Project title:	**Brassica crops: Evaluation of non-organophosphorus insecticides for controlling the cabbage root fly.**
Project number:	FV 223
Project Leader:	Dr Stan Finch, Department of Entomological Sciences Horticulture Research International, Wellesbourne, Warwick CV35 9EF
Report:	Year 2 report 2000/2001
Previous reports:	1999/2000
Key workers:	Mr Andrew Jukes (Insecticide trials/residue analysis) Ms Marian Elliott (Insect rearing/glasshouse trials)
Location of project:	Horticulture Research International, Wellesbourne, Warwick CV35 9EF
Project co-ordinators:	Mr Ian Morrison, Kettle Produce Ltd, Balmalcolm Farm, Cupar, Fife, KY15 7TJ Mr Fred Tyler, Alphagrow Ltd, ACRS, Tarnside, Dimples Lane, Barnacre, Garstang, Lancashire, PR3 1UA
Date project commenced:	1 May 2000
Date project completed:	30 April 2001.
Key words:	Swedes, turnips, cauliflower, cabbage root fly, Birlane (chlorfenvinphos), Dimilin (diflubenzuron), Dursban (chlorpyrifos), Fipronil (fipronil), Gaucho (imidacloprid), Marshall (carbosulfan), Neporex (cyromazine), Spintor (spinosad), Yaltox (carbofuran), film-coated seed, module-drench, mid-season sprays

Contents

1. PRACTICAL SECTION FOR GROWERS

Background, scope and objectives of the project

The cabbage root fly (*Delia radicum*) is the most serious pest of brassica and radish crops in the United Kingdom. Since 1963, the larvae of this pest have been controlled by seed-treatments, drenches, sprays and granular formulations of mainly organophosphorus (OP) insecticides. In 1994, a report by the Independent Advisory Committee on Pesticides drew attention to the occurrence of higher than expected residues of OP-insecticides in harvested carrots. Coupled with the recent adverse publicity from the use of OP-insecticides in the Gulf War and the high OP-residues found in stream water associated with sheep dips, it appears that all OP-compounds might in the next few years be banned from use in horticultural crops. The need to find alternative insecticides for cabbage root fly control has never been so urgent.

The purpose of this project was to find ways of controlling the cabbage root fly with non-OP insecticides.

A total of seven experiments were done, two involving film-coated seed; two involving drenching plant modules with insecticide immediately prior to transplanting; two involving spraying plants after drilling/transplanting into the field and finally one was established to determine the periods of cabbage root fly egg laying which present the most risk to the crop at harvest. Owing to the concern being expressed by swede growers the experiments concentrated on swede/turnip crops (see Finch, Collier & Jukes, 1999). However, the conclusions produced apply equally to leafy brassica crops, as levels of control do not have to be as stringent when the pest damages the part of the plant that is not used for human consumption. With leafy brassica crops, once the plants are established the crop can tolerate some damage to the roots without any measurable loss in yield. In contrast, in swede and turnip crops where the fly larvae damage the part of the plant that is used for human consumption, the crop has to be kept pest-free throughout most of its growth period if the roots are to be acceptable at harvest.

Summary of results

Eight insecticides were included in this research, four of which are either Ops or carbamates. The new micro-encapsulated formulation of chlorpyrifos (Empire) was no more effective than the standard formulations. Carbofuran was very effective under glasshouse conditions, but poor outdoors and Carbosulfan granules have very limited efficacy. The remaining four compounds all exhibited some activity against the cabbage root fly larvae. Fipronil (Fipronil) was the most potent and effective compound tested and spinosad (Spintor, a microbial fermentation product) also showed great promise. The insect growth regulators, cyromazine (Vetrazine) and diflubenzuron (Dimilin) showed promise as module drench treatments, but were less effective as seed treatments.

Imidacloprid (Gaucho) should not be used for root fly control as it extends the period that the fly larvae feed and so increases crop damage. Used in conjunction with fipronil it can reduce the efficacy of the fipronil, so great care and further study will be needed if imidacloprid is used as a seed treatment on brassicas for aphid or flea beetle control. Please be advised that not all the products tested are approved for use in the UK. For approval status please visit www.pesticides.gov.uk.

Action points for growers

Film-coated seed (turnip)

- **Carbofuran -** Very effective under controlled glasshouse conditions. Under field conditions the high mobility and short persistence (due to microbial breakdown) of carbofuran render seed treatment doses (which are at the lower limit needed for control) ineffective.
- **Chlorpyrifos -** The standard Gigant formulation could be phytotoxic at effective doses. The micro-encapsulated Empire formulation is less phytotoxic, but also less effective.
- **Cyromazine -** The phytotoxicity problems encountered with both the Neporex and Vetrazine formulations have been eliminated with the use of a WP formulation. However, an effective dose has yet to be found.
- **Diflubenzuron -** No phytoxicity problems have been encountered, but it was ineffective within the dose range tested. Higher doses are unlikely to be viable due to the restrictions of using seed as an insecticide carrier.
- **Fipronil -** As with carbofuran, it worked well under glasshouse conditions but was less effective in the field. Cabbage root fly mortality was high in the field, but with a large pest pressure too many larvae survived and roots were damaged as a result.
- **Imidacloprid -** Has been shown previously to be ineffective as a cabbage root fly control chemical. However, as it has potential use as a control for aphids and flea beetles it was tested in conjunction with known effective chemicals. Preliminary results suggest it can adversely effect the performance of fipronil.
- **Spinosad -** This naturally derived chemical was found to have great potential and was almost as effective as fipronil.

Module drenches (cauliflower)

- **Carbofuran -** Ineffective in field trials.
- **Chlorfenvinphos -** As effective as Dursban, but phytotoxic at 5 mg a.i./plant.
- **Chlorpyrifos -** Both the standard Dursban formulation and the micro-encapsulated Empire formulation were effective at 20% of the reccommended rate (5 mg a.i./plant) for Dursban application. In glasshouse trials Dursban was more effective than Empire at all doses tested.
- **Cyromazine -** Effective at the rate recommended for Dursban.
- **Diflubenzuron -** Effective at the rate recommended for Dursban.
- **Fipronil -** More effective than Dursban at all doses tested.
- **Spinosad -** Effective at rate recommended for Dursban.

Post-planting sprays (cauliflower)

- **Chlorfenvinphos** - Effective at the recommended rate (30 mg a.i./plant).
- **Chlorpyrifos** - Both the standard Dursban formulation and the micro-encapsulated Empire formulation were similarly effective at the recommended rate (34 mg a.i./plant) for Dursban application.
- **Cyromazine** - Effective at 10 mg a.i./plant.
- **Fipronil** - Very effective at 10 mg a.i./plant.
- **Spinosad** - As effective as Dursban at rate recommended for Dursban application.

Post-planting sprays (swede)

Field trial results emphasised the difficulties encountered with protecting swedes with mid-season sprays. None of the chemicals tested (carbofuran, chlorfenvinphos, chlorpyrifos and fipronil) provided adequate protection against the cabbage root fly larvae even after 6 full-dose applications. This could have been due to the high pest pressure encountered and the period of its activity.

Cabbage root fly activity

- **Second generation** - More than 50% of roots exposed to cabbage root fly for 1 week only were severely damaged in the 6 week period from early July to mid August
- **Third generation** - Less damage was caused than by the second generation, but over a 2 week period in early September about 50% of roots were severely damaged.

Practical and financial anticipated benefits

Brassica field vegetable crops occupy about 55,000 ha of land each year and are worth currently about £250M per annum. At present, soil insecticides are applied to control the cabbage root fly on about 34,000 ha of crop at an annual cost of about £9M. About £8M of this money is spent on organophosphorus compounds of which the approved chemicals during 2000 were Birlane (chlorfenvinphos), Cudgel (fonofos), Dipterex (trichlorfon), Dursban (chlorpyrifos), Twinspan (chlorpyrifos + disulfoton), and Phorate (phorate). The alternative approved chemicals available currently, the carbamates Marshal (carbosulfan), and Yaltox (carbofuran), are all prone to enhanced degradation and so a switch to relying solely on these insecticides would be likely to cause problems for some growers.

By 2001 three of these products (Cudgel, Dipterex and Phorate) were no longer available to brassica growers or had been withdrawn completely. To compound this loss of products the approvals for carbofuran and chlorfenvinphos will terminate in December 2001. This will leave just Dursban, Twinspan and Marshal. As a consequence, the current work has been targeted to look for alternative insecticides, mainly from within the new groups of chemicals.

Without adequate insecticidal control, it is estimated that about 24% of the plants in field brassica crops would be rendered unmarketable by the cabbage root fly. In crops such as swedes and turnips, in which the pest attacks directly the part of the crop used for human consumption, the losses would be considerably higher. In addition, even if cultural methods could be relied on to lower overall damage to 15-20%, the Industry would still be facing losses of between £23-31M per annum from the area of crop (34,000 ha) that needs protecting currently against attacks by the cabbage root fly.

2. SCIENCE SECTION

Concise review of previous research

The cabbage root fly has been used as the standard pest-fly of field vegetable crops against which all new insecticidal, cultural, and biological control methods have been tested at Wellesbourne during the last 40 years.

Dr Finch was involved in the development of the original mass rearing method (Finch & Coaker, 1969) that enabled experiments to be done with this fly throughout the year. As a consequence, Drs Finch and Collier used the detailed data collected on the cabbage root fly, during a 7-year period, to produce the first "pest-insect forecast" (Collier & Finch, 1985; Finch & Collier, 1986). They have also published more than 150 papers on various aspects of the behaviour and control of the cabbage root fly (e.g. Collier *et al.*, 1991; Finch, 1993).

In March 1999, they completed a MAFF Commissioned Project entitled " To optimize the efficiency of soil-applied insecticides for controlling the cabbage root fly in field brassica crops " (HH 1734 SFV) (Finch, 1999). The techniques and expertise developed during this project, which was based entirely on Birlane (chlorfenvinphos – OP) and Yaltox (carbofuran – carbamate), were used as the basis for the current experiments.

During 1996 and 1997, as part of a Confidential Contract for Dr Bill Lankford, of Rhône-Poulenc, the team developed several ways in which fipronil could be used commercially to control the cabbage root fly (Jukes & Finch, 1998).

The team also did experiments parallel to the ones described here in an HDC project entitled "Radish: evaluation of non-OP insecticides for controlling cabbage root fly" (FV 159a) (Finch, Hartfield & Jukes, 1999).

A field trial has been conducted for the HDC (FV 66a) by ADAS colleagues who during the period from 1997-2000 have looked for insecticidal treatments that would give better control of the cabbage root fly in swede crops

In the first year of this project (FV223) (Jukes *et al*, 2000) several active ingredients were tested using a number of methods of application. The current trials are based on results from these experiments.

It is hoped that the results from the ADAS work will complement the current results and those collected in the earlier HDC trials (FV 159a and FV223).

Introduction to experimental work

The current proposal involves some glasshouse trials, as these can be used to estimate how much insecticide is required to give the desired level of control. The advantages of glasshouse trials are that they allow 1) all insecticides to be tested at the same insect pressure and 2) a range of insecticide doses can be tested in a limited space prior to the extensive, and hence more expensive, field trials. In addition, 3) variations in the results caused by changing weather conditions and/or beneficial insects can also be avoided.

Results from glasshouse experiments pinpoint directly the treatments unlikely to be accepted in commercial crops. Hence, a strong scientific base can be used to decide which new insecticides to include in new research programmes. The work during this one-year project was "short-term", and was concerned solely with finding possible replacements for the OP-based treatments applied currently.
Experiments were done to answer the following 6 questions:-

Film-coated seed

1 What quantities of the test insecticides have to be coated onto brassica seed to give optimum control of cabbage root fly larvae under glasshouse conditions?

2 How effective at controlling the cabbage root fly under field conditions is seed coated with the two best loadings of the test insecticides?

Module drenches

3 What quantities of the test insecticides have to be watered over plant modules to give optimum control of cabbage root fly larvae under glasshouse conditions?

4 How effective at controlling the cabbage root fly under field conditions are the test insecticides when watered over the plant modules shortly before transplanting?

Crop sprays

5 Can sprays of the insecticides applied shortly after transplanting give levels of control comparable to those obtained from sprays of chlorpyrifos (Dursban)?

6 How frequently do the test insecticides have to be applied to the foliage of brassica crops to keep swede and turnip crops damage free?

Cabbage root fly activity

7 Which periods of egg-laying by the second and third fly generations contributes most to crop damage at harvest?

The seven experiments

For scientific reasons the test chemicals are shown as the active ingredients (with one product name in parentheses) in the Materials and Methods sections, as certain chemicals are available under a range of different product names.

The actual active ingredients tested, together with the representative product (shown in parentheses), were, carbofuran (Yaltox), carbosulfan (Marshal), chlorfenvinphos (Birlane), chlorpyrifos (Dursban), cyromazine (Neporex), diflubenzuron (Dimilin), fipronil (Fipronil), imidacloprid (Gaucho) and spinosad (Spintor)

A. FILM-COATED SEED

Experiment 1. What quantities of the test insecticides have to be coated onto brassica seed to give optimum control of cabbage root fly larvae under glasshouse conditions?

Materials and methods

Turnip seeds were film-coated at HRI, Wellesbourne with chlorpyrifos (Gigant), micro-encapsulated chlorpyrifos (Empire), fipronil (experimental seed treatment formulation), spinosad (Spintor), diflubenzuron (Dimilin 24WP), cyromazine (unknown WP formulation) and carbofuran (Furadan 44). Both chlorpyrifos formulations were applied by using a slurry with Talcum powder, as chlorpyrifos is liquid at room temperature. Each of the test insecticides were applied at target loadings of between 0.1 and 100 g a.i./unit (1 unit =100,000 seeds) using a PVA sticker at the rate of 0.5 % of product weight. The actual loadings achieved were assessed by high performance liquid chromatography (hplc) analysis (Table 1). A further batch of seed was left untreated.

Table 1. Insecticide doses applied to turnip seeds for glasshouse evaluation of the control of cabbage root fly larvae

	Actual dose	
Insecticide	(g a.i./unit)	(mg a.i./seed)
Chlorpyrifos (Gigant)	0.1	0.001
	9.1	0.91
Chlorpyrifos (Empire)	0.1	0.001
	4.0	0.04
	14.2	0.14
Spinosad	1.0	0.01
	5.1	0.05
	24.6	0.25
	50.4	0.50
	99.1	0.99
Fipronil	0.2	0.002
	0.9	0.009
	4.1	0.41
	20.4	0.20
	58.4	0.58
Cyromazine	10.0	0.10
Diflubenzuron	1.4	0.01
	5.1	0.05
	22.0	0.22
	43.4	0.43
	67.7	0.68
Carbofuran	77.8	0.78

On 26 January, the treated turnip seed was sown (16 seeds/treatment) in Optipot 9M pots containing John Innes no. 2 compost. All seeds were sown at a depth of 1 cm from the soil surface. The pots were maintained under glasshouse conditions (20 ± 2 ºC) and the numbers of seedlings that emerged were monitored daily. On 31 January the treatments were arranged in 14 blocks each containing 22 plants, that is 1 plant from each treatment. The positions of the plants within each block were randomised fully.

On 6 February, fifteen cabbage root fly eggs, obtained from the laboratory culture (Finch & Coaker, 1969), were washed onto the soil at the base of each plant. On 12 April, most of the insects had pupated and so the pots were transferred to a 5 ºC cold store to arrest further insect development as full pupae are much easier to count than pupae from which the adults have emerged. April 12 was chosen to ensure that any larvae that survived the experimental treatment had sufficient time to develop into the pupal stage. From 12-19 April batches of the pots were taken from the cold store so that the fly pupae could be extracted. The cabbage root fly pupae were extracted from the potting compost by flotation in water. Records were taken of the numbers of pupae found and root weight. The numbers of pupae recovered from the treated pots were expressed as a percentage of those recovered from the untreated pots.

Results

Most treatments caused a slight delay in the germination of the seeds (Figure 1). The carbofuran treatment caused the greatest delay, as it almost doubled the mean time required for the seedlings to emerge from the soil. The rate of germination was also effected badly by the Gigant formulation of chlorpyrifos but the effect of the micro-encapsulated formulation, Empire, was less pronounced.

All treatments increased root weight (Figure 2) relative to the untreated plants. The best treatments produced up to a 4-fold increase. The slower rate of germination of the carbofuran treated seeds did not give rise to lower root weights, but there was evidence for loss of root weight at the highest dose tested using Empire (0.14 g a.i./plant).
The mean number of pupae recovered from each untreated pot was 8.6. This value was used subsequently to represent 100% survival when calculating the estimated percentage survival of larvae in the treated pots (Figure 3).

- **Chlorpyrifos** - Both formulations were ineffective at the dose (0.001g a.i./plant) recommended for module-raised brassica plants. Although the higher (0.09 g a.i./plant) dose gave some control, Gigant would probably become too phytotoxic if tested at a dose higher than this. The Empire formulation of chlorpyrifos was less phytotoxic, but dose for dose it was also less effective than Gigant.

- **Spinosad** - Decreased larval survival at the lowest dose tested. Fewer larvae survived as the dose of spinosad was increased. At the highest dose tested, only about 10% of the fly larvae survived. Spinosad shows potential as an effective insecticide for controlling the cabbage root fly, but there are some questions concerning persistence that still need to be answered.

Figure 1. The time taken in days for 75% of the treated seeds to germinate.

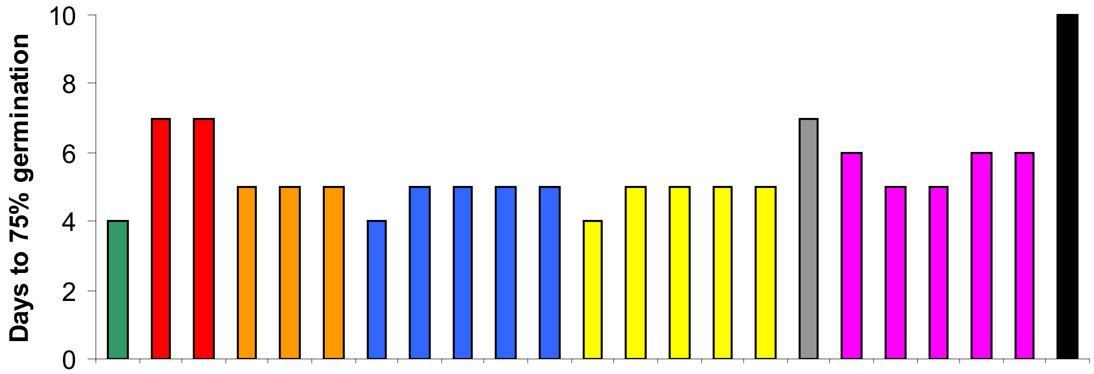


Figure 2. The combined effect of seed treatment and cabbage root fly feeding activity on the weight of turnip roots at the time the fly pupae were extracted from the pots.

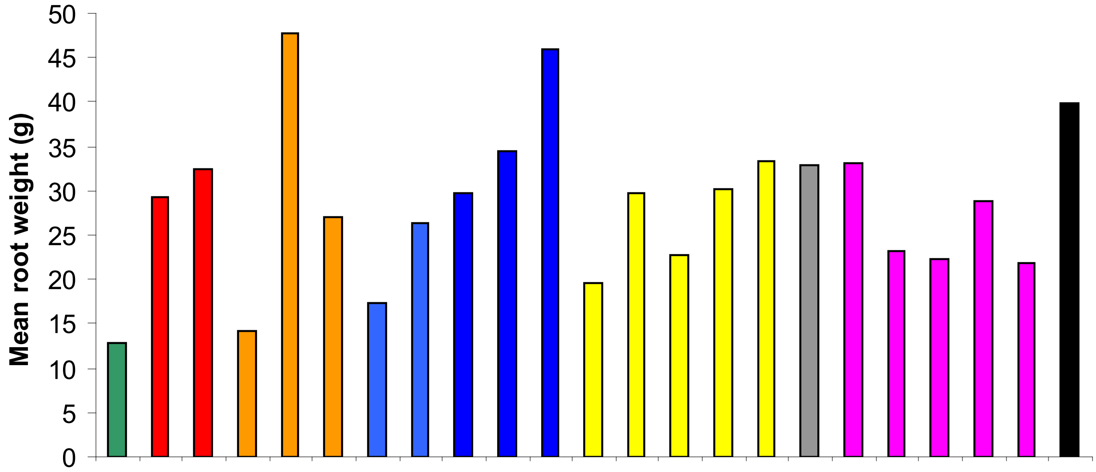
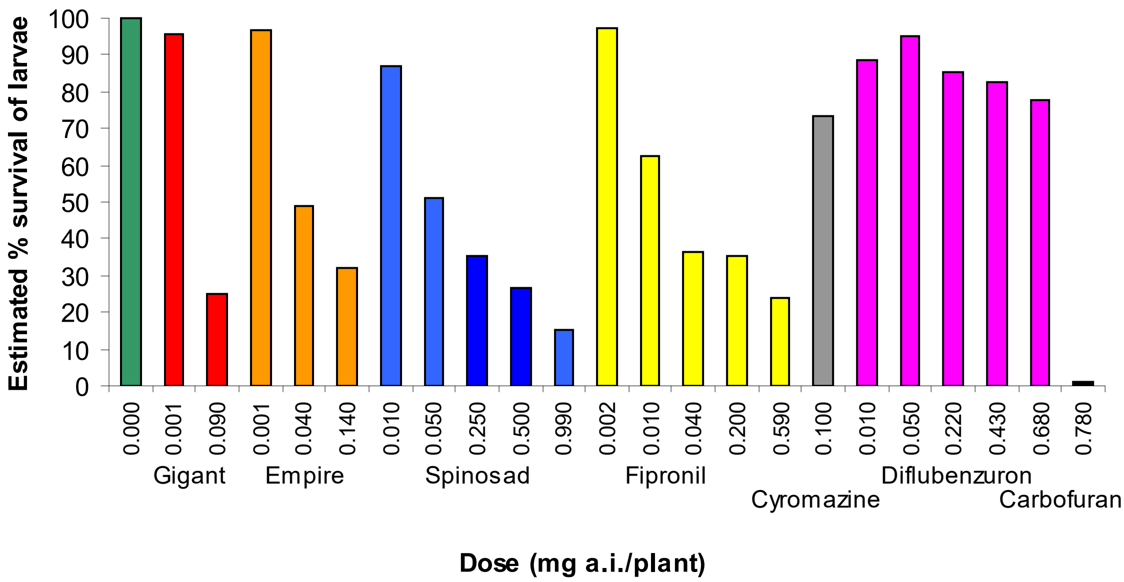


Figure 3. The estimated % survival of cabbage root fly larvae after treating the seed with 1-5 rates of seven different insecticide products.



- **Fipronil** - Did not perform as well as in previous years, but still showed potential at the highest dose tested. The reduction in efficacy in the 2000 trial may have been due to the sowing regime. In previous years the seeds had been sown into propagation modules (and hence the fipronil would have been bound within the crucial area around the plant stem) and then transplanted into larger pots. This year the seeds were sown directly into larger pots and this may have allowed the fipronil to move further away from the crucial zone.

- **Cyromazine** - A small quantity of an old WP formulation was sourced which was sufficient only for a single dose to be tested. Although control was limited at the dose tested, the problems of phytotoxicity recorded in 1999 were eliminated.

- **Diflubenzuron** - The levels of control produced were not sufficient even at the highest dose tested. This treatment had little value for cabbage root fly control, but results with this and the other insect growth regulator (cyromazine) tested indicated that there was potential for chemicals of this type if the right active ingredient and/or formulation could be found.

- **Carbofuran** - Was easily the most effective chemical tested. However, it is unlikely that it will remain available and under field situations it can suffer from persistence and mobility problems.

Experiment 2. How effective at controlling the cabbage root fly under field conditions is seed coated with the best loadings of the test insecticides

Materials and methods

Turnip seeds were film-coated at HRI, Wellesbourne with chlorpyrifos (Gigant), fipronil (experimental seed treatment formulation), spinosad (Spintor), diflubenzuron (Dimilin 24WP), imidacloprid (Guacho) and carbofuran (Furadan 44). Seed treatments containing a mixture of chlorpyrifos and imidacloprid and a mixture of fipronil and imidacloprid were also prepared to assess how the inclusion of imidacloprid, at a dose sub-lethal to cabbage root fly, affected fly control by the other two active ingredients. The insecticides were applied at pre-determined target loadings using a PVA sticker at the rate of 1% of product weight. Actual loadings achieved were assessed by hplc analysis (Table 2). A further batch of seed was left untreated.

An area of eight (1.83 m wide x 16 m long) seed beds were prepared in the field at HRI, Wellesbourne. On 6 June, each of the 6 inner beds was sub-divided into two 7 m plots with 2 m between plots. This date was chosen to allow the seeds sufficient time to establish before the forecasted time of the second fly generation (Phelps *et al.*, 1993). The 11 seed treatments were drilled using a tractor mounted Stanhay, Singulaire seed drill at 15 seeds/m row. Four rows were drilled into each bed to give a row spacing of 46 cm. The treatments were randomised such that the experiment consisted of 4 randomised blocks of twelve 7 m rows. Each block contained 1 untreated row and the 11 treatments.

During the week of 7-12 August, five plants were sampled from each plot and a 15 cm diameter x 15 cm deep soil core was taken from around the root of each harvested plant. The foliage of the test plants was discarded and the roots were washed and weighed. The cabbage root fly pupae were extracted from the soil samples by flotation in water and the numbers of pupae were counted.

Table 2. The doses of insecticide applied to the seed used to drill the field trial.

Insecticide	Actual dose (g a.i./unit)	(mg a.i./plant)
Chlorpyrifos (Gigant)	0.1	0.001
	9.1	0.91
(+ imidacloprid, 50g ai/unit)	0.1	0.001
Spinosad	52.3	0.52
	125.7	1.26
Fipronil	26.1	0.26
	71.4	0.71
(+ imidacloprid, 50g ai/unit)	20.5	0.21
Diflubenzuron	42.7	0.43
Imidacloprid	45.1	0.45
Carbofuran	77.8	0.78

Results

Damage due to the cabbage root fly was severe. Regardless of treatment, more than half of the roots in all treatments suffered >25% damage (Figure 4). The mean number of pupae recovered from the untreated turnips was 5.1. Although, most treatments reduced larval survival (Figure 5), overall efficacy was poor compared to that recorded in the glasshouse experiments.

- **Chlorpyrifos** – Had little effect on the levels of root damage, but at the higher dose (0.09 mg a.i./plant) tested it reduced larval survival by about 70%.

- **Spinosad** – At the higher (1.26 mg a.i./plant) dose tested, spinosad reduced the levels of root damage by about 50% and larval survival by about 80%. The potential of spinosad as an effective treatment has been confirmed, but the questions of persistence and effective dose still need to be answered.

- **Fipronil** – Reduced damage and larval survival at both doses tested. Results were disappointing compared to previous years, due possibly to the method of planting. In previous experiments, the seeds were sown in modules (which hold the insecticide in the crucial region for cabbage root fly control) and the subsequent plants were transplanted from them directly into the field plots. This experiment was direct drilled and as a result the distribution of the insecticide may have been far from optimum.

- **Diflubenzuron** – Was totally ineffective at the dose (0.43 mg a.i./plant) tested.

- **Imidacloprid** – Previous findings that imidacloprid had limited toxicity against cabbage root fly larvae were confirmed. When applied in conjunction with fipronil the efficacy of fipronil was reduced even further. Additional work may have to be done to establish the true extent of these effects, particularly if imidacloprid seed treatments are to be used as a control measures for aphids and flea beetles.

- **Carbofuran** – In stark contrast to its potency in the glasshouse trials, carbofuran had almost no effect in the field trial. Microbial degradation and movement of the insecticide away from the root zone become extremely important factors when the amount of carbofuran applied is close to the minimum effective dose.

Figure 4. The % of roots with >25% cabbage root fly damage from the seed treatments tested in the field trial.

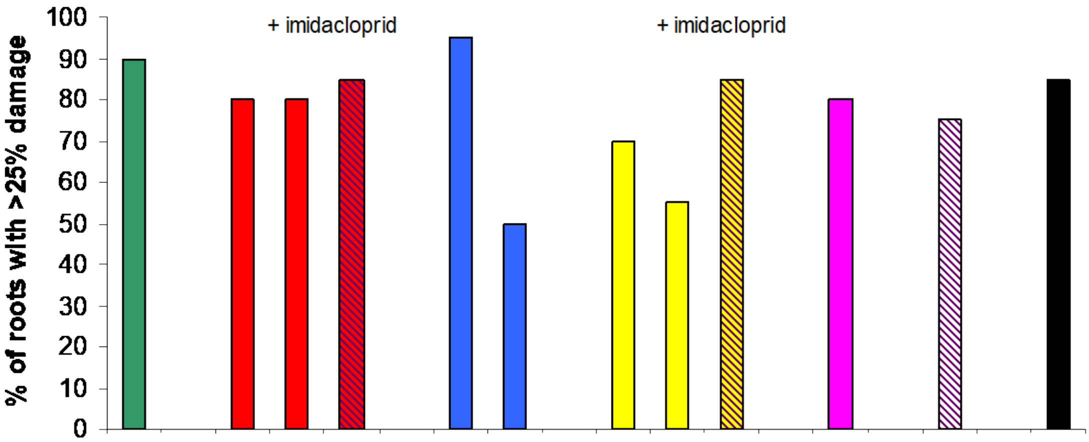
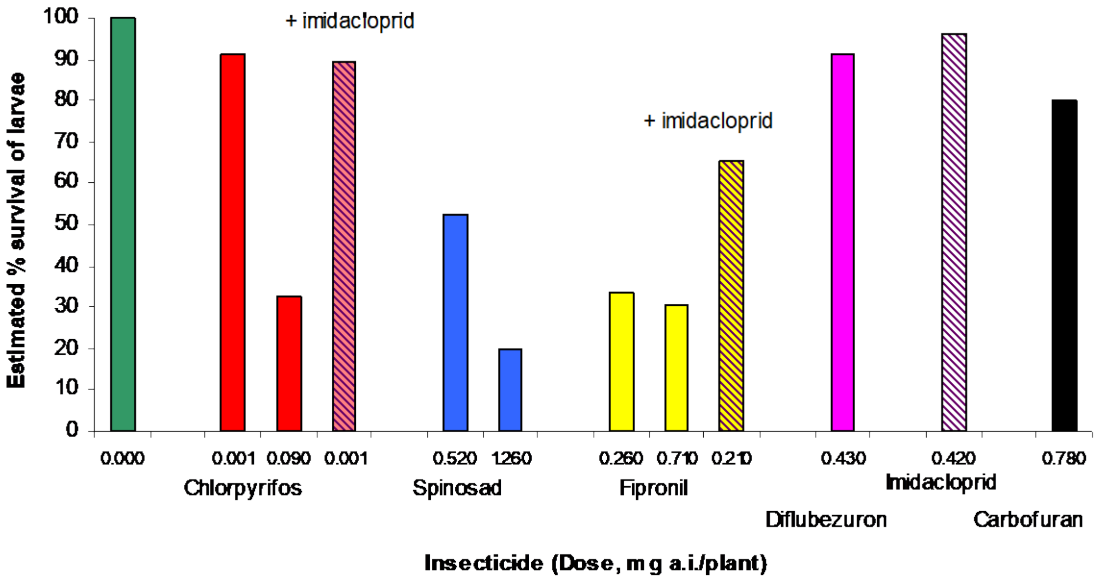


Figure 5 The estimated % survival of cabbage root fly larvae from the seed treatments tested in the field trial .



B. MODULE DRENCES

Experiment 3. What quantities of the test insecticides have to be watered over plant modules to give optimum control of cabbage root fly larvae under glasshouse conditions?

Materials and methods

On 10 January, four 308 Hassy trays were sown with untreated cauliflower seeds and maintained under glasshouse conditions. On 23 February, 5 sets of 28 plants (2 rows of modules) were transferred to a clean Hassy tray, leaving one empty row between each set of plants. Each set was treated with one of five doses of one of the test insecticides. The process was repeated for each of the six test insecticides, that is chlorpyrifos (Dursban 4), micro-encapsulated chlorpyrifos (Empire), spinosad (Spintor), fipronil (80% WP), cyromazine (Vetrazine) or diflubenzuron (Dimilin Flo). Each treatment was applied by adding 1 ml of a solution in water using a laboratory pipette. The doses applied were 0.5, 1, 2.5, 5 and 10 for both cyromazine and diflubenzuron and 0.2, 0.5, 1 2.5 and 5 (the rate currently recommended for chlorpyrifos) mg a.i./plant for the other four insecticides. The insecticide was washed into the peat with a similar volume of clean water immediately after the insecticide had been applied. One Hassy tray was left untreated. On 27 February, four days after applying the insecticide treatment, sixteen plants from each treatment were transplanted into FP11 square pots filled with John Innes no. 2 compost. Cyromazine caused some yellowing and curling of the outer leaves at the highest dose (10 mg a.i./plant) applied, but the plants recovered as they matured. The newly-potted plants were moved into a glasshouse compartment maintained at 20 ± 2 ºC . The treatments were arranged in 16 blocks each containing 1 plant from each of the 31 treatments. The positions of the plants within each block were randomised fully.

On 14 March (19 days after treatment), twenty cabbage root fly eggs, obtained from the laboratory culture (Finch & Coaker, 1969), were washed onto the soil at the base of each plant. On 23-30 April, by which time the root fly larvae had completed their development, the cabbage root fly pupae were extracted from the potting compost by flotation in water and the numbers of pupae found and plant weight were recorded. The numbers of pupae recovered from the treated pots were expressed as a percentage of those recovered from the untreated pots.

Results

All treatments increased plant weight (Figure 6) relative to the untreated plants. The best treatments increased plant weight by about 50%.
The mean number of pupae recovered from each untreated pot was 13.3. This value was used subsequently to represent 100% survival when calculating the estimated percentage survival of larvae in the insecticide treated pots (Figure 7).

Figure 6. The combined effect of the module drench treatments and cabbage root fly damage on the harvested weight of the cauliflower plants in the glasshouse trial.

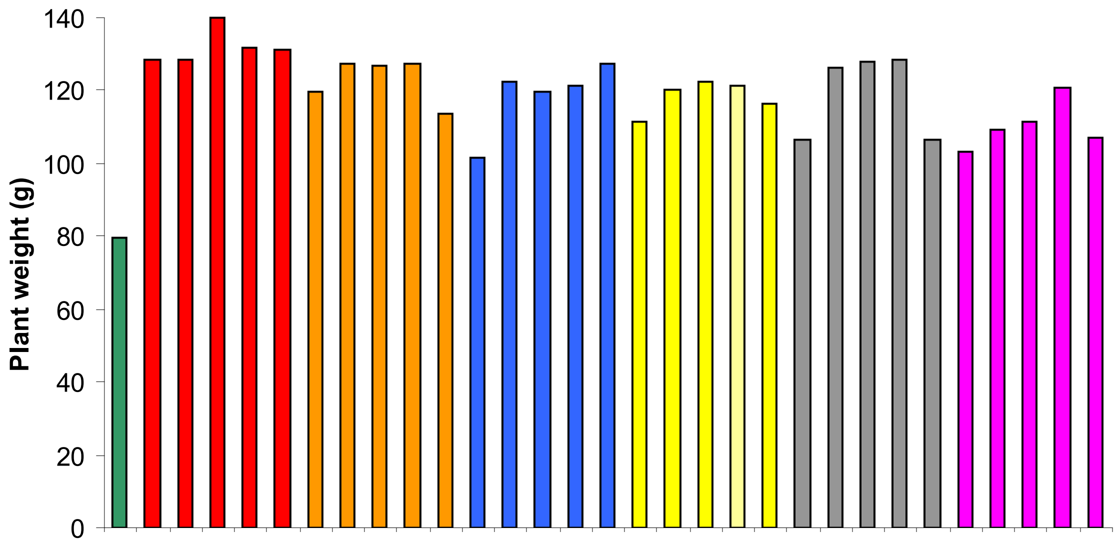
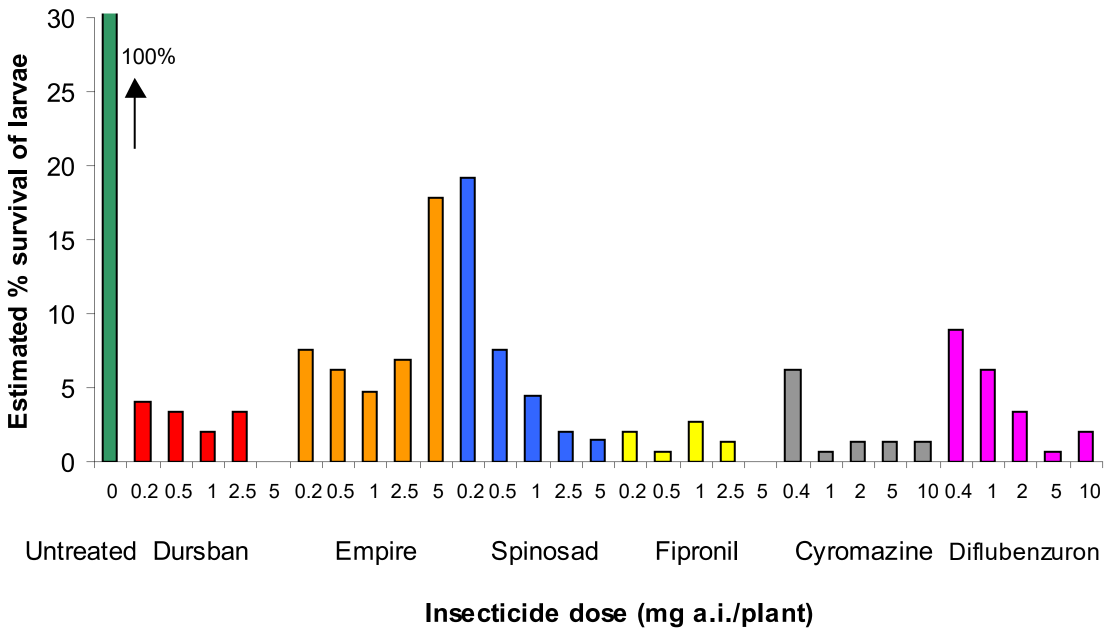


Figure 7. The estimated % survival of cabbage root fly larvae from the module drench



treatments tested in the glasshouse trial.

- **Chlorpyrifos** – Highly effective at all doses tested. Dose for dose the standard Dursban formulation gave consistently better control of the fly pupae than the new Empire formulation.

- **Spinosad** – Highly effective at all but the lowest (0.2 mg a.i./plant) dose tested.

- **Fipronil** – Performance was comparable to that of the standard Dursban treatment.

- **Cyromazine** – Highly effective at all doses tested. There was some evidence of reduction in plant growth at the highest (10 mg a.i./plant) dose tested.

- **Diflubenzuron** - Effective at all doses tested. There was some evidence of reduction in plant growth at the highest (10 mg a.i./plant) dose tested.

Experiment 4. How effective at controlling the cabbage root fly under field conditions are the test insecticides when watered over the plant modules shortly before transplanting.

Materials and methods

Six 308 Hassy trays, sown with untreated cauliflower seeds on 5 June, were maintained under glasshouse conditions. On 6 July, two sets of 70 plants (5 rows of modules) were transferred to a clean Hassy tray, leaving two empty rows between each set of plants. Each set was treated with one of two doses of one of the test insecticides. The process was repeated for each of the eight test insecticides, that is chlorpyrifos (Dursban 4), micro-encapsulated chlorpyrifos (Empire), spinosad (Spintor), fipronil (80% WP), cyromazine (Vetrazine), diflubenzuron (Dimilin Flo), carbofuran (Furadan 44) or chlorfenvinphos (Birlane 24). Each treatment was applied by adding 1 ml of a solution in water using a laboratory pipette. The doses applied were 0.5 and 2.5 for cyromazine and 1 and 5 for the other seven insecticides. The insecticide was washed into the peat with a similar volume of clean water immediately after the insecticide had been applied. One Hassy tray was left untreated.

On 7 July, the cauliflower plants were transplanted, at 50 cm spacing, into a field plot. The eight insecticide treatments and the untreated plants were arranged in a 3 x 9 plot block. Each plot had two sub-plots, each of which contained fifteen (5 x 3) plants, and each sub-plot had the plants treated with one of the two insecticide doses.
On 22 August, all of the plants were cut off just above the soil surface and the foliage was weighed. From 23-31 August, a 15 cm diameter x 15 cm deep soil core was taken from around the root of 6 plants in each sub-plot. The cabbage root fly pupae were extracted from the soil samples by flotation in water and the numbers of pupae recovered were counted. The roots were washed and weighed.

Results

Most treatments produced a small increase in plant weight (Figure 8), but differences were not as marked as those recorded in the glasshouse trial.

The mean number of pupae recovered from around each untreated root was 7.5. This value represented the 100% survival level used for calculating the estimated percentage survival of larvae in treated plots (Figure 9). No treatment was as effective in the field as it had been under glasshouse conditions

Figure 8. The combined effect of the module drench treatments and cabbage root fly damage on the harvested weight of the cauliflower plants in the field trial.

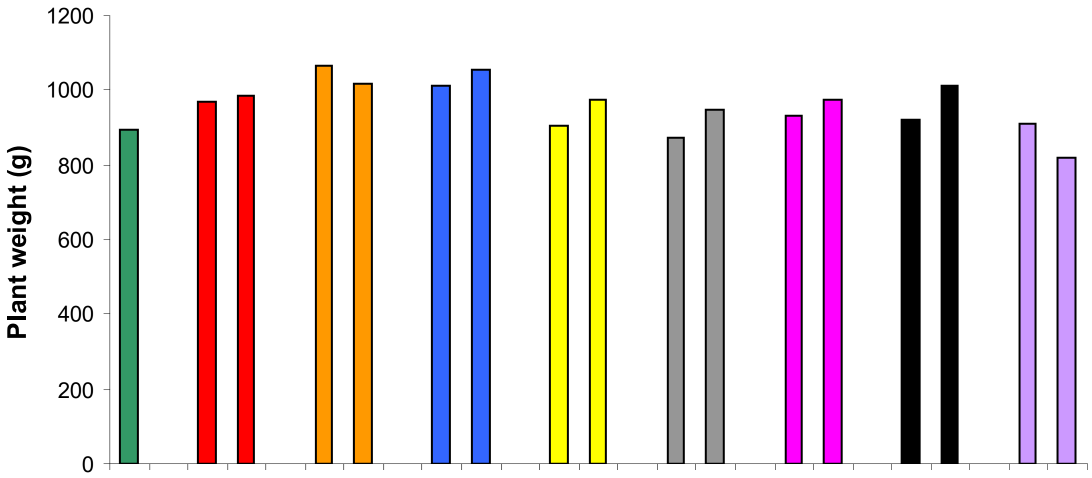
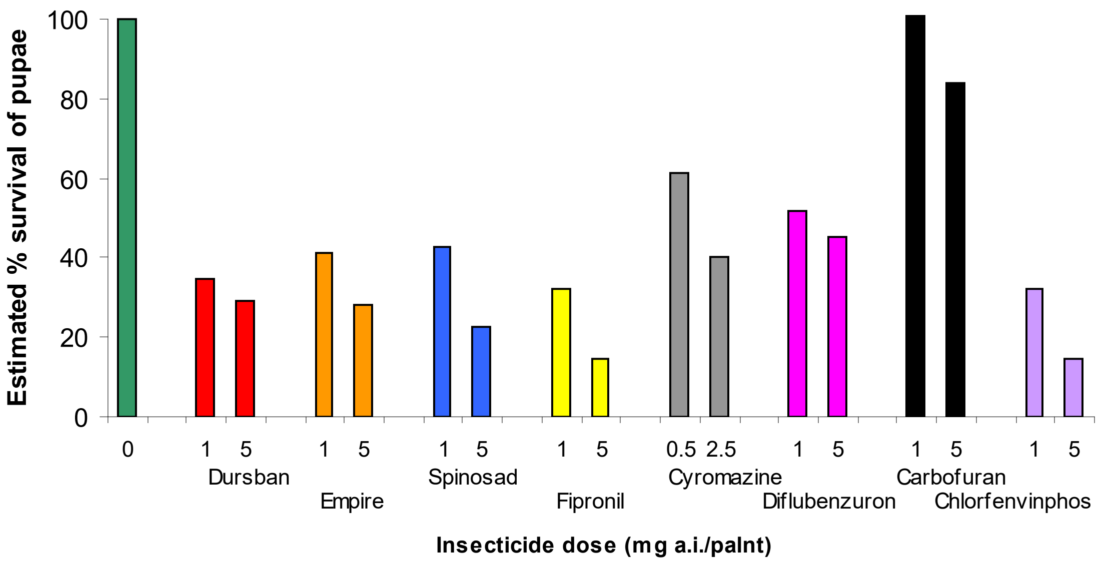


Figure 9. The estimated % survival of cabbage root fly larvae from the module drench treatments tested in the field trial.



- **Chlorpyrifos** – Both formulations provided adequate protection at both doses tested.

- **Spinosad** – Was at least as effective as chlorpyrifos at 5 mg a.i./plant.

- **Fipronil** – Was, dose for dose, the most effective chemical tested.

- **Cyromazine** – Due to problems of phytotoxicity in the experiments done in previous years, the doses applied were reduced by 50%. However, a dose of 2.5 mg a.i./plant still killed over 50% of the fly larvae.

- **Diflubenzuron** – Not as effective as cyromazine and the relatively flat dose response curve indicated that increasing the dose would be unlikely to create any great improvements in fly control. However, control was probably sufficient to protect leafy brassicas from being destroyed.

- **Carbofuran** – Virtually ineffective and phytotoxic at 5 mg a.i./plant.

- **Chlorfenvinphos** – More effective than the standard chlorpyrifos treatment, but phytotoxic at 5 mg a.i./plant.

C. CROP SPRAYS

Experiment 5. Can sprays of insecticides applied to crops shortly after transplanting give levels of control comparable to those obtained from sprays of chlorpyrifos?

Materials and methods

Four 308 Hassy trays, sown with untreated cauliflower seeds on 5 June, were maintained under glasshouse conditions. On 7 July, the cauliflower plants were transplanted, at 50 cm spacing, into a field plot which was made up of 3 blocks of 10 plots. Each plot contained 15 plants.

Table 3. The doses of the various insecticides drenched onto the test plants in an attempt to control cabbage root fly larvae on cauliflower plants already transplanted into the field.

Insecticide	Treatment solution (product./100l)	Dose (mg a.i./plant)	(g a.i./ha)
Chlorpyrifos (Dursban 4)	100ml	33.6	1344 [1]
Chlorpyrifos (Empire)	231ml	33.6	1344
	46ml	6.7	269
Spinosad (Spintor)	218ml	33.6	1344
	44ml	6.7	269
Fipronil (80% WG)	18g	10	400 [2]
	3.6g	2	80
Cyromazine (Vetrazine)	240ml	10	400
Chlorfenvinphos (Birlane 24)	180ml	30	1210 [1]

[1] Product label recommendations
[2] Maximum permitted dose (Aventis)

On the same day, the plots were treated, at the doses shown in Table 3, with the six insecticides chlorpyrifos (Dursban 4), micro-encapsulated chlorpyrifos (Empire), spinosad (Spintor), fipronil (80% w/w WP), cyromazine (Vetrazine) or chlorfenvinphos

(Birlane 24). The insecticides were applied from solutions made in a bucket and applied, using a 70 ml beaker, at the rate of 70 ml/plant. One plot in each block was left untreated. Each block contained one plot of each treatment and the treatments were randomised fully within each block.

On 23 August, all of the plants were cut just above the soil surface so that the foliage could be weighed. From 4-7 September, a 15 cm diameter x 15 cm deep soil core was taken from around the root of 6 plants in each plot. The roots were washed and weighed. The cabbage root fly pupae were extracted from the soil samples by flotation in water and the numbers of fly pupae were counted.

Results

Figure 11. The combined effect of a post-planting drench treatment and cabbage root fly damage on the harvested weight of cauliflower plants in the field trial.

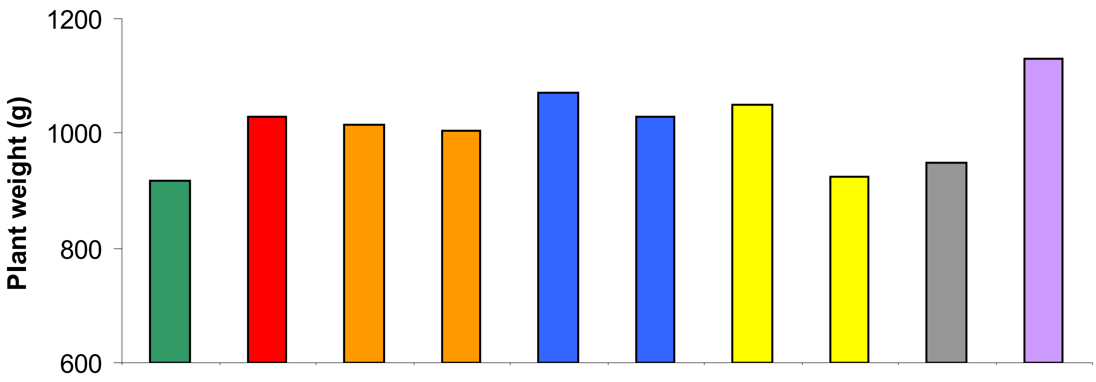
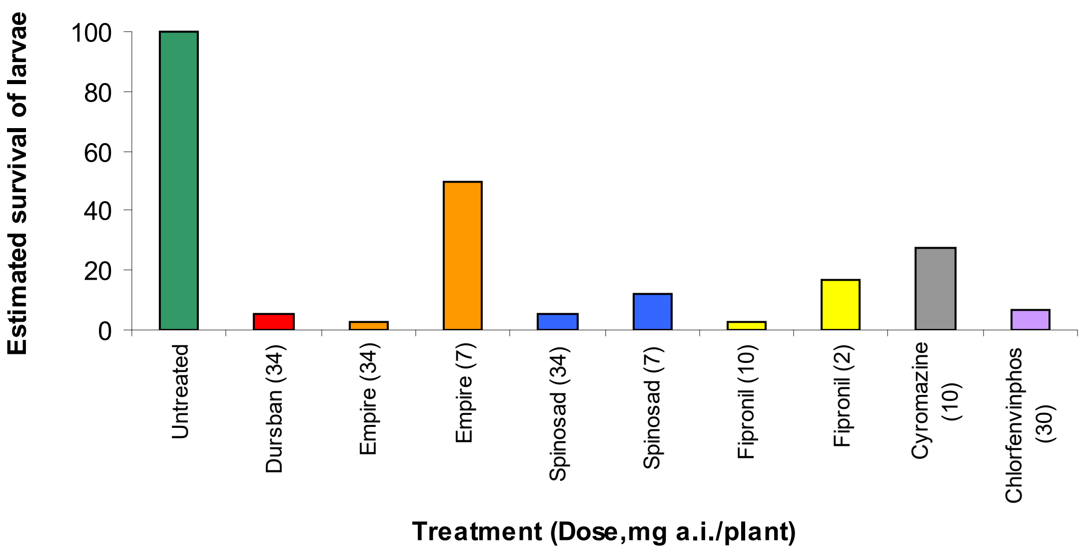


Figure 12. The estimated % survival of cabbage root fly larvae from the post-planting drench treatments tested in the field trial.



Most treatments produced a small increase in plant weight (Figure 10) and there were no signs of phytotoxicity

The mean number of pupae recovered from around each untreated root was 7.6. This value was used to represent 100% survival when calculating the estimated percentage survival of the larvae in treated plots (Figure 11).

- **Chlorpyrifos** – Both formulations were very effective at the dose recommended for a Dursban application, but at 20% (7 mg a.i./plant) of this rate Empire gave inadequate control.

- **Spinosad** – Was at least as effective as Dursban at 34 mg a.i./plant and still provided adequate control at 20% of this dose.

- **Fipronil** – Dose for dose, fipronil was the most effective chemical tested and provided adequate control at 2 mg a.i./plant (80 g a.i./ha).

- **Cyromazine** – Dose for dose, cyromazine was comparable to chlorpyrifos, but not as effective as fipronil.

- **Chlorfenvinphos** – Comparable to the chlorpyrifos treatments. When drenched onto the soil there was no evidence of the phytotoxity that was observed on the module treated plants.

Experiment 6. How frequently do the test insecticides have to be sprayed onto established crops to keep swede and turnip crops damage free?

Materials and methods

An area of twenty six (1.83 m wide x 17 m long) seed beds were prepared in the field at HRI, Wellesbourne. On 8 May, alternate beds were drilled with swede seed, using a tractor mounted Stanhay, Singulaire seed drill, at 15 seeds/m row. Four rows were drilled into each bed to give a row spacing of 46 cm. On 31 May, the remaining beds were each drilled with 4 rows of turnip seed. Carbosulfan granules (Marshall 10G, 7g/10m row) were added to all rows at drilling using a Horstine Farmery granule applicator. The granules were placed onto the soil surface and incorporated to a depth of about 5 cm by the following seed drill. The twenty four inner beds were sub-divided into six 2m long plots with 1 m between each plot. The crop in the inter-plot areas was destroyed. The treatments were randomised such that the experiment consisted of 3 randomised blocks of 24 plots for each crop. Each block contained, for each crop, 6 plots which were sprayed once, 6 plots sprayed every 2 weeks, 6 plots sprayed every 4 weeks and 6 plots which were left unsprayed. One of the 6 plots, for each crop, was sprayed with one of six test insecticides. The insecticides tested were chlorpyrifos (Dursban 4, 960 g a.i./ha), chlorpyrifos (Dursban 4, 960 g a.i./ha) + Silwet (0.15%), micro-encapsulated chlorpyrifos, (Empire, 960 g a.i./ha), fipronil (80% WG, 400 g a.i./ha), carbofuran (Furadan 44, 960 g a.i./ha) and chlorfenvinphos (Birlane 24, 720 g a.i./ha). All treatments were applied, using a knapsack sprayer fitted with a single 0.5 mm hollow cone nozzle, at a rate of 4.5 litres/100 m row. The first spray was applied to all treated plots on 30 June to coincide with the start of the second generation of the cabbage root

Figure 12. The % of swede roots in the field spray trial that had greater than 25% of the roots damaged by cabbage root fly larvae.

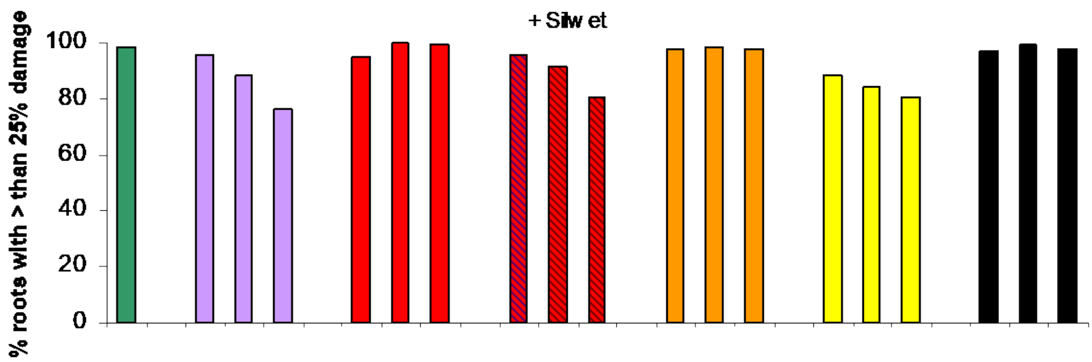


Figure 13. The mean number of cabbage root fly pupae recovered from around the roots of the swedes in the insecticide spray trial.

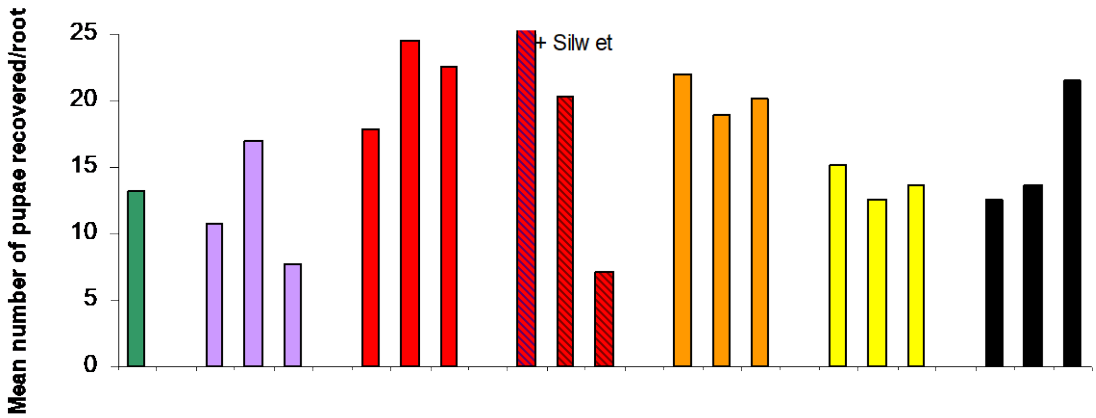
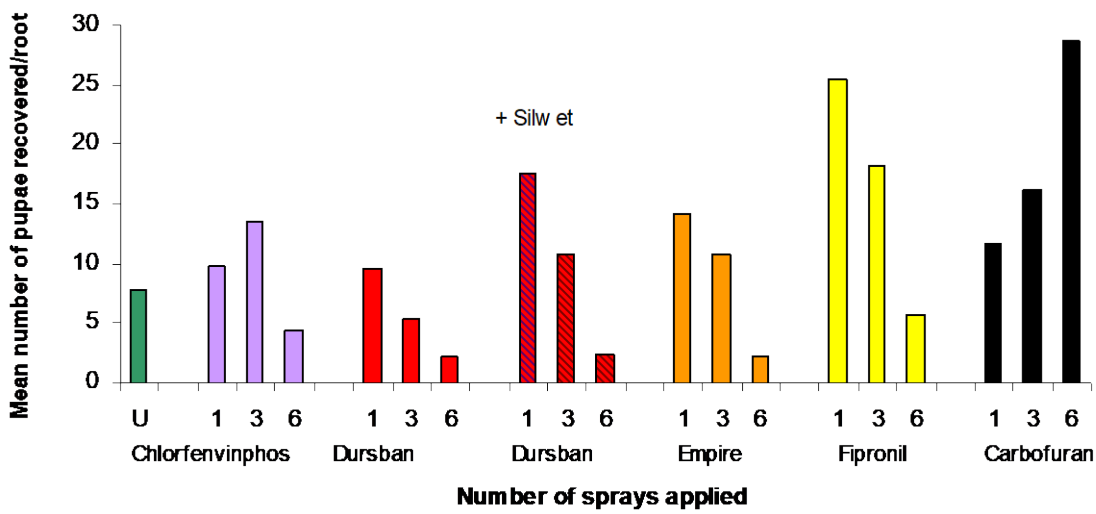


Figure 14. The mean number of cabbage root fly pupae recovered from around the roots of the turnips in the insecticide spray trial.



fly. Further sprays were applied every 2 weeks up to 8 September. Hence, the plots sprayed every 2 and 4 weeks received totals of 6 and 3 applications, respectively.

During the week of 23-28 October, five plants were sampled from each plot and a 15 cm diameter x 15 cm deep soil core was taken from around the root of each harvested plant. The foliage was discarded and the roots were washed and weighed. The cabbage root fly pupae were extracted from the soil samples by flotation in water and numbers of pupae were counted. The remaining swede roots were harvested, washed and graded for the damage done by cabbage root fly larvae. The turnip roots could not be assessed accurately owing to the poor state of the crop, that resulted from a combination of a severe powdery mildew infection and from cabbage root fly damage.

Results

Damage was severe on all plots (Figure 12). Virtually all (98%) of untreated swede roots were unmarketable and the best treatment (chlorfenvinphos every 2 weeks) reduced damage by only 25%. Both formulations of chlorpyrifos and carbofuran on their own had no effect on damage, but chlorpyrifos (Dursban) with a wetter (Silwet) did reduce damage when applied every 2 weeks.
The number of pupae recovered from swede roots (Figure 13) followed a similar pattern to the damage. Chlorfenvinphos and chlorpyrifos + Silwet reduced the numbers of pupae by about 50% when applied every 2 weeks. Many of the other treatments increased the numbers of pupae when compared to the untreated plots.

The numbers of pupae recovered from the turnip roots were generally lower (Figure 14) than those recovered from the swedes and insecticide efficacy appeared to be better, but there was no root damage data to support this. All treatments except carbofuran reduced pupae numbers when applied every 2 weeks, but the best (chlorpyrifos) only reduced the numbers by about 70%. Many of the other treatments again increased the numbers of pupae when compared to the untreated plots.

D. MONITORING CABBAGE ROOT FLY ACTIVITY

Experiment 7. Which periods of egg laying by the second and third fly generations contribute most to crop damage at harvest?

Materials and methods

An area of thirteen (1.83 m wide x 23 m long) seed beds were prepared in the field at HRI, Wellesbourne. On 30 May, swede seed was drilled, using a tractor mounted Stanhay, Singulaire seed drill, at 15 seeds/m row. Four rows were drilled into each bed to give a row spacing of 46 cm. On 6 June, ten of the eleven inner beds (the centre bed was left undivided) were sub-divided into eight 2 m plots with 1 m between each plot. The plants in the inter-plot areas were destroyed. The treatments were randomised such that the experiment consisted of 4 randomised blocks of 20 plots. Eighteen of the twenty plots in each block were covered with Envirofleece (Agralan). Two plots were left permanently uncovered and 2 plots were left permanently covered. The remaining plots were each uncovered, using a randomised design, for 1 week only during the period 22 June to 12 October.

During the week of 6-13 November, five plants were sampled from each plot and a 15 cm diameter x 15 cm deep soil core was taken from around the root of each harvested plant. The foliage was discarded and the roots were washed and weighed. The cabbage root fly pupae were extracted from the soil samples by flotation in water and the numbers of fly pupae were counted. The remaining swede roots were harvested, washed and graded for the damage done by cabbage root fly larvae.

Results

Figure 15. The mean number of cabbage root fly pupae recovered from around the roots of swede which had been uncovered for individual weeks during a period starting 29 June and ending 12 October.

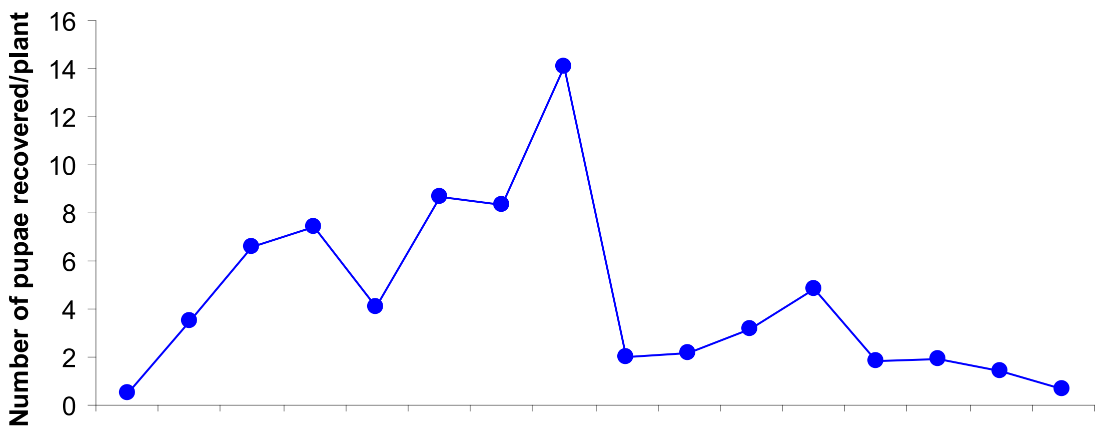
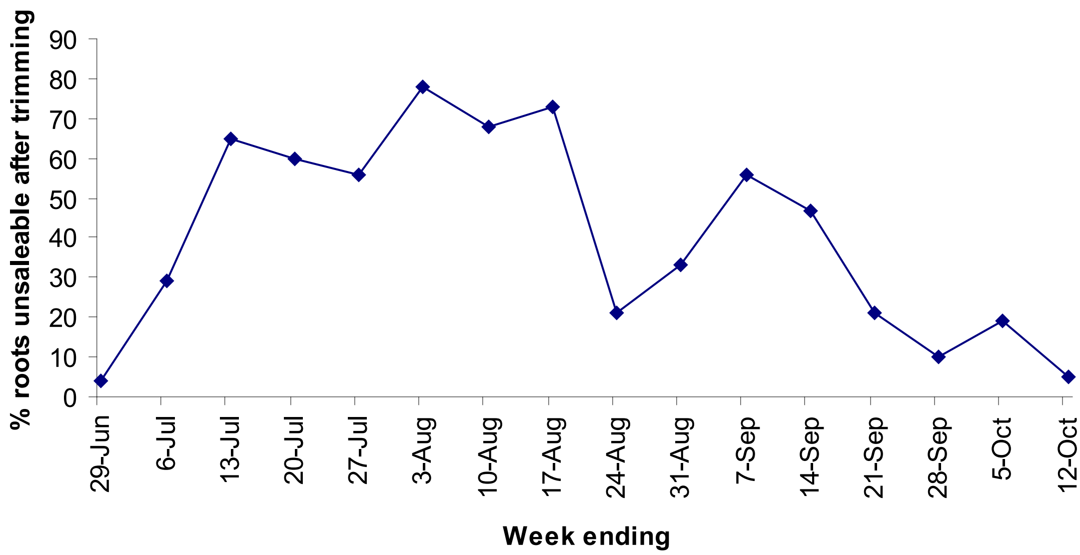


Figure 16. The % of swede roots which were unsaleable after allowing the cabbage root fly infestation access to them for only individual weeks during a period starting 29 June and ending 12 October.



The mean numbers of cabbage root fly pupae recovered from the permanently uncovered and permanently covered plots were 10.8 and 0.4 pupae/root respectively. The numbers of pupae from the plots that were uncovered for 1 week only rose steadily (Figure 15) during June and July and reached peak numbers in the plots uncovered in the week beginning 17 August (14 pupae/root). After this, the numbers of pupae declined rapidly to a much lower level. A second peak occurred in the week beginning 14 September (5 pupae/root). Thereafter, numbers declined further and reached a level of less than 1 pupae/root by mid October.

The mean percentage of unsaleable roots in the permanently uncovered and the permanently covered plots were 88% and 4% respectively. The pattern of damage observed in plots uncovered for 1 week mirrored the numbers of pupae recovered (Figure 16). Initially damage was slight, but damage rose quickly and from the exposure made on the week beginning 13 July over 60 % of roots were unsaleable. Damage remained around this level (50 – 80% of roots unsaleable) until the week beginning 17 August (the exposure from which most pupae were recovered). Damage then declined rapidly before peaking again in the week beginning 7 September (the week before the second peak of pupae). Thereafter, damage declined so that >80% of roots were saleable in the remaining weeks of the experiment.

Conclusions

Two further chemicals (diflubenzuron & spinosad) can be added to fipronil and cyromazine (Jukes *et al*, 2000) as potential candidates for non-OP control of the cabbage root fly.

All four of the above chemicals would provide adequate protection if applied as a drench to modules of leafy brassica plants. Under field conditions, fipronil and spinosad were as effective, dose-for-dose, as the standard chlorpyrifos treatment. Although cyromazine and diflubenzuron were less effective than the chlorpyrifos treatment, they should still provide adequate protection. Similarly, when compared dose-for-dose, cyromazine, fipronil and spinosad were also as effective as chlorpyrifos, when applied to leafy brassica plants shortly after they had been planted into the field.

Obtaining adequate control of cabbage root fly on root brassica crops is a much more difficult problem. Chlorpyrifos, fipronil and spinosad seed treatments all showed considerable promise under glasshouse conditions but, the control obtained under field conditions was unsatisfactory. While there is some scope for increasing doses and developing better formulations it is unclear whether these small, highly targeted doses will ever provide sufficient protection for roots of swedes and turnips as these soon grow out of the insecticide-treated zone. Previous trials (Jukes *et al*, 2000) have suggested that growing swedes or turnips in peat modules before transplanting can increase the efficacy of seed treatments by holding the chemical within the peat module. At present however, growers consider that this method of propagation would not be suitable for the production of swedes and turnips. In the recent past, granular insecticides have generally been applied to the soil at sowing to control the first generation of cabbage root fly. Mid-season sprays have then been applied to control subsequent generations of the fly. Although not assessed directly, it seems likely that chlorpyrifos, fipronil or spinosad applied to the seed would provide adequate protection during the seedling stage of crop growth. Hence, seed treatments could prove useful provided insecticides can be found that will give effective control when applied as mid-season sprays. Swedes and turnips grown at Wellesbourne in 2000 were subjected to high fly pressure and even six applications of the favoured OP (chlorfenvinphos) insecticide failed to reduce satisfactorily cabbage root fly damage. Similar numbers of sprays of chlorpyrifos, micro-encapsulated chlorpyrifos, fipronil and carbofuran were also ineffective.

At present, imidacloprid is used as a seed treatment, as it is a highly effective against both the aphids and flea beetles that infest the foliage of brassica crops. The problem with applying imidacloprid to the soil in this way is that imidacloprid does not kill larvae of the cabbage root fly (Jukes *et al.,* 2000). A further problem is that imidacloprid prolongs the period over which the fly larvae continue to feed and so, in some cases, can increase crop damage (Finch, 1996; Finch & Edmonds, 1999). The current trials showed also that when imidacloprid was applied to seed already treated with fipronil, the imidacloprid made the fipronil treatment less effective at killing larvae of the cabbage root fly.

Recording root damage from areas of swede that were exposed for different one-week periods during the second and third generations of the cabbage root fly indicated that the roots were at most risk during most of July, the first half of August and 2 weeks in early September. This indicates that good protection was needed for a period of 8 weeks. It is unlikely that this could be achieved with a single spray of any chemical tested to date. Although harvesting the plants before the third generation of flies attacks would reduce the time at which the crop is at risk to 6 weeks, this may not be too much of an advantage, as most of the root damage is caused by larvae from the second generation of flies.

Glossary

a.i.	active ingredient
EC	emulsifiable concentrate
mg	milligram or one-thousandth of a gram (g)
OP	organophosphorus
PVA	polyvinyl acetate – sticks the insecticide onto the seed coat
Unit	100,000 seeds
WP	wettable powder
w/w	weight/weight

Acknowledgements

We thank the HDC for funding this work and the two project co-ordinators, Mr Ian Morrison of Kettle Produce Ltd, Fife and Mr Fred Tyler of Alphagrow Ltd, Lancashire, for the information they supplied and for the considerable enthusiasm and encouragement they provided throughout the project

References

Collier, R.H. & Finch, S. (1985). Accumulated temperatures for predicting the time of emergence in the spring of the cabbage root fly, *Delia radicum* (L.), (Diptera: Anthomyiidae). *Bulletin of Entomological Research* **75**, 395-404.

Collier, R.H., Finch, S., Phelps, K. & Thompson, A.R. (1991). Possible impact of global warming on cabbage root fly (*Delia radicum*) activity in the UK. *Annals of Applied Biology*, **118**, 261-271.

Finch, S. (1993). Integrated pest management of the cabbage root fly and the carrot fly. *Crop protection,* **12** (6), 423-430.

Finch, S. (1996). Evaluation of imidacloprid against flea beetles, *Phyllotreta* spp., and cabbage root fly, *Delia radicum*, in glasshouse trials. *Confidential Technical Report*, 6 pp. [For Richard Lloyd of Bayer].

Finch, S. (1999). To optimise the efficiency of soil-applied insecticides for controlling the cabbage root fly in field brassica crops. *Final Report MAFF Project* **HH1734SFV**, 23pp.

Finch, S. & Coaker, T.H. (1969). A method for the continuous rearing of the cabbage root fly *Erioischia brassicae* (Bouché) and some observations on its biology. *Bulletin of Entomological Research* **58**, 619-627.

Finch, S. & Collier, R.H. (1986). Forecasting the times of attack of the cabbage root fly (*Delia radicum*) on vegetable brassica crops. *Aspects of Applied Biology* **12,** 37-46.

Finch, S. & Edmonds, G. H. (1999). Evaluation of imidacloprid against flea beetles, *Phyllotreta* spp., and cabbage root fly, *Delia radicum*, in glasshouse trials. *Tests of Agrochemicals and Cultivars* No. 20, (*Annals of Applied Biology* **134**, Supplement), pp.2-3.

Finch, S., Collier, R. H. & Jukes, A. A. (1999). Ultimate challenge. *Grower*, **132 (3)**, 51-52.

Finch, S., Hartfield, C.M. & Jukes, A.A. (1999). Radish: Evaluation of non-OP insecticides for controlling the cabbage root fly. *Final Report HDC Project* **FV 159a**, 25pp.

Jukes, A. A. & Finch, S. (1998). Assessing the relative merits of the insecticide fipronil for controlling the carrot fly and the cabbage root fly. *Confidential Technical Report*, 26 pp. [For Bill Lankford of Rhône-Poulenc]

Jukes, A.A. Hartfield, C.M., Elliott, M.S. & Finch, S. (2000). Brassica crops: Evaluation of non-organophosphorus insecticides for controlling the cabbage root fly. *Final Report HDC Project* **FV 223**, 19pp.

Phelps, K., Collier, R.H., Reader, R.J. & Finch, S. (1993). Monte Carlo simulation method for forecasting the timing of pest insect attacks. *Crop Protection* **12**, 335-342.