

DEPARTMENT for ENVIRONMENT, FOOD and RURAL AFFAIRS

Research and Development

Final Project Report

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CSG 15

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Project title

DESK STUDY TO APPLY KNOWLEDGE DEVELOPED FOR
 CONVENTIONAL HORTICULTURE TO THE CONTROL OF PESTS IN
 ORGANIC VEGETABLES

DEFRA project code

OF 0179

Contractor organisation
and location

Horticulture Research International
 Wellesbourne
 Warwick CV35 9EF

Total DEFRA project costs

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Project start date

01/04/99

Project end date

31/03/02

Executive summary (maximum 2 sides A4)

The demand for organic vegetable and salad crops is likely to increase as a result of the projected requirements of the multiple retailers. A major constraint to growing field vegetable crops is the reduction in yield and quality that occurs when pest insects damage crops grown organically. The aim of this project is to demonstrate how methods of pest control developed for conventional vegetable production can be adapted for use by organic growers. The project concentrates on the pest insects that cause damage to umbelliferous and cruciferous vegetable crops. Umbelliferous crops are attacked by one major pest insect, the carrot fly (*Psila rosae*), and two minor pests, whereas cruciferous crops are attacked by about eight major, and over 40 less important pests.

A strategy for reducing carrot fly damage in organically grown umbelliferous crops was produced. The strategy is based on the existing carrot fly forecast, on published data and on information collected previously at HRI. This includes the contribution that can be made by partial host plant resistance. Commercial breeding lines of carrots now have levels of partial resistance up to 75% and, if used in combination with late sowing, could reduce infestations by more than 90% when compared with a susceptible variety sown early.

The carrot fly forecast was adapted to predict 1) the proportion of the first generation of flies that will lay eggs on crops sown on different dates and 2) the timing of emergence of the subsequent (second) fly generation within the crop. The effects of crop sowing date on second generation fly emergence were verified in a field experiment at HRI Wellesbourne in 1999. Plots of carrots were sown at intervals from March until June and exposed to the field population of carrot fly. Prior to the start of the second fly generation, part of each plot was enclosed to record fly emergence. Most flies (502/plot) emerged from plots that were sown at the end of March, whilst least flies (13/plot) emerged from those that were sown in mid-June. This confirms that late sowing is an effective method of reducing carrot fly damage. The time of emergence of the second generation

flies was affected by sowing date. Flies emerged on 19 July (50% emergence) from plots sown in mid March, whereas flies emerged in early September from plots sown in mid-May.

The carrot fly forecast has been adapted to predict the timing of fly emergence from crops with different sowing dates. In addition, a sub-model based on the rate of development of eggs and larvae has been developed to predict how carrot fly damage develops over time. The output of this sub-model compared favourably with validation data collected in the field at HRI Wellesbourne. Finally, the model was modified to identify the times at which crops should be covered to reduce damage by carrot fly larvae. Previous experiments have shown that to avoid damage by carrot fly larvae, crop covers should be applied to susceptible crops before the start of fly emergence. Although third generation carrot flies may be active after the end of September, their progeny do not damage overwintering crops, so late control is unnecessary.

The strategy for reducing carrot fly damage in umbelliferous crops grown organically was evaluated in 2001. Participating growers grew plots of a partially resistant variety and applied/removed crop covers according to the carrot fly forecast. Because none of the growers have automatic weather stations, forecasts were provided using the national network of meteorological stations and were delivered weekly by post, fax or e-mail. At harvest, the experimental plots, with one exception, suffered similar or less damage than the main area of crop, that had been grown according to standard practice.

A strategy for controlling the pest insects of organically-grown cruciferous crops was developed. This is based on existing forecasts for several crucifer pests. The pest forecasts were verified in a field experiment in 2000. In this experiment, plots of cabbage were planted on 8 occasions from April-July in the organic area at HRI Kirton. The plots were sampled weekly to determine pest numbers, and assessed for damage at harvest. Peak numbers of first and second-generation cabbage root fly eggs were laid close to the dates predicted by the forecast. More eggs were laid during the first generation and plots planted early suffered the greatest plant losses due to feeding larvae. Although the plants were infested with aphids and several caterpillar species, only diamond-back moth affected marketability. None of the cabbages from the first four plantings were marketable. Marketability started to increase from Planting 5 (15 June) onwards. These plots missed the first generation of diamond-back moth, but were infested by the second generation.

The literature was reviewed to 1) identify crop/pest combinations where it would be advantageous to apply covers to exclude pests, 2) find simple ways of sampling crops to detect the presence of each species, and 3) indicate the best time to apply the control measures available to organic growers. Crop covers can be used to exclude many crucifer pests. However, if aphids are able to penetrate the covers then infestations may be greater than if the crop was left uncovered. In the absence of reliable treatment thresholds for all but a few crop/pest combinations, most sampling methods can be used only to demonstrate the presence of pests and to indicate whether their numbers are increasing or decreasing. The best times to apply the various control measures available to organic growers were identified. Avoidance or exclusion of the cabbage root fly and rapid control of diamond-back moth are vital. The output from the cabbage root fly forecast was modified to indicate the periods when the risk of infestation was high.

The crucifer pest control strategy was evaluated in 2001 in the organic areas at HRI Kirton and HRI Wellesbourne using forecasts for several pests and pheromone traps to monitor diamond-back moths. Plants were inspected for aphids and caterpillars. Treatments (crop covers or garlic for cabbage root fly, soft soap for aphids, *Bacillus thuringiensis* for caterpillars) were applied as necessary. In general, pest damage was not severe and where a large percentage of the crop was unmarketable, this was due to non-pest damage.

A workshop on carrot fly control was held at HDRA, Ryton in January 2002. The aim of the workshop was to explore the underlying causes of carrot fly problems in organic production systems and, using the expertise of the participants, to try and outline any control strategies that would be likely to be effective in organic carrot production. As a result of this project, and the conclusions drawn from this workshop, two factsheets (carrot fly and crucifer pest control in organic crops) have been produced for publication by the HDC. Other sources of information, such as the HDC/HRI pest forecasts, will be publicised through the HDRA pest and disease e-mail group.

Scientific report (maximum 20 sides A4)

1. Introduction

The demand for organic vegetable and salad crops is likely to increase and at present, only about 15% of the produce is grown in the UK (Organic Food and Farming Report 2001). A major constraint to growing field vegetable crops is the reduction in yield and quality that occurs when pest insects damage crops grown organically. Multiple retailers demand high quality produce from conventional growers and, although they are willing to make concessions on the size and shape of organic vegetables, they are not willing to accept vegetables that show signs of pest damage. The aim of this project is to demonstrate how methods of pest control developed for conventional vegetable production can be adapted for use by organic growers. Much of the previous research on pest control has been funded by DEFRA and the HDC.

The project concentrates on the pest insects that cause damage to umbelliferous and cruciferous vegetable crops, as these account for 24% of the farmgate value of organic vegetable production (including potatoes) in the UK (Organic Food and Farming Report 2001). Umbelliferous crops are attacked by one major pest insect, the carrot fly (*Psila rosae*), and two minor pests, whereas cruciferous crops are attacked by about eight major, and over 40 less important pests.

The carrot fly can be a major pest in crops of carrots, parsnips, celery, celeriac and several herbs. Previous research has identified several cultural control techniques that can be used in conjunction with other methods of control. In addition, adult carrot flies can be excluded completely by applying crop covers at appropriate times. An extensive research programme was undertaken during the 1980's, to breed carrots that were partially resistant to carrot fly damage. Some of the breeding lines were sold to commercial seed companies, who have now developed lines that are approximately 75% resistant to carrot fly damage. The effects of partial plant resistance and cultural techniques, such as the judicious choice of sowing and harvesting dates, are additive and could be exploited further in organic systems of carrot production.

A simulation model that uses weather data to predict when the peaks of carrot fly activity will occur has been developed at HRI Wellesbourne. Conventional growers use the model to indicate when crops should be monitored closely and/or sprayed. Apart from indicating treatment windows for conventional growers, the model could be used by organic growers to time the application and removal of crop covers to avoid egg laying by the carrot fly. It could be used also to indicate when crops should be sown to avoid attack, and when they should be harvested to avoid the development of damage.

In contrast to umbelliferous crops, a complex of about 50 pest insects can damage cruciferous crops. The four major pests are the cabbage root fly (*Delia radicum*), the cabbage aphid (*Brevicoryne brassicae*), the diamond-back moth (*Plutella xylostella*) and the small white butterfly (*Pieris rapae*). Many pest insects can be excluded from cruciferous crops by the judicious use of crop covers and by the careful choice of planting dates. Phenological models to forecast the timings of attack by the major fly, beetle, caterpillar and aphid pests of cruciferous crops have been developed at HRI. These forecasts can be used to decide when to apply crop covers to reduce pest damage, to indicate when crops should be planted to avoid pest attack, and to time accurately the application of approved insecticides and biocontrol agents. The aphid and caterpillar forecasts still require further refinement prior to being used widely in commercial crops.

2. Objectives of the project

The overall objective is to demonstrate how methods of pest control developed for conventional vegetable production can be adapted for use by organic growers. The project concentrates on the pests of umbelliferous and cruciferous crops.

Carrot fly

1. Adapt the existing carrot fly forecast to quantify how the date the crop is drilled influences the subsequent fly pressure.
2. Produce a model to quantify how crop damage can be reduced by altering the harvest date.
3. Identify times at which crops should be covered to reduce carrot fly damage.
4. Quantify the contribution possible from host-plants with various levels of resistance.
5. Verify the carrot fly control strategies produced from work done in Objectives 1-4

Pests of cruciferous crops

For each of the major beetle, fly, aphid and caterpillar pests:

6. Adapt the existing pest forecasts to quantify how the judicious choice of planting and harvesting dates can be used to reduce crop damage.
7. Identify the crop/pest situations where it would be an advantage to apply crop covers.
8. Evaluate simple methods of inspecting crops to determine the presence or absence of any given pest species.
9. Identify accurately the critical periods during which control measures should be applied.
10. Verify the pest control strategies produced in Objectives 6-9.

All pests

11. Produce a user-friendly format for disseminating the above crop protection information to organic growers.
- 3. Adapt the existing carrot fly forecast to quantify how the date the crop is drilled influences the subsequent fly pressure (Objective 1).**

Information collected at Wellesbourne in 1983-85 (Ellis *et al.*, 1987) was used to verify predictions made by the carrot fly forecast of the effect of sowing date on subsequent larval feeding damage to carrots.

To determine the effects of sowing date on the timing of emergence of the second generation of flies, and verify the model further, plots of carrots were sown in an area close to the source of the main carrot fly population at HRI Wellesbourne. The plots (3 x 1.83m beds (4 rows) x 5m long) were sown every two weeks from mid-March until mid-June 1999. There were 7 treatments in total, replicated three times, and the plots were arranged in a randomised block design. Individual plots were separated from one another by at least 4 m of bare soil. Because of heavy rainfall at the end of May, the late May sowing was not made. Instead, the remaining six plots were sown on 15 June (the last sowing date).

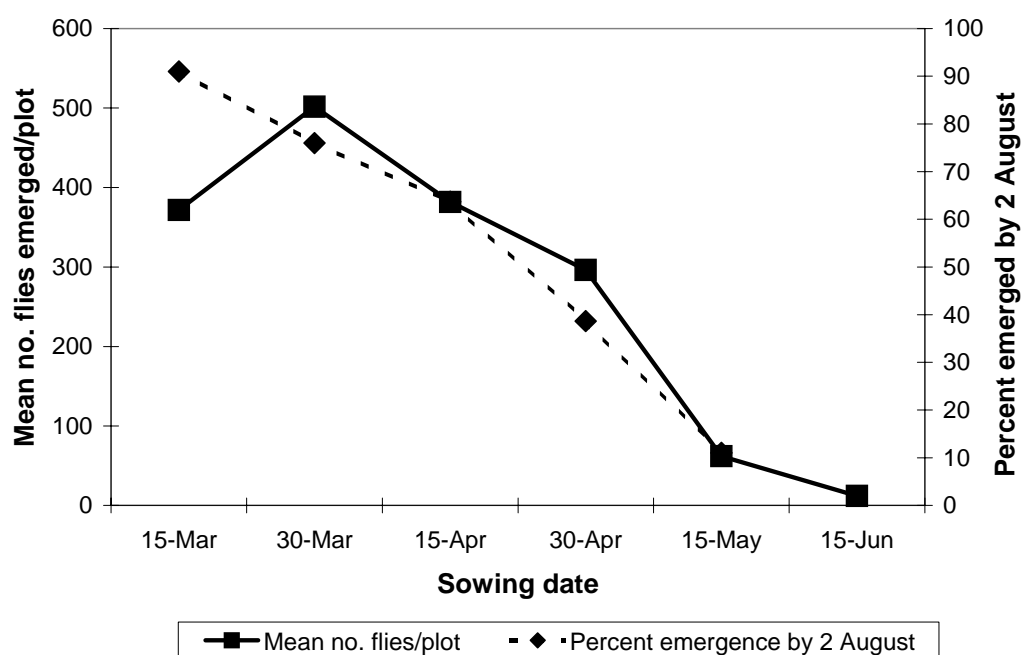
Because they were located close to the carrot fly overwintering site, the plots were exposed to high levels of infestation. The first adult carrot fly was captured between 26 and 29 April and the largest numbers of flies (>3 flies/trap/day) were captured during the period 4-27 May. In mid-July, prior to the start of the second fly generation, part of each plot was enclosed within a fine-mesh netting cage, supported by metal hoops, to record the numbers of flies that emerged from the various plots. Flies were captured between mid-July and early November on orange sticky traps (Rebell®, Swiss Federal Research Station) placed within these emergence cages. The traps were inspected every 3-4 days and replaced as necessary.

The largest numbers of flies (502/plot) emerged from the plots sown at the end of March, and the smallest numbers (13/plot) from the plots sown in mid-June (Figure 1). From the plots that were sown in mid-May, part-way through the first fly generation, a mean of 62 flies was caught/plot, which is equivalent to only 12% of the flies that emerged from the plots drilled in late March. The timing of emergence by flies of the second generation was affected also by the date the crop was sown. The later the plots were sown, the greater the

delay in emergence of the second fly generation (Figure 1). Very few flies emerged from the plots sown in mid-June, so the data on emergence times were not included.

The existing carrot fly forecast (Phelps *et al.*, 1993) was adapted to account for the effect of sowing date on subsequent second generation fly emergence. It was assumed that flies will not lay eggs on a crop until at least 50% seedlings have emerged. The date of 50% seedling emergence was estimated (190 day-degrees > 0°C - Finch-Savage, 1990) for each sowing date in the 1999 experiment, and was used to provide input to the model. Estimated seedling emergence times ranged from 20 (March) to 12 (June) days from sowing. As expected, the forecast predicted that lower numbers of second generation flies would emerge from the plots as the sowing date was delayed. Figure 2 compares observed and forecast emergence times for the second generation of carrot fly for the first five sowing dates (15 March – 15 May). Very few flies emerged from the plots sown in mid-June so the data from these plots were not included. There was a strong correlation between observed and forecast dates ($r^2 = 0.9538$; 3 d.f.; $p < 0.01$).

Figure 1. The numbers of carrot flies that emerged from carrot plots sown sequentially and the percentage of flies that emerged by 2 August 1999.



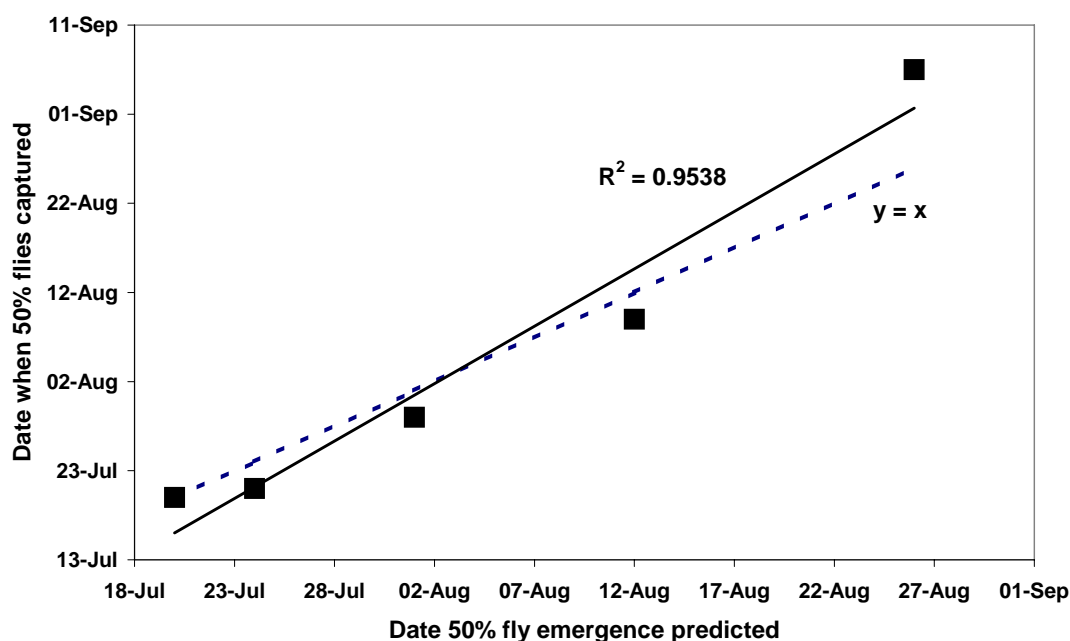
4. Produce a model to quantify how crop damage can be reduced by altering the harvest date (Objective 2).

First instar carrot fly larvae feed on the fibrous side roots of the carrot, whilst older larvae feed on the main root (Dufault & Coaker, 1987). Harvesting the crop early also curtails the development of carrot fly damage. In the UK, crops harvested before October can suffer as little as 1% damage (Coaker & Hartley, 1988). In Sweden, the development of carrot fly damage is predicted using a combination of pest monitoring and a prediction based on accumulated day-degrees (Jonsson, 1992). This information is used to ensure that the growing season is extended for as long as possible, by harvesting the crop immediately prior to the critical time that crop damage starts to increase.

The HRI carrot fly model was adapted in two ways so that damage development could be predicted:

1. The day-degree model from Jonsson (1992) was used to estimate when damage would start to become apparent. To do this, the HRI carrot fly model was adapted to calculate when 500 air day-degrees above 3°C had been accumulated from the forecast dates of 10% emergence and 10% egg-laying.
2. Since it is unlikely that the first larval instar feeds on the main root, damage can be assumed to start once larvae move into the second instar. Information from Vincent (1999) was used to estimate the relative duration of the first, second and third instars. The first instar took approximately 23% of the entire larval stage and the second instar, a further 29%. The carrot fly forecast was adapted to predict when insects would move from one development stage to the next (larval instars and pupation).

Figure 2. Observed and forecast dates of emergence by second generation flies from carrot crops drilled sequentially.



Three replicate plots of carrot (5.4 x 20 m) were drilled in March and June 1999, adjacent to the area with the high carrot fly population at HRI, to ensure that the plots became infested. Weekly assessments of carrot fly damage were made throughout the summer, autumn and winter to quantify the rate at which damage developed, following attack by the first and second generations of carrot fly. However, damage did not develop sufficiently to obtain meaningful validation results, so the assessments were repeated in 2001-2002. Figure 3 shows comparisons of observed and forecast carrot fly activity during 2001. Damage due to feeding by second generation carrot fly larvae was assessed by taking random 100-root samples from beds of insecticide-free carrots. Damage increased from August onwards and reached a maximum in early January 2002 (Figure 4). The day-degree forecast (Jonsson, 1992) predicted that damage would start to develop between 22 and 29 August (depending on whether the prediction was made from 10% emergence or 10% egg-laying). The HRI forecast predicted that damage would increase between 9 August (10% larvae entered second instar) and 27 December (90% pupae formed).

Figure 3. Comparisons of the timing of observed and forecast carrot fly activity at Wellesbourne in 2001.

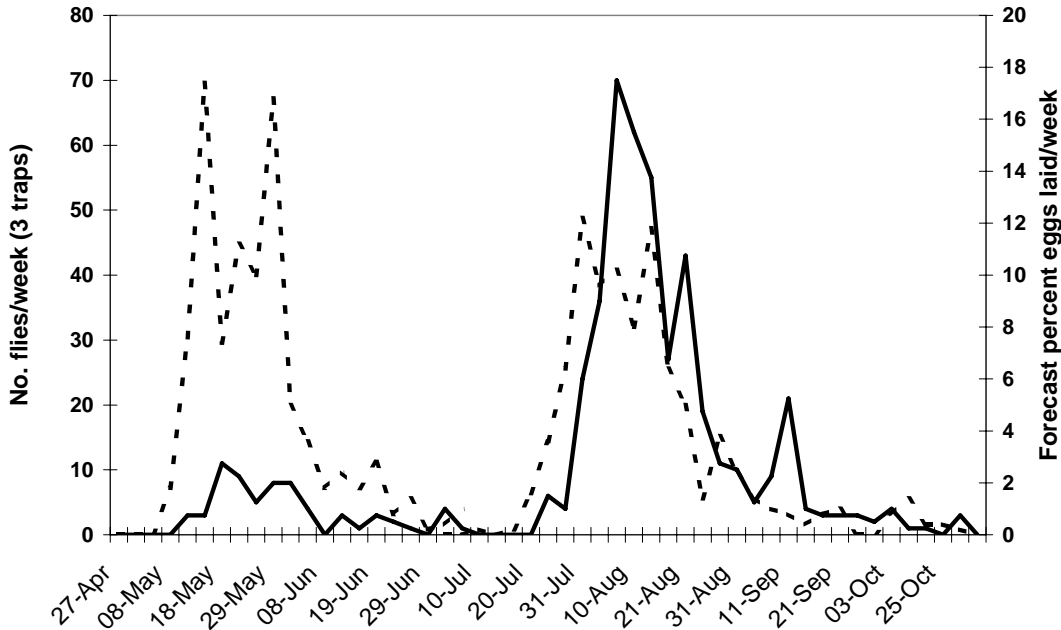
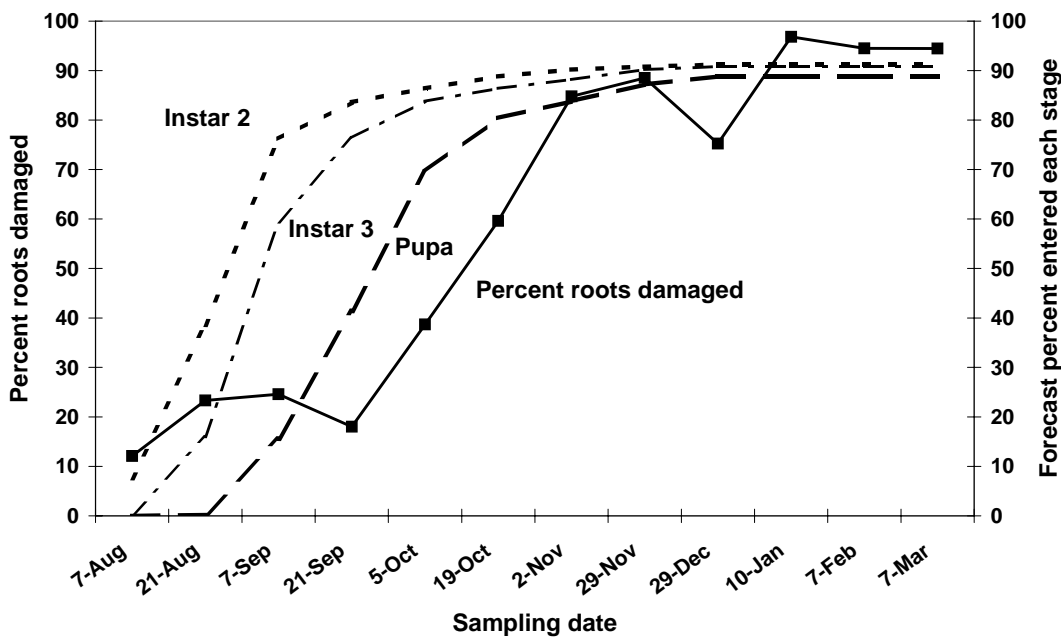


Figure 4. Development of damage in plots of insecticide-free carrots at Wellesbourne in 2001-2002 compared with predictions of carrot fly development.



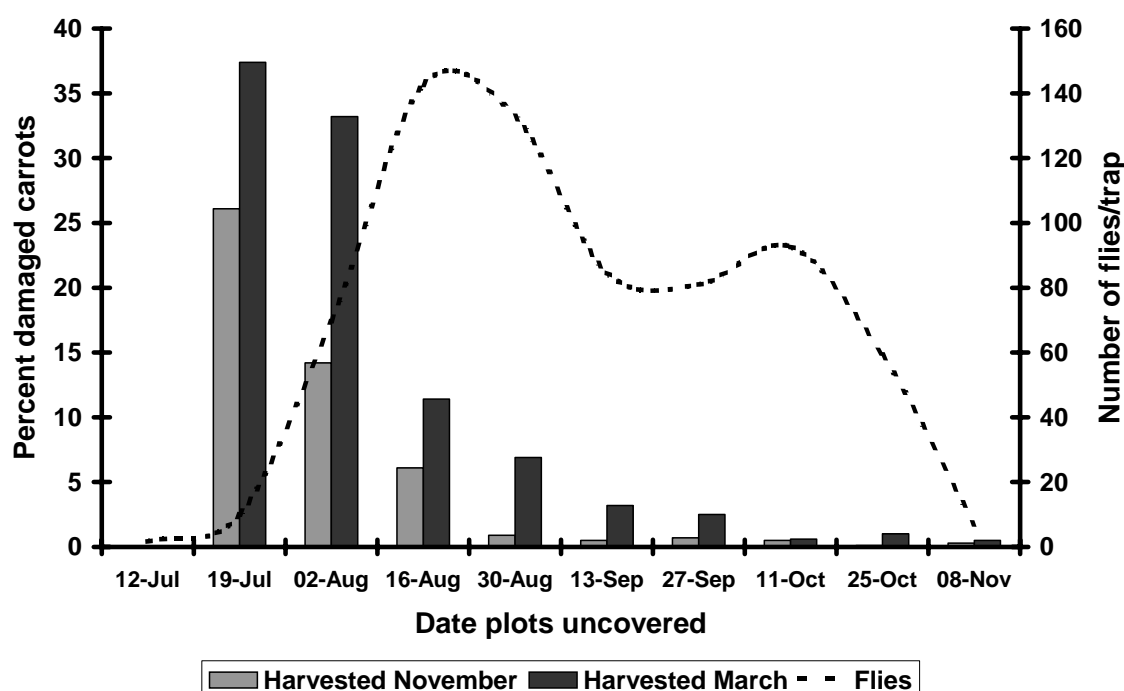
5. Identify times at which crops should be covered to reduce carrot fly damage (Objective 3).

Various types of covers can be used to prevent pest insects from damaging field crops (Antill *et al.*, 1990; Leatherland, 1995). However, whatever types of covers are used to exclude carrot flies from crops, they obviously need to be in place before the flies enter the crop.

In a DEFRA-funded experiment in 1995, crop covers were used to determine when the last insecticide spray should be applied to control carrot flies of the second and third generations. Carrots were sown on 16 May at HRI Stockbridge House. Each plot was 5 m x 1.8 m wide and adjacent plots were separated by a 1.8m width of bare soil to prevent the carrot fly larvae moving between plots. There were eight replicates of each treatment arranged in a double contiguous-replicate, 3 x 4 rectangular lattice. A granular insecticide (chlorfenvinphos) was applied to the whole experiment at sowing to control larvae of the first generation of carrot fly. Plots were then covered with fleece (Agryl P17), which was secured along the edges with soil. The treatments consisted of a series of sequential uncovering dates. Selected plots were uncovered, at two-week intervals, from 19 July, just before the start of the second generation of carrot fly, until 8 November. There were three control treatments: 1) plots covered from sowing to harvest, 2) plots left uncovered, and 3) plots left uncovered but with foliar sprays of insecticide (chlorfenvinphos) applied on 27 July and 6 September. The timing of adult carrot fly activity was monitored using three orange sticky traps (Rebell[®]) placed in an area of carrots approximately 100 m away from the plots. A sample of 200-250 roots/plot was taken from each plot on 30 November 1995 and 22 March 1996. The roots were washed and assessed for carrot fly damage.

The results are summarised in Figure 5. A total of 1901 flies was captured between 4 July and 28 November 1995. Relatively high numbers of flies were captured until early November. The plots uncovered during July and August were the most heavily damaged. Less carrot fly damage occurred in plots uncovered after the end of August, and the percentage of damaged carrots in plots uncovered from 13 September onwards did not differ from that in the control plots, which had been covered permanently from drilling to harvest.

Figure 5. The percentage of carrots damaged when carrots were covered at drilling and then uncovered at two-week intervals from the start of the second carrot fly generation.



The results showed clearly that it was the offspring from flies that were in the field before the end of September that damaged carrots left in the field during the winter period. Additional studies funded by DEFRA (Vincent, 1999) and HDC (FV 13d) have shown that although third generation carrot flies may be active after the end of September, their progeny do not damage overwintering crops.

The carrot fly forecast can be used to indicate when the risk of infestation is increasing or decreasing in any particular locality, so that crops can be covered and uncovered for weeding at times that minimise the risk of carrot fly damage. To avoid damage by carrot fly larvae, susceptible crops should be covered before the start of fly emergence. If seedlings are likely to emerge when flies are laying eggs, then the crop should be covered soon after sowing.

6. Quantify the contribution possible from host-plants with various levels of resistance (Objective 4).

Partial plant resistance to carrot fly damage has been identified in about 20 carrot varieties, most of which belong to the Nantes type of carrot. The damage found on such varieties is about half that found on Danvers, a cultivar that has been used for the last 30 years at HRI Wellesbourne as the "standard" susceptible variety (Ellis, 1999).

An extensive research programme was done at HRI Wellesbourne during the 1980's, to breed lines of carrots that were partially resistant to carrot fly damage (Ellis, 1999). Some of this material was produced from crosses between a wild *Daucus* species, *Daucus capillifolius*, and various commercial carrot (*Daucus carota*) cultivars that possessed the required agronomic characteristics. The remainder of this partially-resistant plant material was selected from an intensive breeding programme, based solely on cultivars of *D. carota*. During 1990, certain breeding lines from both sources, some with 60% resistance to the fly, were sold to several commercial seed companies (Ellis, 1999). The commercial companies have now developed breeding lines that are approximately 75% resistant to carrot fly damage (Ellis & Kift, 2000). Such levels of resistance would make a substantial contribution to the control of carrot fly in organic crops, particularly if used in conjunction with some of the methods of cultural control (Ellis *et al.*, 1987).

The effects of host plant resistance on the reduction in carrot fly damage were quantified using simple mathematical models. Although commercially-available varieties have levels of partial resistance of approximately 50% when compared with a susceptible variety, breeding lines of carrots evaluated at HRI Wellesbourne during 1999-2000 now have levels of resistance as high as 75%. If, for example, such resistant varieties were to be used in combination with a cultural technique such as late sowing, there is the potential to reduce infestations by more than 90% when compared with a susceptible variety sown before the start of the first fly generation.

7. Verify the carrot fly control strategies produced from work done in objectives 1-4 (Objective 5).

Participating growers were recruited through a presentation made at an HDRA meeting for organic growers on 30 November 2000 and by personal contact. A strategy was produced for reducing carrot fly damage in organically grown carrot crops at each location. This was based on the sowing dates and harvest dates that participating growers wished to use.

Growers were asked to sow small plots (3 x 5m lengths of bed) of a variety that was partially resistant to carrot fly within their main carrot crop (farm crop) and, if they wished to use crop covers on these plots, then to apply/remove the covers according to the carrot fly forecast. Members of HDRA visited the growers to help with siting the plots. Because none of the growers had automatic weather stations, forecasts were produced every week by HRI, using the national network of meteorological stations. The forecasts were delivered, together with regular updates on carrot fly biology and control, by post, fax or e-mail.

The treated plots and similar areas of 'untreated' farm crop were harvested at the same time and assessed for yield and damage. Because these were unreplicated trials and little account was taken of the spatial distribution of carrot fly, the data cannot be analysed formally. The treated plots were considerably less damaged than the farm crop at Kirton, and when fleece was used at Farm 3. In contrast, the treated plots were considerably more damaged when fleece was not used at Farm 3 (Flyaway vs Nantes). There was no difference between treatments at the other three sites. The use of fleece reduced total yield at Farm 3 by about 8%.

Table 1. Results of verification trials on carrots in 2001. A variety with a susceptibility ratio >1.2 is significantly more susceptible than 'Sytan', which is the standard 'resistant' variety used in screening trials. The susceptibility ratio of Flyaway is 1.19.

Site	Percent damaged roots		Variety		Susceptibility ratio of farm crop
	Trial plots	Farm crop	Trial plots	Farm crop	
Farm 1	0.9	1.5	Flyaway	Nairobi	1.26
Farm 2	8.1	7	Flyaway	Nigel	-
Farm 3	22.5	8.6	Flyaway	Nantes	-
	0.4	10.6	Flyaway+	Nairobi	1.26
		34.7	fleece	Berlicum	-
Wellesbourne	1.3	1.3	Flyaway	Berlicum	-
Kirton	1.3	8.7	Flyaway	Bangor	1.69

PESTS OF CRUCIFEROUS CROPS

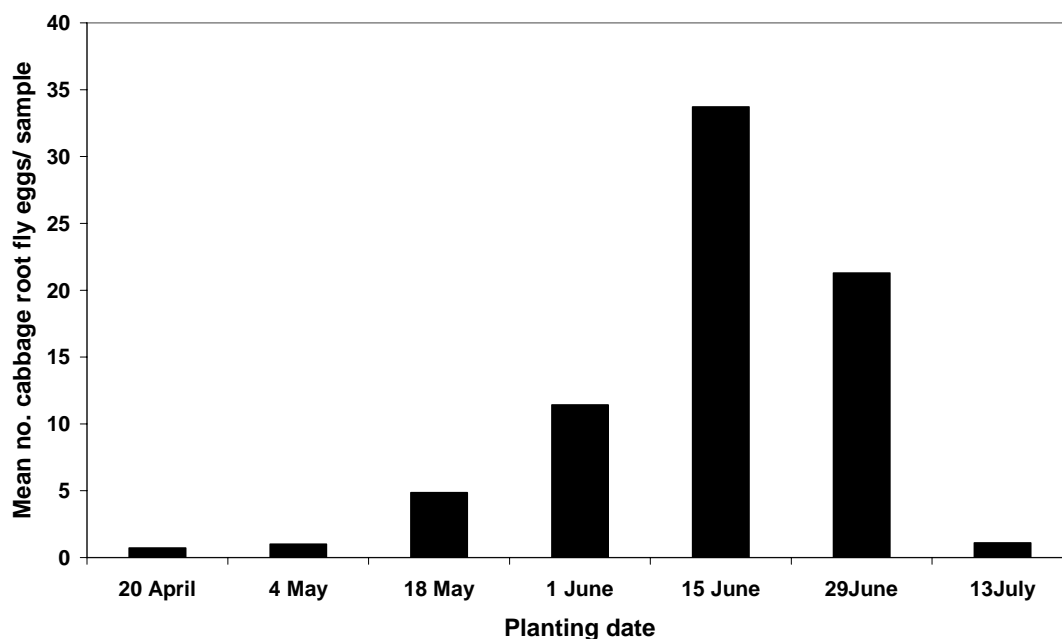
8. Adapt the existing pest forecasts to quantify how the judicious choice of planting and harvesting dates can be used to reduce crop damage (Objective 6).

The forecasts developed for fly, beetle, aphid and caterpillar pests of brassicas were used to identify the periods when crops are at risk from each of these pest species. This information was verified in a field experiment in 2000. Sequentially planted plots of cabbage cv Castello (3 plots x 10 plants x 16 rows) were grown in the organic area at HRI Kirton. Plots were planted on 8 occasions from 20 April until 27 July. The plots were sampled at weekly intervals to determine pest numbers. This included the use of 1) water traps to monitor flying insects, 2) soil sampling for cabbage root fly eggs and 3) leaf inspection for foliar pests. When the cabbages were mature, the plots were harvested and assessed for damage. The assessments included a comparison with a commercial specification for organic cabbage.

Peak numbers of cabbage root fly eggs (20 eggs/plant/week in Planting 1) were laid in the week ending 18 May (50% egg laying forecast for 10 May) and peak numbers of second generation eggs were laid in the week ending 24 July (50% egg-laying forecast for 19 July). At the time of the second generation, seven plots had been planted and of these Planting 5 (15 June) was the most preferred by female cabbage root flies (3

eggs/plant/week) and Plantings 1, 2 and 7, the least preferred (≤ 0.3 eggs/plant/week) (Figure 6). This confirmed previous observations that actively growing plants were the most attractive to ovipositing female flies. As would be expected from the numbers of eggs laid, plots exposed during the first generation suffered the greatest plant losses due to cabbage root fly damage, but these losses were less than 10%. Plants suffered little damage due to the second generation of cabbage root fly.

Figure 6. The mean numbers of cabbage root fly eggs/plot laid on 24 July 2000.



Although the cabbage leaves were infested with aphids and several species of caterpillar, only diamond-back moth caterpillars affected marketability. The effects of this pest were severe and none of the cabbages from the first four plantings were marketable, due to caterpillar damage (Figure 7). Marketability started to increase from planting 5 onwards (planted 15 June). These plots missed the first generation of diamond-back moth (peak 5 July) but were infested by the second generation (peak 15 August) (Figure 8). After 15 June, the later the planting, the greater the proportion of marketable cabbages, due to the shorter duration and size of the caterpillar infestation.

9. Identify the crop/pest situations where it would be an advantage to apply crop covers (Objective 7).

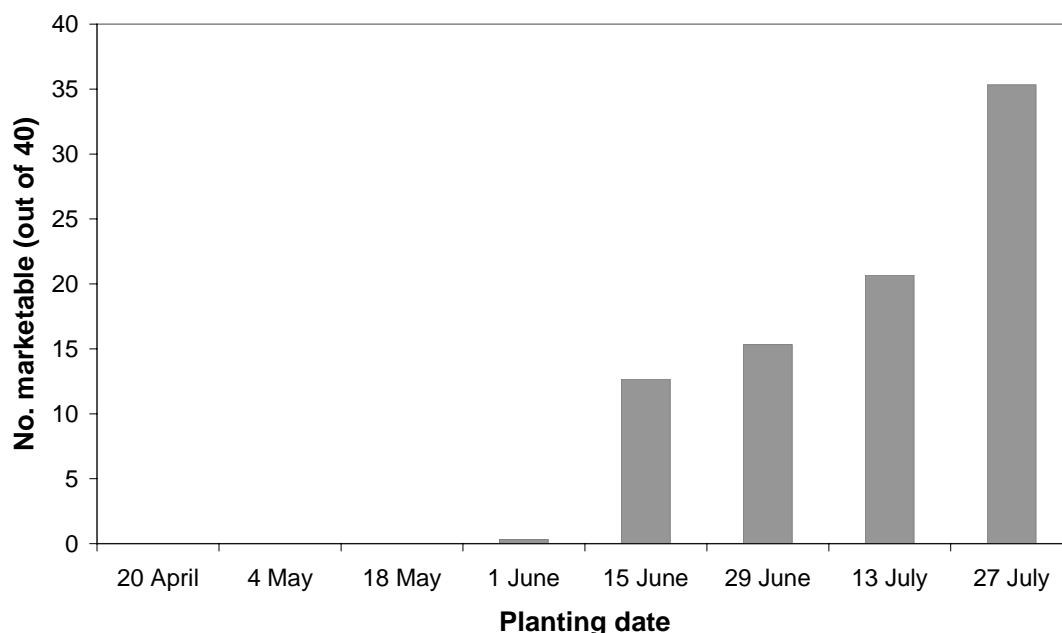
The literature was reviewed to identify crop/pest combinations where it would be advantageous to apply covers to exclude brassica pest insects. Some of this information was summarised in an article for the Vegetable Farmer (Collier, 2001).

The cabbage root fly is a major pest of cruciferous crops and damage may be categorised according to whether it is 'direct' and affects the marketable part of plant (e.g. swedes, radish, turnips) or 'indirect' and is likely to cause plant death or yield reduction only during the early life of the crop (e.g. cabbage, cauliflower, Brussels sprouts). In cases of direct damage then crops should be covered throughout the period when cabbage root flies are laying eggs. This may be for the entire life of the crop in areas such as Devon and southwest Lancashire, where pressure from early- and late-emerging biotypes of the cabbage root fly (Finch & Collier, 1983) and also the turnip fly (northern areas of the UK) may be virtually continuous. In cases of

indirect damage, covers can be removed once the plants are established and their root systems are sufficiently large to tolerate larval feeding damage.

Crop covers may be used to exclude many of the other pests of crucifers such as caterpillars and flea beetles, provided the mesh size is sufficiently small to prevent them entering the crop or laying their eggs through the mesh (e.g. Ester *et al.*, 1994; Evans *et al.*, 1997; Ferguson & Barratt, 1993; Leatherland, 1995). In contrast, the use of certain types of crop cover may increase the numbers of slugs infesting crucifer crops. Crop covers can be used to exclude the cabbage aphid and other pest aphids. However, if aphids are able to penetrate the covers then infestations may be greater than if the crop was left uncovered.

Figure 7. Numbers of marketable cabbages (out of 40) harvested from sequentially planted cabbage plots.



10. Evaluate simple methods of inspecting crops to determine the presence or absence of any given pest species (Objective 8).

The literature was reviewed to find simple ways of sampling cruciferous crops to detect the presence of each species of pest insect. Methods of sampling the pests of crucifer crops include direct sampling by visual inspection using an appropriate sampling scheme (Perry *et al.*, 1998; Collier, 1999; Collier & Mead, 1999;), soil sampling (for cabbage root fly eggs - Finch *et al.*, 1975) or the use of traps (e.g. Finch & Skinner, 1974; Steene & Callens, 2000; Prasad Reddy & Guerrero, 2001). Traps may be baited with semiochemicals (pheromones or host plant volatiles) or may be visually attractive. Whilst direct sampling produces an absolute estimate of the size of the pest infestation, trap captures provide only relative estimates. In the absence of reliable treatment thresholds for almost all crop/pest combinations (Kennedy & Collier, 2000), most sampling methods can be used to demonstrate only the presence of pests and to indicate whether their numbers are increasing or decreasing.

11. Identify accurately the critical periods during which control measures should be applied (Objective 9).

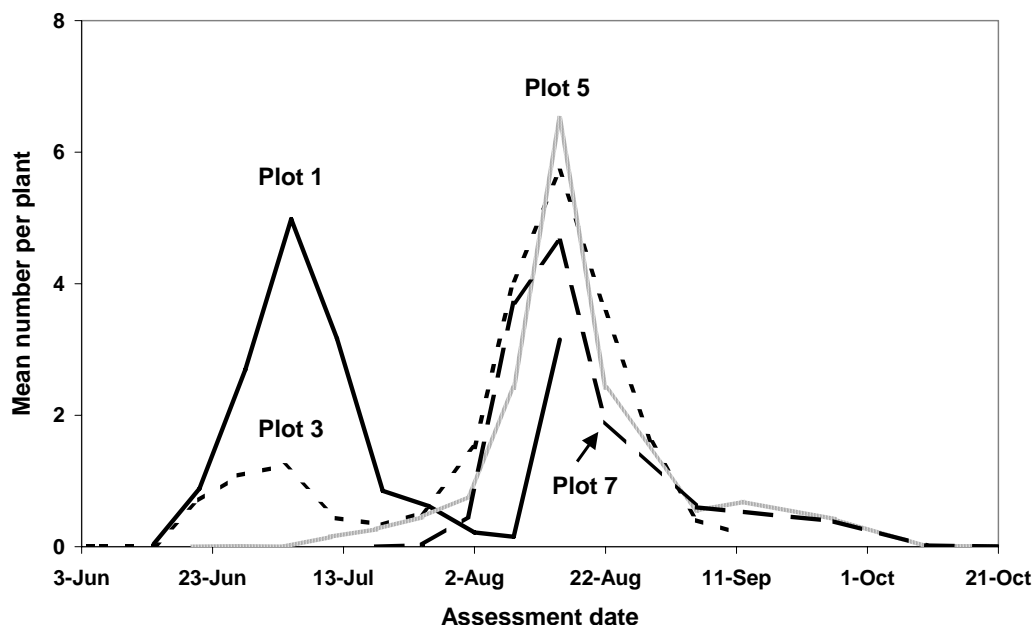
The best times to apply various control measures available to growers of organic crucifer crops have been identified. In summary they are as follows:

Cabbage root fly – leafy brassicas are most susceptible to cabbage root fly damage soon after planting. If cabbage root fly egg laying is likely to occur during the next month, the plants should be protected. As leafy brassica plants grow, they become less susceptible to cabbage root fly damage, particularly if they are growing in moist soil. The risk of damage to root brassicas continues throughout the life of the crop and these should be protected during each fly generation. If crop covers are to be used they should be applied before egg laying begins.

Aphids - soft soap sprays can be applied if crop inspection indicates a potentially damaging infestation.

Caterpillars – if pheromone trap captures indicate a potentially damaging infestation of diamond-back moth then crop inspections should be made. Female moths will be laying their eggs on crucifer plants at the time that the males are captured in pheromone traps (Collier & Minns, 2001). Crop inspections should be used to make decisions about other caterpillar pests. To be most effective, *Bacillus thuringiensis* sprays should be applied when the caterpillars are young.

Figure 8. Numbers of diamond-back moth caterpillars found on plots of cabbage planted sequentially (4 planting dates shown).



12. Verify the pest control strategies produced in objectives 6-9 (Objective 10).

A strategy for controlling the pest insects of organically grown cruciferous crops was developed. This was evaluated during 2001 at the Wellesbourne and Kirton organic sites. Three plots of cabbage (8 plants x 14 rows) were planted sequentially at each site and treated according to best practice. Fleece was used to cover

newly transplanted crops, which were then uncovered subsequently. Sprays of *Bacillus thuringiensis*, soft soap or garlic were applied to control caterpillars, aphids and cabbage root fly respectively.

Plots of cabbage cv Castello were planted at Kirton on 23 May, 19 June and 24 July. Forecasted dates of 50% egg-laying for the first and second generations of cabbage root fly were 21 May and 27 July and peak numbers of cabbage root fly females were captured in yellow water traps on 29 May and 24 July respectively. The plots were covered with fleece for at least the first four weeks after planting and no plants were lost to cabbage root fly.

As in 2000, the diamond-back moth was the main pest insect affecting marketability of the Kirton crops and caterpillars were most numerous in July, when a spray of *Bacillus thuringiensis* was applied. As a consequence, the first planting suffered most insect damage. At harvest, 80%, 90% and 100% of heads were marketable from the three plantings respectively. Cabbage aphids and peach-potato aphids were present in July-August (one application of soft soap was made) and peach-potato aphids were numerous in September. However, neither of these pests affected marketability at harvest.

At Wellesbourne, plots of Savoy cabbage (cv Wirosa) and green cabbage (cv Tundra) were planted on 27 June and 7 July respectively and harvested on 10 December. Some of the plots of cv Tundra were grown under fleece. The Savoy cabbage was treated with soft soap (for aphid control) on 9 July and garlic (for cabbage root fly control) on 16 and 24 July. At harvest, a lower percentage of heads was marketable than from the Kirton plots. However, this was mainly as a result of rotting and not due to pest damage. The use of fleece covers appeared to reduce caterpillar damage on cv Tundra. There were also some varietal differences in susceptibility to pests. Foliar disease (mainly ringspot) affected cv Tundra more than the Savoy cabbage and may have been exacerbated by the use of fleece covers.

Table 2. Harvest assessments on cabbage grown at Wellesbourne in 2001.

	Savoy	Tundra	Tundra (fleece)
% marketable heads	51	79	71
Cabbage root fly score (1-9 scale, 1 = little damage; 9 = severe damage)	3.3	4.4	3.2
Mean no. caterpillar 'holes'	2.6	3.8	0.8
Mean no. plants infested with aphids	3.0	0.3	0.0

13. Produce a user-friendly format for disseminating the above crop protection information to organic growers (Objective 11).

A workshop on carrot fly control was held at HDRA, Ryton on 23 January 2002. The aim of the workshop was to explore the underlying causes of carrot fly problems in organic production systems and, using the expertise of the participants, to try and outline any control strategies that would be likely to be effective in organic carrot production. The specific aims of the workshop were:

1. to explore the underlying causes of carrot fly problems taking into account research findings and grower experience;
2. to define a range of strategies that organic growers could use to manage carrot fly problems during the growing season;
3. to identify research and extension priorities that would allow growers to implement more effective carrot fly control strategies.

Knowledge from the workshop was intended to aid the production of an HDC factsheet on carrot fly control in crops grown organically.

The workshop was organised around group participation. Organic growers, advisors and researchers were invited to attend, and 17 people participated, representing all these backgrounds. Initially, a group exercise was undertaken to examine the causes and effects of carrot fly problems. The exercise was carried out by asking participants to write down the effects of carrot fly attack (from their point of view) on cards, which were then pinned on a board. After some discussion, they were then asked to write down the causes of the problems on cards, which were also pinned on the board. The causes and effects were ordered on the board and the chain of cause and effect briefly discussed. After the group exercise, Rosemary Collier gave a talk on carrot fly biology and control. Finally an open discussion was held to discuss management strategies for carrot fly in light of the exercise, current research knowledge, and the experience of the workshop participants in practice.

The main direct effects of carrot fly are to damage the roots, reducing the quality of carrots, which increases grade-out and ultimately reduces marketable yield. It can also lead to reduced customer satisfaction. Other less direct effects are the increased management costs of monitoring carrot fly and of manipulating fleeces, which can also reduce the effectiveness of weed control. Other indirect effects include increased damage from other pests and pathogens and the need for wider rotations and for soil conditioning to reduce attack.

The causes of carrot fly problems are less tangible and more complex. The causes posted in the exercise tended to fall into four different areas:

1. high background populations of carrot fly
2. ineffective direct control strategies
3. poor agronomic practices or management
4. inflexibility of market standards

High background populations of carrot fly are themselves caused by failing to manipulate the cropping environment to reduce carrot fly populations (using adjacent fields for susceptible crops, failure to encourage predators, poor disposal of waste carrots). These problems are ultimately rooted in grower management priorities (and pressures). Ineffective direct control strategies are caused by a lack of 1) resistant varieties, 2) approved biocides and 3) biocontrol agents, which may be due, in turn, to regulatory issues (organic standards and PSD).

Poor agronomic practices that were identified included late or slow harvesting, ineffective fleecing, sequential drillings and inappropriate irrigation. The ultimate causes of some of these problems are a result of the costs of barriers, allied to the low sale price and grower priorities in the face of these pressures. They also include the need for intensive production. Poor knowledge transfer, both between growers, and between growers and researchers is also an underlying cause of carrot fly problems.

Following on from the exercise and talk, an open discussion was held about ideas on management methods that organic growers could incorporate into carrot fly management strategies. During the discussion, gaps in current knowledge or potential management methods were also discussed. Methods discussed included trap cropping, crop covers and other barriers, biological control, acceptable pesticides/sprays, intercropping, crop management, habitat management and resistant varieties. Transfer of research results between scientists and growers and knowledge transfer between growers, were also identified as aspects that merit more attention. Research projects should have greater funding built in for technology transfer and research could be more participatory and interactive. To this end open days and workshops should be more interactive and practical. Growers could better identify problems that need research solutions.

A management strategy for organic carrot growers is likely to revolve around the flexible use of the following elements:

- **Use of fleece/mesh** combined with forecasts and monitoring to exclude flies at the times they are likely to be laying eggs and to avoid trapping them under the fleece.
- **Late sowing (or sowing with fleece for early carrots)** also combined with the use of forecasts and monitoring to avoid peak periods of egg laying.
- **Early or targeted harvests** once again combined with the use of forecasts and monitoring, in order to avoid build up of damage in the crop. Targeted harvests would aim to harvest those parts of the crop most at risk first.
- **Destruction of crop remains/reject piles** either mechanically or by using animals to reduce background population levels.
- **Rotation and/or isolation of new sowings** to reduce immigration of adult flies into new crops.
- **Use of partially resistant varieties**, possibly in hot spots, to reduce the build up of fly populations. Although not completely effective in itself, when combined with the other management methods mentioned here partial resistance could be a valuable management tool (provided the varieties are acceptable for marketing).
- **Holding off irrigation at key stages in the pest life cycle** will be beneficial where irrigation is customarily used.

During the discussion it was apparent that some of the causes of carrot fly problems were rooted in technology transfer, communication, marketing and consumer issues. These issues need to be dealt with as part of on-going education programmes and as part of technology transfer events for growers. As a result of this meeting and after consultation with the HDC, two factsheets (on the control of carrot fly and of crucifer pests in crops grown organically) were produced for publication by the HDC. Other sources of information, such as the HDC/HRI pest forecasts, will be publicised through the HDRA pest and disease e-mail group.

14. Technology transfer

a) Meetings and workshops

- COLLIER, R.H. 'Forecasting the timing of attacks by insect pests of vegetables'. HDRA, Ryton, 8 Dec 1999.
- DAVIES, J. 'Using crop covers to control insect pests of vegetables' HDRA, Ryton, 8 Dec 1999.
- COLLIER, R.H. 'Strategies for controlling the carrot fly (*Psila rosae*) in organic crops' 52nd International Symposium on Crop Protection, Gent, 9 May 2000.
- COLLIER, R.H. 'Brassica pest control' HRIA Organic Day at Kirton, 23 Aug 2000.
- COLLIER, R.H. 'Novel methods of pest management' British Association Festival of Science, 8 Sep 2000.
- COLLIER, R.H. 'Pest control trials in carrots and cabbage' HDRA Open Day - Disease control for organic vegetables, 30 Nov 2000.
- COLLIER, R.H., FINCH, S. & CHANDLER, D. 'Brassica pest control without insecticides' HDC/HRIA Workshop, 11 Jan 2001.
- COLLIER, R.H. 'Pest control in organically-produced crops of field vegetables'. 53rd International Symposium on Crop Protection, Gent, 8 May 2001.
- COLLIER, R.H. HDRA Workshop on brassicas and carrots. 'Farming to manage pests and diseases - pest management in carrots', 1 November 2001.
- COLLIER, R.H. & FINCH, S., R.H. 'Strategies for controlling the carrot fly (*Psila rosae* F.) in organic crops'. UK Onion and Carrot Conference 28 November 2001 (Poster).
- COLLIER, R.H. & FINCH, S. Strategies for controlling the carrot fly (*Psila rosae* F.) in organic crops. *Forum National Fruits et Legumes Biologiques et Bilan du Programme Interregional Nord Pas-de-Calais/Kent 'Agrobiologie Transmanche'*. 11-12 December 2001, Bouvines Nord, France. 42-44. (Poster)
- FINCH, S. & COLLIER, R.H. The effect of increased crop diversity on host plant selection by insects. *Forum National Fruits et Legumes Biologiques et Bilan du Programme Interregional Nord Pas-de-Calais/Kent 'Agrobiologie Transmanche'*. 11-12 December 2001, Bouvines Nord, France. 21-23.
- DAVIES, G. & COLLIER, R.H. Workshop on carrot fly control, HDRA, Ryton, 23 January 2002.

- COLLIER, R.H. & FINCH, S. Pest insect control in organically-produced crops of field vegetables. 2nd International Conference On The Alternative Control Methods Against Plant Pests And Diseases, Lille – 4, 5, 6, And 7th March 2002
- FINCH, S. & COLLIER R.H.. The effect of increased crop diversity on host-plant selection by insects. 2nd International Conference On The Alternative Control Methods Against Plant Pests And Diseases, Lille – 4, 5, 6, And 7th March 2002

b) Reports and publications

- COLLIER, R.H., FINCH, S. & LENNARTSSON, M. (1999). Stop your carrots getting stick. *Organic Farming*, Autumn 1999, Issue 63, 18-19.
- DAVIES, G. (2001). Pest management in organic vegetables. *Grower*, 26 April. 20-22.
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