp A - untreated	0.6460	ab	0.9897	f	0.8233	a	1.0000	e
2. Exp A - treated	0.9629	ef	1.0000	f	0.9773	cde	1.0000	e
3. Exp B - untreated	0.5305	a	0.9712	ef	0.7752	a	0.9904	de
4. Exp B - treated	0.8329	de	1.0000	f	0.9482	cde	1.0000	e
5. Force - untreated	0.6770	bc	0.9485	ef	0.8490	ab	0.9833	de
6. Force - treated	0.8412	de	0.9972	f	0.9200	cd	0.9972	de
7. Exp C - untreated	0.6654	ab	0.9944	f	0.8231	a	1.0000	e
8. Exp C - treated	0.7926	cd	1.0000	f	0.9055	bc	1.0000	e
SED	0.0410				0.0267			
LSD	0.0969				0.0550			
df	24				24			

b) Harvest – 27 November

Plant counts and weight

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 14 and Figure 12 (weight) and Table 15 and Figure 13 (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 14. 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			

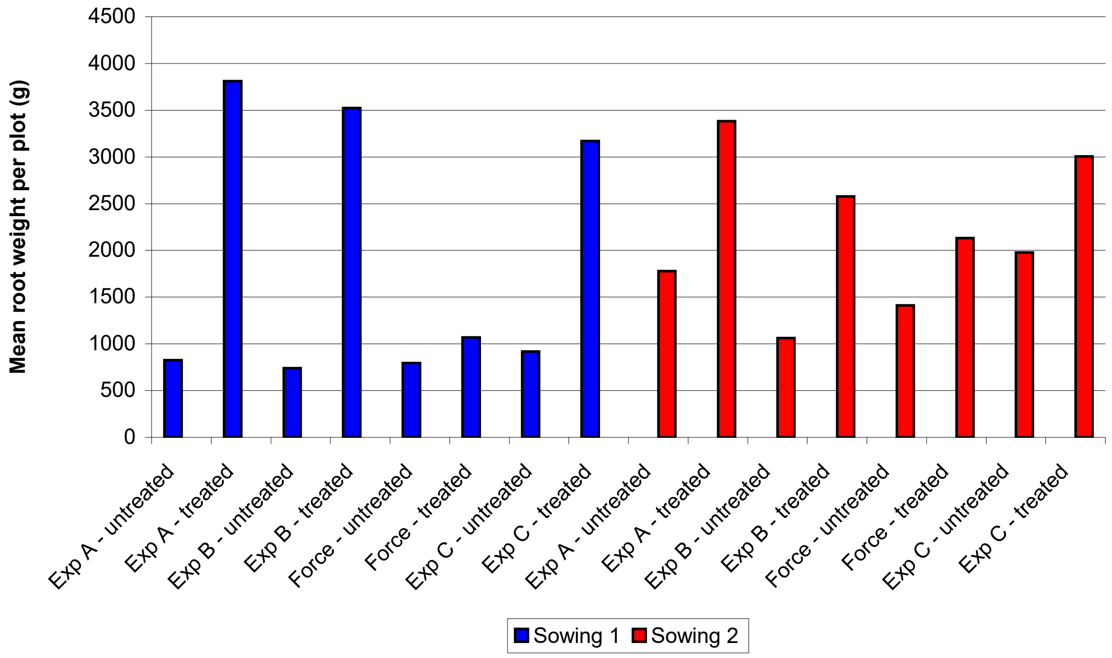

Figure 12. The mean weight of roots per plot (1 m row) from sowing 1 and sowing 2 on 27 November.

Table 15. 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			

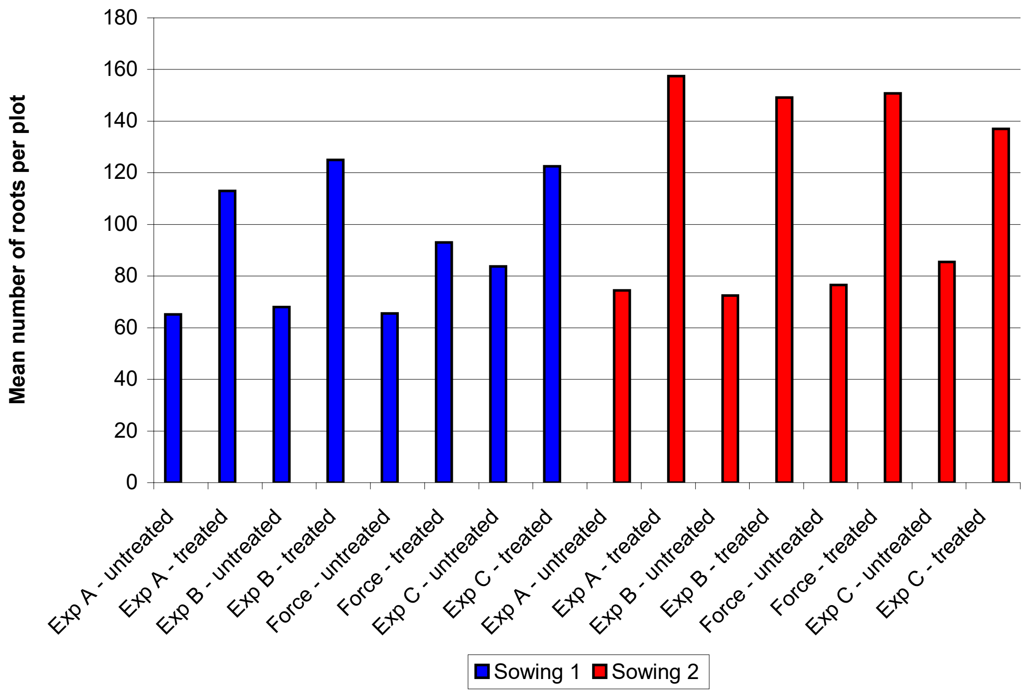

Figure 13. The mean number of roots per plot (1 m row) from sowing 1 and sowing 2 on 27 November.

Carrot Fly Damage

The damage categories were 0%, <5%, 5-10%, 10-25%, 25-50% and >50% damage to the surface of the root due to 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 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 14 and Table 16.

The results for the individual damage categories are summarized in Tables 17 - 19

No 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.

Less than 5% Damage:

No statistically significant differences were found between the sowing dates. Treated Exp A and Force had less damage than their comparable untreated plots in sowing 1 and in sowing 2, this was the case for Exp C.

5-10% Damage:

No statistically significant main effects or interactions were identified and very few statistically significant pair-wise comparisons were noted.

10-25% Damage:

Only Force in sowing 1 and Exp A in sowing 2 had statistically significant differences between the treated and untreated plots, with the untreated plots having a significantly higher proportion of roots with 10-25% damage.

25-50% Damage:

Sowing 2 had a lower proportion of untreated plants with damage between 25-50% compared with sowing 1, except when considering Exp B. No statistically significant differences were found when comparing treated sowing 1 roots with treated sowing 2 roots for the different sources.

More Than 50% Damage:

Within sowing 2, no statistically significant differences were identified, while for sowing 1, the treated plots had a lower proportion of roots with severe damage compared with untreated plots. When considering treated plots against untreated plots within sowing 1, statistically significant differences were found for all sources except Exp B.

Table 16. The mean root 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			

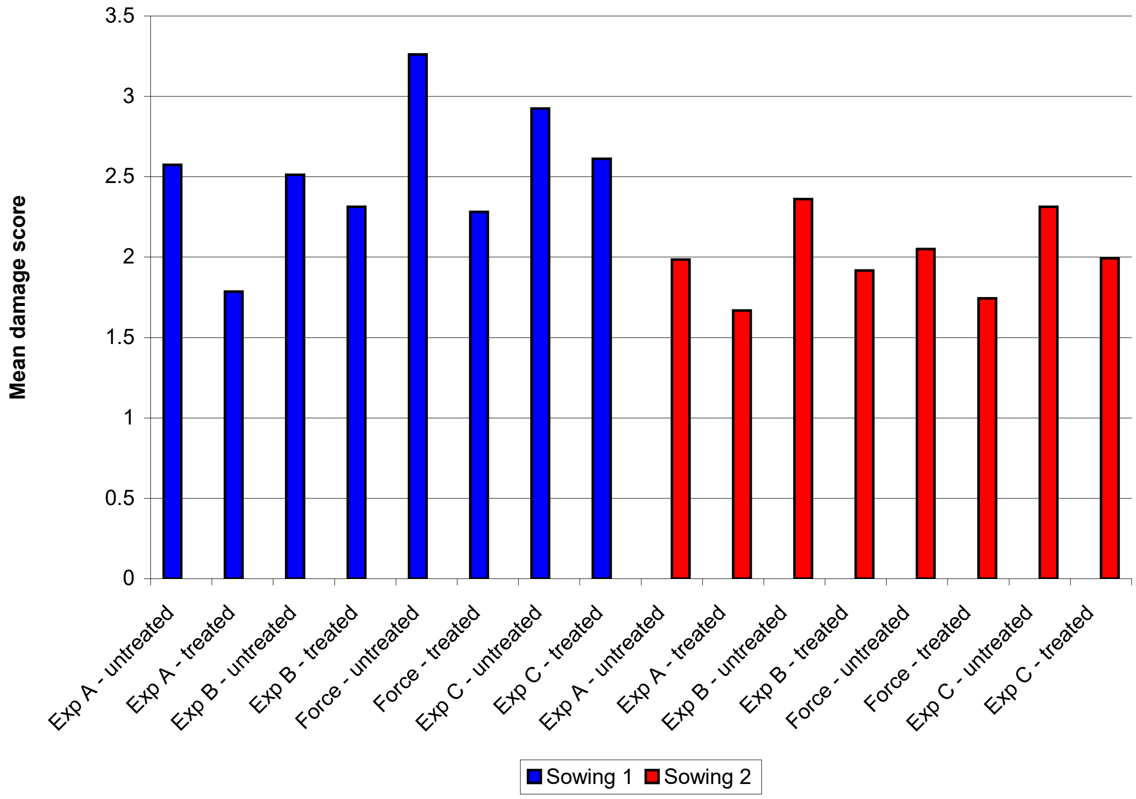

Figure 14. The mean damage score of roots from sowing 1 and sowing 2 on 27 November.

Table 17. The mean proportion of roots with no damage and < 5% 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.

Damage	0%				<5%			
Sowing	1		2		1		2	
Treatment								
1. Exp A - untreated	0.0812	abc	0.2204	e	0.1348	abcd	0.1142	abcd
2. Exp A - treated	0.1765	cdef	0.2588	f	0.2612	e	0.2040	de
3. Exp B - untreated	0.0742	abc	0.1054	abcd	0.1570	bcd	0.1435	abcd
4. Exp B - treated	0.0907	abcd	0.1911	def	0.1830	bcde	0.2038	de
5. Force - untreated	0.0203	a	0.1664	bcdef	0.0458	a	0.1781	bcde
6. Force - treated	0.1477	bcde	0.2566	f	0.1694	bcde	0.1947	bcde
7. Exp C - untreated	0.0687	ab	0.1422	bcde	0.0960	ab	0.1005	ab
8. Exp C - treated	0.0783	abc	0.1790	cdef	0.1110	abcd	0.1988	cde
SED	0.0546				0.0450			
LSD	0.1128				0.0929			
df	24				24			

Table 18. The mean proportion of roots with 5 – 10 and 10 – 25% 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.

Damage	5-10%				10-25%			
Sowing	1		2		1		2	
Treatment								
1. Exp A - untreated	0.1959	ab	0.1971	ab	0.3734	abc	0.4088	bc
2. Exp A - treated	0.2271	b	0.1960	ab	0.2749	ab	0.2957	a
3. Exp B - untreated	0.2148	b	0.2398	b	0.3225	ab	0.3596	abc
4. Exp B - treated	0.2249	b	0.1979	ab	0.3519	abc	0.3279	ab
5. Force - untreated	0.1019	a	0.2166	b	0.4758	c	0.3481	abc
6. Force - treated	0.1474	ab	0.1957	ab	0.3708	ab	0.2664	a
7. Exp C - untreated	0.1696	ab	0.2233	b	0.3150	ab	0.3946	abc
8. Exp C - treated	0.2262	b	0.2101	b	0.3692	abc	0.3013	ab
SED	0.0456				0.0506			
LSD	0.0941				0.1043			
df	24				24			

Table 19. The mean proportion of roots with 25 – 50 and >50% 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.

Damage	25-50%				>50%			
Sowing	1		2		1		2	
Treatment								
1. Exp A - untreated	0.1453	cdef	0.0476	ab	0.0695	bcd	0.0119	ab
2. Exp A - treated	0.0560	ab	0.0424	abcd	0.0042	a	0.0031	a
3. Exp B - untreated	0.1490	def	0.0990	abcd	0.0725	cd	0.0526	abcd
4. Exp B - treated	0.1224	abcdef	0.0631	a	0.0271	abcd	0.0162	abc
5. Force - untreated	0.1961	ef	0.0587	abc	0.1600	e	0.0321	abcd
6. Force - treated	0.1188	abcde	0.0733	abcd	0.0459	abcd	0.0132	ab
7. Exp C - untreated	0.2101	f	0.1192	abcde	0.1407	e	0.0212	abc
8. Exp C - treated	0.1347	bcdef	0.0851	abcd	0.0805	d	0.0256	abcd
SED	0.0418				0.0253			
LSD	0.0863				0.0521			
df	24				24			

The cumulative proportion of roots with less than 5%, less than 10%, less than 25% and less than 50% carrot fly damage were analysed for both sampling occasions. A summary of the results is given in Tables 20 and 21.

Cumulative Proportion <5% 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 Figure 15.

Cumulative Proportion <10% damage:

Again no statistically significant differences were found between the treated sources within sowing 2 and the untreated sources within sowing 2. Within sowing 1, untreated Force and Exp A both had a significantly lower proportion of roots with <10% damage than their respective treated plots.

Cumulative Proportion <25% damage:

Within sowing 2, no statistically significant differences were found, while within sowing 1, the untreated plots for each source, except for Exp B, had a lower cumulative proportion with < 25% damage compared with the corresponding treated plots.

Cumulative Proportion <50% damage:

Within sowing 2, no statistically significant differences were found. Both Force and Exp C treated plots had a larger proportion of roots in this category than their respective untreated plots.

Table 20. The cumulative proportion of roots with less than 5% and less than 10% 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.

Damage	<5%				<10%			
Sowing	1		2		1		2	
Treatment								
1. Exp A - untreated	0.216	abcd	0.335	cdef	0.412	bc	0.532	bcde
2. Exp A - treated	0.438	f	0.463	f	0.665	e	0.659	e
3. Exp B - untreated	0.241	bcde	0.249	bcd	0.456	bcd	0.489	bcde
4. Exp B - treated	0.274	bcde	0.395	ef	0.499	bcde	0.593	cde
5. Force - untreated	0.066	a	0.344	cdef	0.168	a	0.561	cde
6. Force - treated	0.317	bcdef	0.451	f	0.464	bcde	0.647	de
7. Exp C - untreated	0.165	ab	0.242	bc	0.334	ab	0.465	bcde
8. Exp C - treated	0.189	abc	0.378	def	0.416	bc	0.588	cde
SED	0.0648				0.0866			
LSD	0.1337				0.1788			
df	24				24			

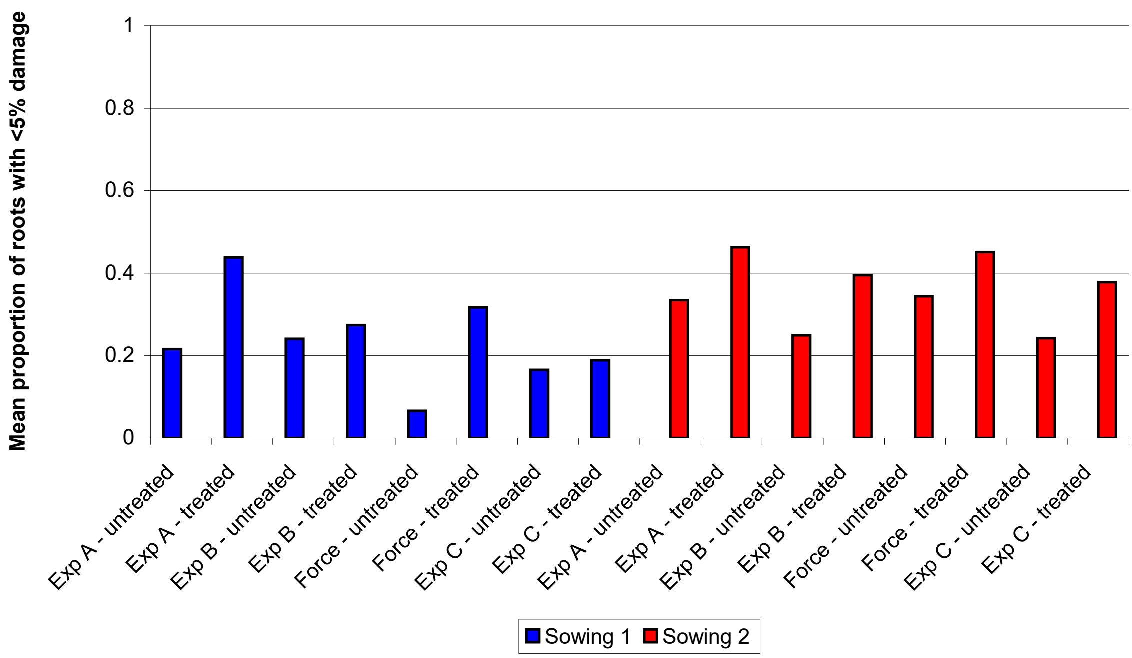

Figure 15. The proportion of roots with less than 5% damage from sowing 1 and sowing 2 on 27 November

Table 21. The cumulative proportion of roots with less than 25% and less than 50% 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.

Damage	<25%				<50%			
Sowing	1		2		1		2	
Treatment								
1. Exp A - untreated	0.7852	b	0.9405	d	0.9305	bcd	0.9881	de
2. Exp A - treated	0.9397	d	0.9545	d	0.9958	de	0.9969	e
3. Exp B - untreated	0.7785	b	0.8484	bcd	0.9275	bc	0.9474	bcde
4. Exp B - treated	0.8505	bcd	0.9207	d	0.9729	bcde	0.9838	de
5. Force - untreated	0.6438	a	0.9093	cd	0.8400	a	0.9679	bcde
6. Force - treated	0.8353	bcd	0.9135	d	0.9541	bcde	0.9868	de
7. Exp C - untreated	0.6492	a	0.8596	bcd	0.8593	a	0.9788	cde
8. Exp C - treated	0.7848	bc	0.8892	bcd	0.9195	b	0.9744	bcde
SED	0.0548				0.0253			
LSD	0.1132				0.0521			
df	24				24			

Experiment 2

Novel spray treatments to control carrot fly 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 (Long Meadow Centre) where the population of carrot fly is maintained.

The trial was originally designed as a Trojan Square for 12 treatments each replicated 4 times. The trial 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 23 using the products specified in Table 22.

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

Table 22. 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
B 400	Exp T		400 g

Table 23. 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 23) but not in the plant count. The untreated plots had a higher mean damage score than all of the other treatments (Table 24; Figure 16) 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 24. 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

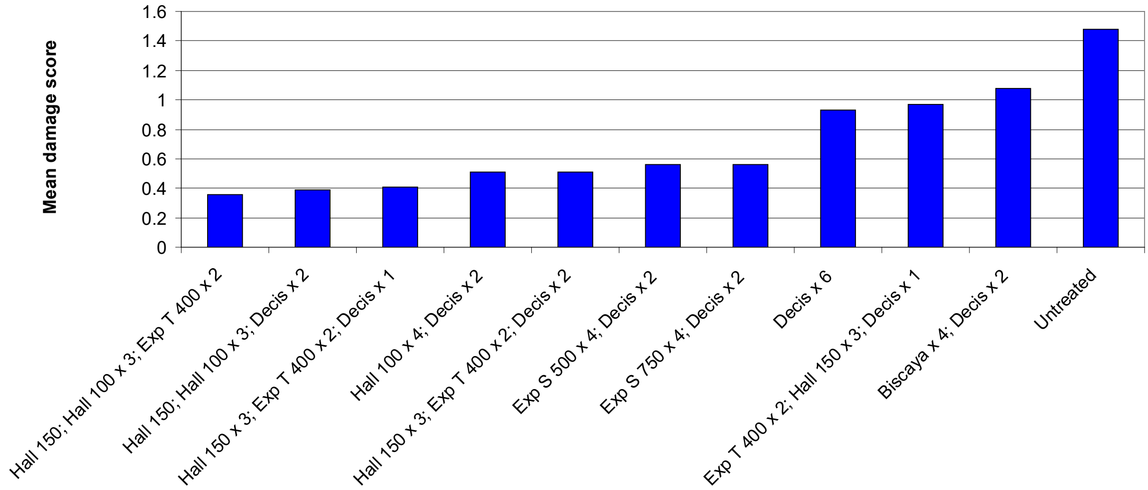

Figure 16. The mean damage score of carrot roots sampled on 22 November 2007.

The proportions of roots in each damage category are shown in Table 25. 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 25. The proportion of carrot roots sampled on 22 November 2007 with no carrot fly damage, 1-5%, 5-10%, 10-25% and 25-50% 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.

		Proportion of carrots in each damage category								
	Treatment	No damage		<5%	5-10%		10-25%		25-50%	
1	Untreated	0.315	a	0.196	0.245	d	0.212	d	0.047	b
2	Hall 100 x 4; Decis x 2	0.678	c	0.172	0.115	b	0.040	abc	0.000	a
3	Hall 150; Hall 100 x 3; Decis x 2	0.741	c	0.150	0.052	a	0.021	ab	0.000	a
4	Exp S 500 x 4; Decis x 2	0.651	c	0.196	0.133	b	0.028	ab	0.004	a
5	Exp S 750 x 4; Decis x 2	0.667	c	0.171	0.089	ab	0.052	abc	0.000	a
6	Biscaya x 4; Decis x 2	0.410	ab	0.221	0.259	d	0.107	bc	0.014	ab
7	Hall 150 x 3; Exp T 400 x 2; Decis x 1	0.718	c	0.179	0.095	ab	0.006	a	0.000	a
8	Exp T 400 x 2; Hall 150 x 3; Decis X 1	0.464	b	0.238	0.143	bc	0.127	cd	0.009	a
9	Hall 150 x 3; Exp T 400 x 2; Decis x 2	0.670	c	0.205	0.098	ab	0.033	ab	0.000	a
10	Hall 150; Hall 100 x 3; Exp T 400 x 2	0.737	c	0.186	0.057	a	0.032	ab	0.002	a
11	Decis x 6	0.486	b	0.219	0.190	c	0.093	abc	0.014	ab
	Wald	13.23		1.32	17.93		5.89		1.89	
	p-value	<0.001		0.213	<0.001		<0.001		0.042	
	SED (Tmt v Control)	0.0572		0.0273	0.0236		0.0386		0.0166	
	SED (Tmt v Tmt)	0.0662		0.0315	0.0272		0.0446		0.0192	
	LSD (Tmt v Control)	0.1164		0.0556	0.0480		0.0786		0.0338	
	LSD (Tmt v Tmt)	0.1347		0.0641	0.0554		0.0907		0.0390	
	df	10		10	10		10		10	

The cumulative proportion of roots with less than 5% carrot fly damage, less than 10% and less than 25% 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 26. The untreated plots had a lower proportion of carrots with < 10% damage compared to all other treatments. Figure 17 shows the proportion of carrot roots with <5% damage due to carrot fly.

Table 26. The cumulative proportion of carrot roots sampled on 22 November 2007 with <5%, <10% and <25% 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.

		Cumulative Proportion of Damaged Carrots								
	Treatment	<5%			<10%			<25%		
1	Untreated	0.551	a	*0.523*	0.876	a	*0.768*	1.330	a	*0.971*
2	Hall 100 x 4; Decis x 2	1.046	de	*0.865*	1.327	de	*0.971*	1.576	b	*1.000*
3	Hall 150; Hall 100 x 3; Decis x 2	1.140	de	*0.909*	1.353	de	*0.976*	1.569	b	*1.000*
4	Exp S 500 x 4; Decis x 2	1.000	cd	*0.841*	1.323	de	*0.970*	1.489	b	*0.997*
5	Exp S 750 x 4; Decis x 2	1.064	de	*0.874*	1.294	cde	*0.962*	1.556	b	*1.000*
6	Biscaya x 4; Decis x 2	0.687	ab	*0.634*	1.100	bc	*0.891*	1.475	ab	*0.995*
7	Hall 150 x 3; Exp T 400 x 2; Decis x 1	1.111	de	*0.896*	1.473	e	*0.995*	1.570	b	*1.000*
8	Exp T 400 x 2; Hall 150 x 3; Decis X 1	0.820	bc	*0.731*	1.066	b	*0.875*	1.461	ab	*0.994*
9	Hall 150 x 3; Exp T 400 x 2; Decis x 2	1.082	de	*0.883*	1.331	de	*0.972*	1.562	b	*1.000*
10	Hall 150; Hall 100 x 3; Exp T 400 x 2	1.196	e	*0.931*	1.382	e	*0.982*	1.585	b	*1.000*
11	Decis x 6	0.785	b	*0.707*	1.144	bcd	*0.910*	1.498	b	*0.997*
	Wald	13.43			7.69			2.55		
	p-value	<0.001			<0.001			0.005		
	SED (Tmt v Control)	0.0809			0.091			0.073		
	SED (Tmt v Tmt)	0.0935			0.106			0.084		
	LSD (Tmt v Control)	0.1646			0.185			0.1486		
	LSD (Tmt v Tmt)	0.1903			0.216			0.1709		
	df	10			10			10		

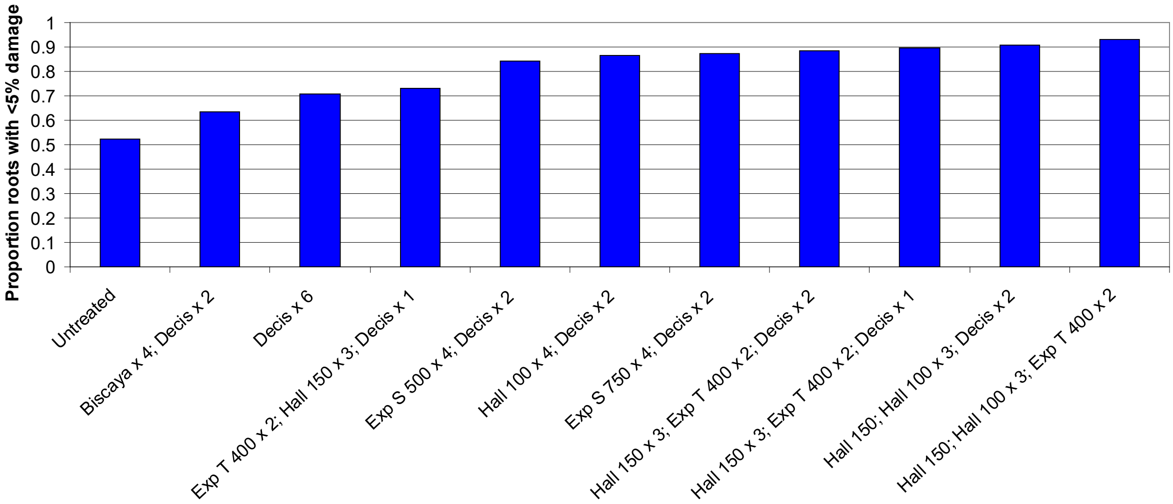

Figure 17. The proportion of carrot roots with <5% damage due to carrot fly on 22 November 2007.

Experiment 3

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 trials 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 18). 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 18. 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 19). 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 27). 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.

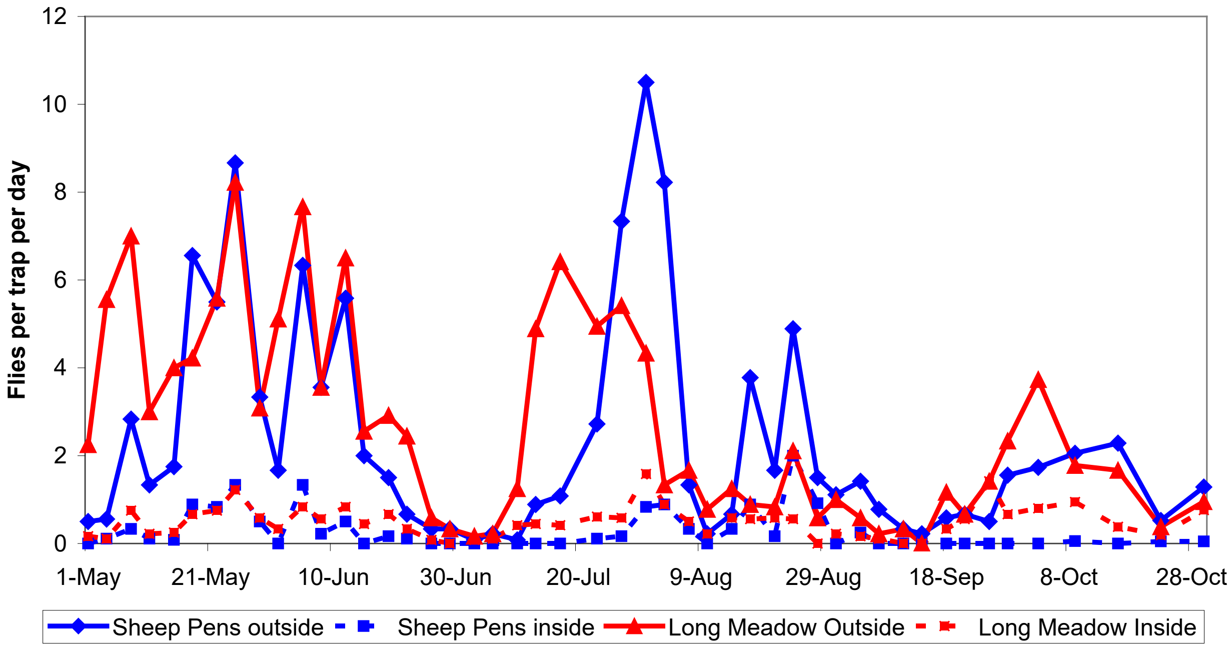

Figure 19. The numbers of carrot flies captured per trap per day on sticky traps placed within and outside the areas enclosed by fences. Long Meadow is closer to the site where the carrot flies spent the winter and is surrounded by hedges.

Table 27. 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

Discussion

The aim of this project is 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 trial at Wellesbourne.

Seed treatments

The seedling 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 from early May until the end of June in the Rothamsted suction trap located at Wellesbourne (Figure 2). The aphid migration (from its winter host – willow) was relatively early because of the exceptionally warm spring. Peak numbers of winged aphids were found when the carrot plants were assessed on 2 May and the highest numbers of wingless aphids were recorded on 2-10 May. Aphid numbers then declined and few aphids were found when plants of the second sowing were assessed on 18

June. Aphids were relatively abundant on the insecticide-free carrots and those treated with Tefluthrin, but very few were found on the plots treated with the three coded products.

Adult carrot flies were captured on sticky traps at Wellesbourne from late April and numbers had declined by mid June (Figure 1). When they were harvested in mid-July, the carrots sown on 23 May (towards the end of the first generation) had suffered considerably less carrot fly damage than those sown on 5 April. Of the carrots sown on 5 April, 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 (Tables 8 & 12)). 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 5 April 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 (Table 6; Figure 8). 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.

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 trials, 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 trial, since all of the sprays were applied at fortnightly intervals and most consisted of a total of 6 sprays.

The trial has confirmed, yet again, the efficacy of Hallmark Zeon as a spray treatment to control carrot fly and has 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 20). 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.

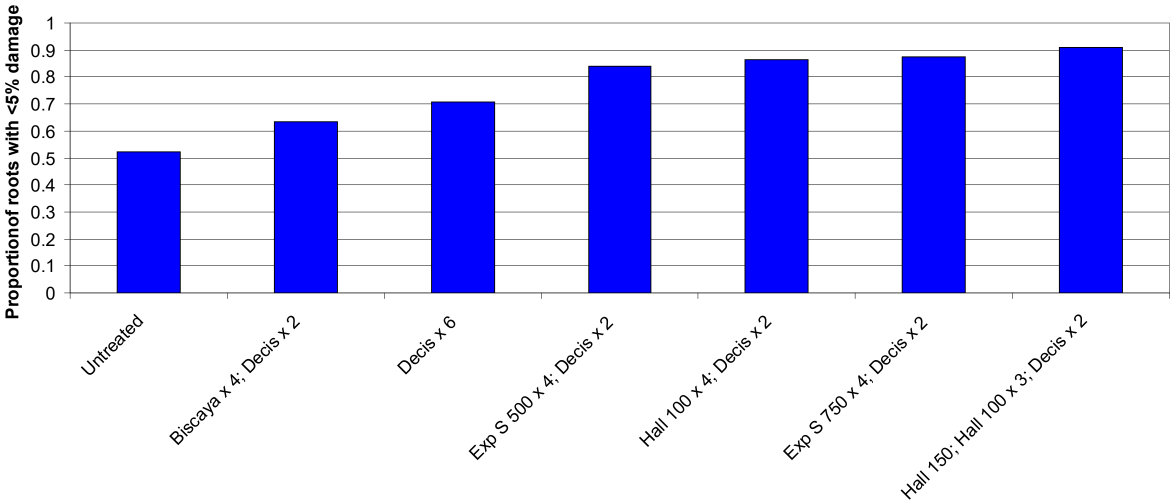

Figure 20. The proportion of carrot roots with <5% damage from treatments where the last two sprays of a 6-spray programme consisted of Decis.

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 21), so probably should not be applied 'first', but was comparable to Decis as a treatment at the end of a programme.

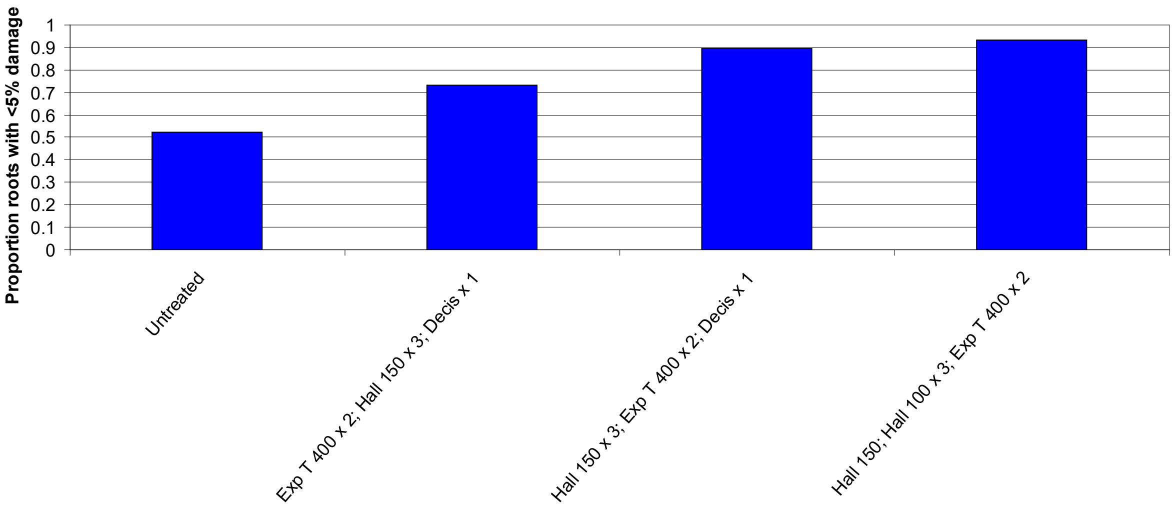

Figure 21. The proportion of carrot roots with <5% damage from treatments where Exp T formed part of a 6-spray programme.

There was only one 7-spray programme (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 trial do not indicate whether it would have been possible to omit a further one or two sprays at the end of the 6-spray programmes.

Exclusion fences

The results from the trial with the fences suggest that there is a basis for using this technique on a field scale. However, the trials 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.

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