Project title:	Quantitative application of trap plants for pest control in field vegetables
Project number:	CP 21
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Location of project:	University of Newcastle upon Tyne, NE1 7RU Warwick HRI, Wellesbourne, Warwick, CV35 9EF
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DISCLAIMER

The results and conclusions in this report are based on an investigation conducted over one year. The conditions under which the experiments were carried out and the results obtained have been reported with detail and accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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CONTENTS

GROWER SUMMARY

GROWER SUMARY

HEADLINE

- Pests displayed strong host preferences that should make them amenable to trap cropping.
- These preferences result from landing and post-landing behaviour differing on trap crop plants as compared to standard crop plants.
- Trap cropping may be further improved by using trap plants that minimise pest population growth.
- Companion planting used in a ‘push-pull’ strategy with trap cropping shows potential for some pests although care must be taken in selection of suitable companion species.

BACKGROUND AND EXPECTED DELIVERABLES

Diamondback moth (*Plutella xylostella*), cabbage root fly (*Delia radicum*) and flea beetles (*Phyllotreta spp*) constitute a major threat to brassica production in the UK and other areas of the world. This threat has been exacerbated further by the withdrawal of many pesticides from the market that were previously available for the control of these pests. Furthermore, consumer and retailer concerns about pesticide residues in produce are making it increasingly difficult to manage these insects with insecticides. As a result, there is now much interest in identifying alternative means of managing brassica pest populations.

Trap cropping may offer one such alternative. In the words of Hokkanen (1991), trap crops can be defined as ‘*plant stands that are grown to attract insects or other organisms like nematodes to protect target crops from pest attack*’. They may take the form of strips of plants within a crop, borders of plants surrounding a crop, blocks of plants adjacent to or within a crop or even plants intersown with a crop. For the control of pest insects, the trap crop and crop plants are typically grown together in time and space although in specialised cases, primarily where nematode control is concerned, trap crop plants may be grown prior to the main crop but on the same plot of land.

The aim of this three year project is to identify plant species or cultivars that have the potential to function as trap plants for the diamondback moth, cabbage root fly and flea beetles. The project will also investigate how insects select oviposition and feeding sites when provided with a choice of cruciferous species and attempt to quantify the features required for an effective trap crop system. The final aim of this project is to determine whether the use of companion plants in conjunction with a trap crop might be more effective as a pest control strategy than the use of one technique on its own.

The expected deliverables from this work include:

- An indication of whether trap cropping is a viable method for reducing the numbers of pest insects in cruciferous crops.
- An indication of whether a combination of the techniques of trap cropping and companion planting is more effective than using one of these techniques on its own.

SUMMARY OF THE PROJECT AND MAIN CONCLUSIONS

- The scientific literature was reviewed and a number of potential trap crop species were identified.
- Potential trap crop species were evaluated for cabbage root fly and diamondback moth in laboratory tests using cauliflower (*Brassica oleracea*; Lateman) as the test main crop. In choice tests, cabbage root fly laid seven times more eggs on yellow mustard (*Sinapis alba*) and turnip (*Brassica rapa*; Goldenball) than on cauliflower. For diamondback moth, salad rocket (*Eruca sativa*), Indian mustard (*Brassica juncea*) and white mustard (*Brassica hirta*) were the most preferred host species and in choice tests female moths laid nine times more eggs on these host plants than on cauliflower. Finally, in field tests, adult flea beetles caused 4-5 times more damage on turnip (*Brassica rapa*; Goldenball) and turnip rape (*Brassica rapa*; Pasja) than on cauliflower.

All plants were the same age when used (5-6 weeks) and trap plants were almost exclusively larger than cauliflower plants when used in experiments, the only exception being the collards (*Brassica oleracea*; Champion) used in diamondback moth experiments.

- Although adult diamondback moths laid more eggs on rocket than on cauliflower, larval development was slower on rocket in the laboratory.
- The behaviour of adult cabbage root flies and adult diamondback moths was observed in the laboratory. When the insects were given a choice, they always made more landings on the larger trap plants than on the cauliflower.
- Once they had landed, adult cabbage root flies and adult diamondback moths also spent longer on the leaves of trap plants than on those of cauliflower.
- For flea beetles, companion planting was successful in reducing pest damage to cauliflower plants in the field. Tomato was the most effective companion plant with mint, garlic, dill and sage (in no particular order) having less impact on flea beetle damage to cauliflower when planted at a density of three companion plants to one cauliflower plant. Tomato was the largest of the companion plants tested and may have been the most successful on this basis.
- For diamondback moth, several companion plants reduced egg laying on cauliflower when positioned at a density of 3:1 in field tests, although none of the differences were statistically significant. The plants that caused the greatest reduction in egg laying were sage and garlic. Dill and mint were notably less successful as companion plants with tomato performing better, but not as well as garlic or sage. Sage was amongst the smallest of the companion plants used and so companion plant size alone is unlikely to explain this result.
- Diamondback moths laid a large proportion of their eggs on the companion plants used in this study. It is possible that larvae hatching from these eggs could move onto the nearby cauliflower plants. This should be considered carefully if using companion planting for control of this pest.

FINANCIAL BENEFITS

- Trap cropping is a relatively simple technique that requires no specialist machinery or knowledge outside of that needed in basic pest management. Therefore there should be no added expense to the grower in adopting trap cropping as a pest management strategy. However, a proportion of land that could otherwise be used for crop production will need to be allocated to the trap crop.
- The remainder of the project will investigate whether or not trap cropping is a viable method of pest reduction and will include a cost-benefit analysis.

ACTION POINTS FOR GROWERS

To date this work cannot identify any action points for growers.

SCIENCE SECTION

INTRODUCTION

The use of pesticides in insect pest management is becoming increasingly problematic for growers. Aside from biological constraints such as the development of insecticide resistance (DeBach & Rosen, 1991) and resurgence of pests shortly after pesticide application (Aziz *et al*., 1992), there are also political, social and economic constraints. Many of the pesticides previously available for use have been withdrawn from the market in response to the EU 91/414 ruling (van Emden, 2003). In addition, the multiple retailers are imposing further restrictions on pesticide use. For example, the Co-operative group have banned the use of more than two-dozen pesticides, mostly organochlorines and organophosphates, on their products. At least one quarter of the pesticides they banned were still permitted for use in the UK at the time. Similarly, in 2001, Marks and Spencer had excluded sixty pesticides from use on their produce, and were considering excluding another sixteen (Vidal, 2002).

Due to the problems associated with pesticide use, alternative measures of pest insect management are being sought and several supermarkets now require their suppliers to investigate the potential of non-chemical pest control methods for their crops. In several countries, significant research effort has been devoted to investigating the use of within-crop plant diversity as a means of achieving this control. These include strategies such as intercropping, undersowing, companion planting (Andow, 1991) and the use of trap crops (Hokkanen, 1991).

In the words of Hokkanen (1991), trap crops can be identified as '*plant stands that are grown to attract insects or other organisms like nematodes to protect target crops from pest attack*'. Trap cropping relies upon the fact that phytophagus insects, such as cabbage root fly and diamondback moth, normally display preferences for certain host plants, or plant physiological stages, above others. The aim of such an approach is to site a relatively small area of these attractive plants (the trap crop) near to or within a crop field, in the hope that the trap crop will arrest and retain pest insects before they reach the main crop. Once in the trap crop, the pests can then be destroyed if necessary, either mechanically or using pesticides, so that damage to the main crop is prevented.

There are several features that are crucial if this technique is to be used effectively in pest insect control. These include:

- The relative attractiveness of the trap crop plants versus those of the main crop. This may depend not only on plant species or cultivar, but also on plant size and age.
- The trap crop must cover a sufficient area and be in an appropriate location to arrest pest insects before they reach the main crop. In situations where trap crops have been effective, they typically occupy 10% of the total field area and are planted as a border surrounding the main crop or as strips of trap plants within it (Hokkanen, 1991).
- Pest numbers on the trap crop must be managed, so they do not multiply and/or spill over onto the main crop at high densities.

There are relatively few examples where trap crops have been effective in a commercial situation. However, where they have worked commercially, there has been an economic benefit (e.g. 10-30% increase in net profits (Hokkanen, 1991)) as a result of reduced pesticide use coupled with reduced pest damage to the crop. Aside from pest control, trap cropping may provide other benefits. Saxena (1982), for example, found that trap strips of early-planted susceptible corn not only offered protection to another corn crop from pest damage, but also protected the crop from wind damage. Similarly, Rebe & van den Berg (2001) suggested that trap crops may play a role in reducing levels of soil erosion and can be used as animal fodder when no longer needed to protect the main crop, providing further economic gains. Finally, as pesticide use is minimised through the adoption of trap cropping, there are obvious ecological benefits with regard to non-target species.

Trap cropping might provide an economically and ecologically viable method of pest control. However, much further research is required to validate this method before it is likely to be widely adopted in temperate agriculture. The aim of the current project is to evaluate trap cropping as a pest management tool for diamondback moth (*Plutella xylostella*), cabbage root fly (*Delia radicum*) and flea beetles (*Phyllotreta* *spp*) in field brassica crops. These are major pests of vegetable brassicas in the UK and elsewhere. Pesticide withdrawals could have a major impact on vegetable crops such as brassicas, since very few alternative pest control methods are available for use within these crops (Wyman, 2003).

Many researchers have shown that the numbers of pest insects colonising crops can be reduced by including non-host plants within the main crop (Andow, 1991). Companion planting is one such method of achieving this control in brassica crops (Finch *et al.*, 2003). The techniques of trap cropping and companion planting could be complementary, providing a 'push-pull' pest management strategy (Pyke *et al.*, 1987). The two techniques combined might be more effective than using either method alone.

The objectives of the research done in Year 1 were as follows:

- To identify plant species that have the potential to act as trap crops for the diamondback moth, cabbage root fly and flea beetles.
- To identify companion plant species that have the potential to disrupt diamondback moth, cabbage root fly and flea beetle host location.

EXPERIMENT 1. HOST PLANT PREFERENCE

Objectives

The objective of this experiment was to confirm plant species that have the potential to act as trap crops for the diamondback moth, cabbage root fly and flea beetles and to select the most promising plant species from those chosen.

Materials and methods

The experiments on diamondback moth and cabbage root fly were done in the laboratory at Newcastle University at 20ºC with a 18:6 light:dark cycle. Potential 'trap crop' species were identified from the literature for each pest insect. For cabbage root fly they were:

- Yellow mustard (*Sinapis alba*)
- Turnip (*Brassica rapa*; Goldenball)

- Indian mustard (*Brassica juncea*)
- Chinese cabbage (*Brassica pekinensis*).

For diamondback moth they were:

- White mustard (*Brassica hirta*)
- Collard (*Brassica oleracea*; Champion)
- Indian mustard (*Brassica juncea*)
- Salad rocket (*Eruca sativa*).

Cauliflower (*Brassica oleracea*; Lateman) was selected as the standard 'main crop'.

Cabbage root fly and diamondback moth

The test plants were grown in a greenhouse (16:8 light to dark cycle, varying temperature between 13ºC (daily minimum) and 35ºC (daily maximum)) in 9 cm pots of John Innes No. 2 compost. The plants were 5-6 weeks old when used in the experiments and varied in size with trap plants typically being larger than cauliflower plants (see Appendix).

Diamondback moths were reared at 20ºC (18:6 light:dark cycle) on Chinese cabbage (with 10% sucrose solution absorbed on cotton wool as adult food) at Newcastle University, having been obtained from cultures maintained at Warwick HRI. Cabbage root flies were reared to the pupal stage at Warwick HRI (see Finch *et al.* (2003) for methods). They were then transported to Newcastle and stored as pupae at 5ºC. As they were needed, pupae were moved to warmer conditions (20ºC, 18:6 light:dark cycle) to promote adult emergence. Upon emergence, adults were provided with 10% sucrose solution absorbed on cotton wool, water absorbed on cotton wool and yeast hydrolysate (marmite) covered with a 70:30% mix of powdered soya flour: yeast powder.

In each experiment, twenty-six adult flies (5-7 days old) or forty adult moths (1-3 days old) were placed into a cage (75 x 50 x 50 cm, consisting of a wooden frame with sides and roof made of plywood and access through a fine net roof cover) with either four host plants of the same species (no-choice tests) or two cauliflower and two trap plants of a given species (choice tests). The plants were left in their 9 cm pots and insects of both species were provided with 10% sucrose solution absorbed onto cotton wool as a food source. For experiments using cabbage root flies, a layer of silver sand approximately 1 cm deep was placed on top of the compost in the pots and then covered with a thin layer of sieved compost.

After 24 hours, the plants were removed from the cages and the numbers of eggs laid on each plant were recorded. Diamondback moth eggs were counted directly on the plant whereas cabbage root fly eggs were extracted from the layer of silver sand by flotation (Finch *et al.*, 2003). In the case of diamondback moth, the numbers of eggs laid on the plastic pots were also recorded. New plants were placed in each of the cages and observations were made for two further periods of 24 hours using the same insects. Each experiment was replicated twice at different times and using different insects. After plants had been used in any experiment, measurements were made of plant height, leaf number and leaf area (using a 'Delta T Leaf Area Meter' from Delta T Services) (see Appendix).

For each species the numbers of eggs laid each day were subjected to Repeated Measures ANOVA having grouped the daily data per cage for any single plant species. All data were square root transformed prior to analysis.

Flea beetles

The flea beetle experiment was done in field plots within a walled garden at Close House Field Station, Heddon-on-the-Wall, Northumberland. The experiment took place between 8 and 13 June 2004.

Four potential trap plants were selected and compared with cauliflower. The trap plants selected for study were:

- Turnip (*Brassica rapa*; Goldenball)
- Turnip rape (*Brassica rapa*; Pasja)
- Radish (*Raphanus sativus*; Sparkler 3)
- Broccoli (*Brassica oleracea*; Hydra).

Plants were grown as for the experiments with the other pest species, but were removed from their pots and planted directly into the soil when used. Again, trap plants of the same age as cauliflower plants tended to be larger when used (see Appendix).

The treatments were laid out in three separate blocks, each designed as a 5 x 5 Latin square, with a three metre gap between each block. Plants were positioned in the centre of 60 x 60 cm squares within each 3 x 3 m Latin square design and all Latin squares were surrounded by at least three metres of potatoes as a buffer (Diagram 1).

SQUARE I

1	3	2	4	5
5	2	3	1	4
3	4	1	5	2
2	5	4	3	1
4	1	5	2	3

SQUARE II

4	5	2	1	3
1	4	5	3	2
2	3	1	4	5
5	1	3	2	4
3	2	4	5	1

SQUARE III

5	3	1	4	2
4	1	2	3	5
1	4	5	2	3
3	2	4	5	1
2	5	3	1	4

Diagram 1. The layout of Latin-squares used in *Phyllotreta* host preference studies in the field. 1 = broccoli, 2 = cauliflower, 3 = radish, 4 = turnip, 5 = turnip rape.

After twelve days, the plants were harvested and the number of feeding holes in each plant was recorded as well as the height, leaf number and leaf area of all plants used (see Appendix).

The data were square root transformed and subjected to Analysis of Variance taking account of plant species and plant position (row and column of the Latin squares) as factors. Data were nested within blocks (Latin squares) to allow all data to be combined for analysis and the effect of block investigated.

Results

Key to graphs:

Graphs may show symbols or letters to indicate statistically significant differences between treatment means. The symbols */**/*** indicate significant difference between paired means at $P < 0.05/0.01/0.001$ respectively. Data points that are labelled with different letters of the same case indicate a significant difference between treatment means at $P < 0.05$.

Cabbage root fly

In no-choice tests, female cabbage root flies laid similar numbers of eggs on each plant species ($F_{(4,5)} = 0.632$, $P = 0.662$, Fig. 1).
However, in choice tests (Fig. 2) females preferred yellow mustard as an oviposition site compared with cauliflower ($F_{(1,2)} = 31.23$, $P = 0.031$). Overall, more eggs were laid on the first day of the test than on the two subsequent days.

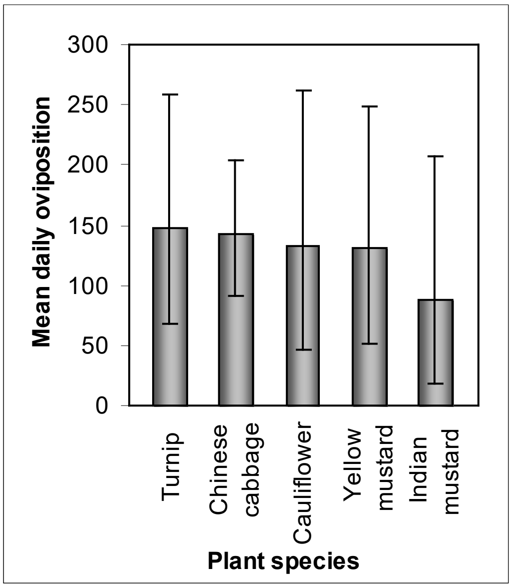

Figure 1. Graph to show mean daily cabbage root fly oviposition on plants in no-choice tests. Error bars are ± 95% CL. All data are back transformed from ANOVA.

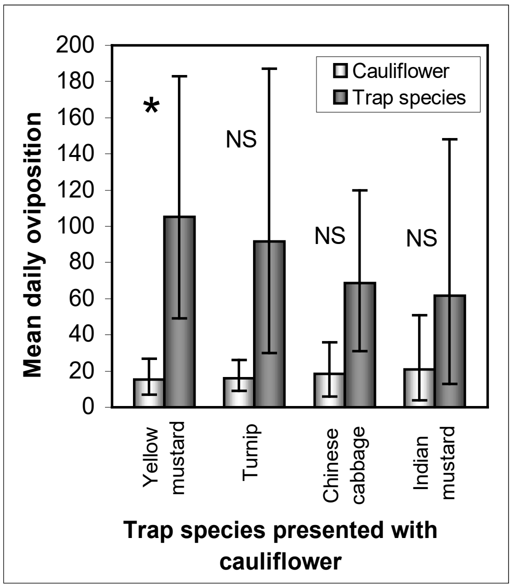

Figure 2. Graph to show mean daily cabbage root fly oviposition on plants in choice tests. Error bars are ± 95% CL. All data are back transformed from ANOVA.

Diamondback moth

Diamondback moth eggs were laid on the cruciferous plants and also on the pots containing the plants. In the no-choice experiments, and with the exception of collards, more eggs were laid on the trap crop plants than on cauliflower ($F_{(4,5)}$ = 28.20, $P = 0.001$, Fig. 3). However, if oviposition near to (on pots) as well as on plants was considered, this preference was reduced considerably and was no longer of statistical significance ($F_{(4,5)} = 5.01$, $P = 0.054$).

In the choice tests, again with the exception of collards (Fig 4), more eggs were laid on the trap crop plants than on cauliflower (white mustard vs cauliflower: $F_{(1,2)}$ =

152.65, $P = 0.006$, Indian mustard vs cauliflower: $F_{(1,2)} = 132.22$, $P = 0.007$, rocket vs cauliflower: $F_{(1,2)} = 31.94$, $P = 0.030$). However, when oviposition near to (on pots) as well as on plants was considered, only Indian mustard and rocket attracted greater oviposition than the cauliflower plants ($F_{(1,2)} = 22.94$, $P = 0.011$ and $F_{(1,2)} = 89.33$, $P = 0.041$ respectively). Like cabbage root fly, diamondback moth also tended to lay more eggs on the first day of an experiment than on subsequent days.

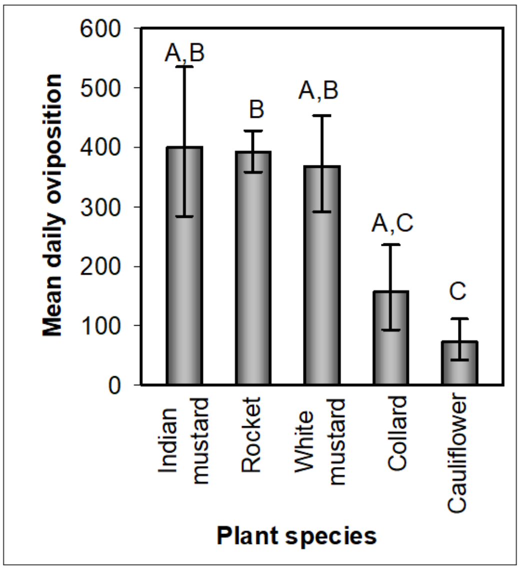

Figure 3. Graph to show mean daily diamondback moth oviposition on plants in no-choice tests. Error bars are ± 95% CL. All data are back transformed from ANOVA.

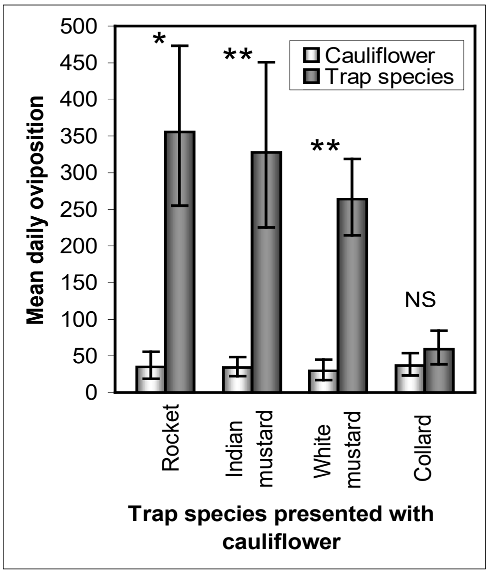

Figure 4. Graph to show mean daily diamondback moth oviposition on plants in choice tests. Error bars are ± 95% CL. All data are back transformed from ANOVA.

Flea beetles

Like the other pest species studied, flea beetles demonstrated clear preferences for certain host plants ($F_{(4,20)} = 74.44$, $P < 0.000$, Fig. 5). Turnip and turnip rape were the most preferred plants and were equally attractive. Radish was also preferred over cauliflower, but to a lesser extent. Broccoli was not preferred for feeding however, receiving similar levels of damage to cauliflower.

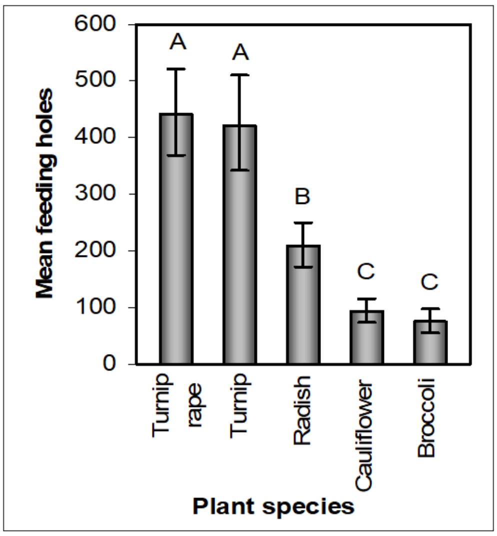

Figure 5. Graph to show mean number of flea beetle feeding holes on plants. Error bars are ± 95% CL. All data are back transformed from ANOVA.

EXPERIMENT 2. BEHAVIOUR ON TRAP AND NON-TRAP PLANTS

Objective

To determine how adult cabbage root flies and adult diamondback moths select oviposition sites and how this might vary according to host plant species.

Materials and methods

The experiments were done in a laboratory at Newcastle University at 20ºC. The experiments were done in cages identical to those described for experiment 1 (but with clear Perspex fronts for observation) using insects and plants of the same ages as used previously. Forty flies or sixty moths were placed into a cage with either four host plants of the same species (no-choice tests) or two cauliflower and two trap plants of a given species (choice tests). Insects were again provided with 10% sucrose solution absorbed on cotton wool as a food source. The insects were observed for three consecutive thirty minute periods (having first allowed 25-30 minutes for insects to settle) and the numbers of landings and immediate re-landings made by female flies and female moths were recorded. The experiment was repeated twice using different insects and plants at different times and the height, leaf number and leaf area of all plants used in each experiment were measured (see Appendix). The diamondback moth experiments always took place between the hours of 0900 h and 1100 h, with cabbage root fly being studied between 1100 h and 1300 h. No attempt was made to discriminate between the first and subsequent landings of any one insect.

Further observations were made on the first ten females to land on each plant species. Records were made of the time spent on the plant (up to a maximum of ten minutes) and the type of activity (e.g. stationary or actively mobile upon the plant) displayed. These experiments were replicated twice at different times and with different insects and plants.

Landing rate data were square root transformed (having added a value of 0.5 to all data) for both pest species and subjected to Repeated Measures Analysis of Variance. Data for the number of re-landings, relative to the number of landings (re-landings/landings) were also analysed in this way for both pest species, but using untransformed data. The data on residence times were log transformed for both pests and subjected to Nested Analysis of Variance.

The data on percentage activity rates (percentage of residence time spent actively moving on the plant) were also analysed using Nested Analysis of Variance. All cabbage root fly data were square root transformed (after adding 0.5 to all values) and diamondback moth data were either log transformed (x+1) or arcsine square root transformed (for no-choice and choice tests respectively). Landings were very low on cauliflower for both pests in choice tests. To obtain equal N-values, residence time and activity data for cauliflower in these tests was combined from all treatments. All treatments were then considered in a single analysis (one group of control data against all groups of trap crop data).

Results

Cabbage root fly

In the no-choice experiment there was a significant difference between treatments ($F_{(4,5)}$ = 6.314, P = 0.034) as female cabbage root flies made more landings on Chinese cabbage than on cauliflower. In the choice experiment, female cabbage root flies landed more frequently on Chinese cabbage and turnip than on cauliflower (Chinese cabbage vs cauliflower $F_{(1,2)}$ = 20.84, P = 0.045 turnip vs cauliflower $F_{(1,2)}$ = 185.75, P = 0.005) (Fig. 6). In the no-choice experiment, cabbage root flies spent more time on turnip and Indian mustard (Tukey Test $q_{(60,5)}$ = 3.98, $P < 0.05$) than on cauliflower and in the choice experiment, flies spent longer on all of the trap crop species than on cauliflower ($F_{(4,90)}$ = 9.98, $P < 0.000$) (Fig. 7). Trap plants were always notably larger than cauliflower plants (see Appendix).

In neither choice nor no-choice tests did re-landings (as a proportion of landings) or the percentage of residence time spent actively moving on plants differ significantly on different plant species (re-landings: $F_{(3,4)}$ = 1.53, P = 0.336 and $F_{(4,5)}$ = 1.78, P = 0.270, percentage activity: $F_{(4,90)}$ = 2.07, P = 0.091 and $F_{(4,90)}$ = 2.18, P = 0.078 in choice (trap species only for re-landing rate) and no-choice tests respectively).

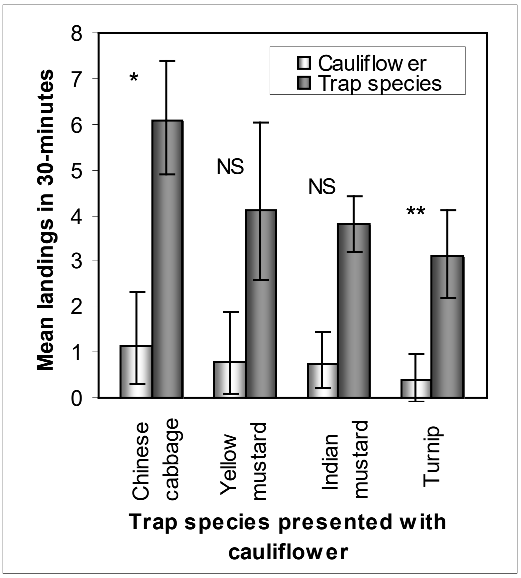

Figure 6. Graph to show mean number of landings by female cabbage root fly on plants in choice tests. Error bars are ± 95% CL. All data are back transformed from ANOVA.

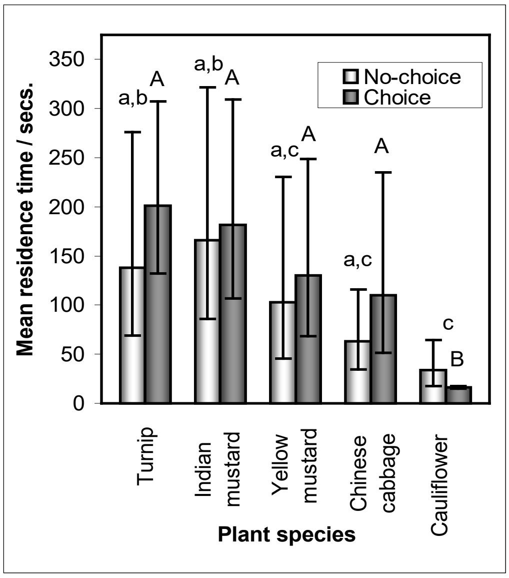

Figure 7. Graph to show mean residence times of female cabbage root fly on plants in no-choice and choice tests. Error bars are ± 95% CL. All data are back transformed from

Diamondback moth

In the no-choice experiment, diamondback moths made similar numbers of landings on all plant species ($F_{(4,5)}$ = 1.56, P = 0.316), whilst more landings were made on white mustard and rocket in the choice experiment (white mustard vs cauliflower $F_{(1,2)}$ = 200.62, P = 0.005, rocket vs cauliflower $F_{(1,2)}$ = 34.59, P = 0.028) (Fig. 8). In both no-choice and choice tests residence times were generally greater on the trap crop plants ($F_{(4,90)}$ = 5.74, P < 0.000 and $F_{(4,90)}$ = 6.93, P < 0.000 respectively). The only exception was on collards where the data were similar to those from cauliflower in both the no-choice and choice tests (Fig. 9). Trap plants were often notably larger than cauliflower plants with the exception of collards (see Appendix).

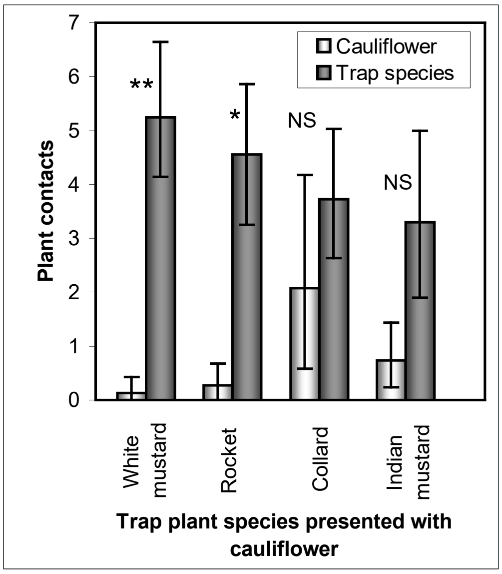

Figure 8. Graph to show mean number of landings by female diamondback moth on plants in choice tests. Error bars are ± 95% CL. All data are back transformed from

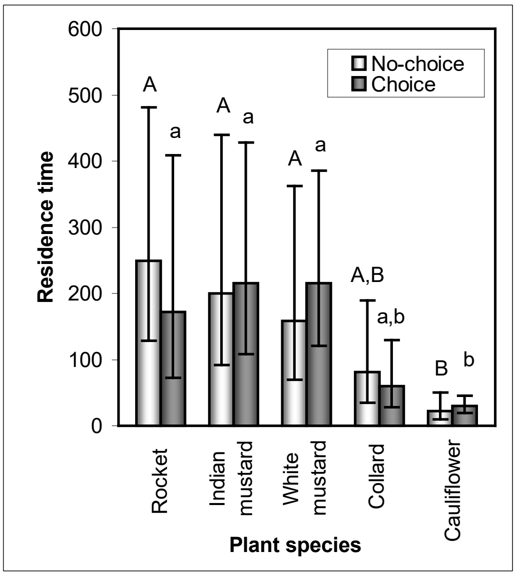

Figure 9. Graph to show mean residence times of female diamondback moth on plants in no-choice and choice tests. Error bars are ± 95% CL. All data are back transformed from ANOVA.

As with the cabbage root fly, in neither the case of choice or no-choice tests did re-landings (as a proportion of landings) or the percentage of residence time spent actively moving on different plants differ significantly between treatments (re-landings: $F_{(3,4)} = 2.34$, P = 0.215 and $F_{(4,5)} = 2.16$, $P = 0.210$, percentage activity: $F_{(4,90)} = 0.78$, $P = 0.544$ and $F_{(4,90)} = 1.88$, $P = 0.121$ in choice (data from trap species only for re-landings) and no-choice tests respectively).

EXPERIMENT 3. PERFORMANCE ON TRAP AND NON-TRAP PLANTS

Objective

To determine whether trap plants could be selected that would minimise diamondback moth population growth, thus reducing the need to control pest numbers in trap crops.

Materials and methods

Twenty freshly laid diamondback moth eggs (1-2 days old) were placed in contact with the stems of five potted cauliflower plants and five potted plants from each of the trap crop plant species for diamondback moth (i.e. white mustard, Indian mustard, salad rocket and collard). Plants were grown in John Innes No. 2 compost in 9 cm pots as in previous experiments. Plants were five weeks old when used. Plants were then enclosed individually in perforated clear plastic hoods (bread bag material: 28 x 50 cm) and these were held in place by rubber bands around the rim of each pot. The plants (in their pots) were set out in a 5 x 5 Latin square design in the laboratory at Newcastle University (20ºC, 18:6 light:dark cycle) with continuous water availability. The plants were examined daily and records were taken of:

- Time to first adult emergence on each plant
- Total number of adults emerged from each plant

The data on emergence times were analysed using a Kruskal-Walis test, as data could not be considered as continuous. Data on the total number of moths were untransformed and analysed using a single factor Analysis of Variance.

Results

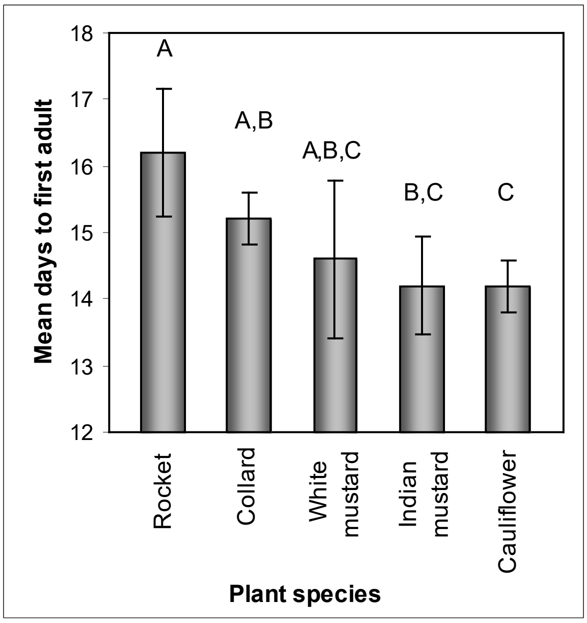

Figure 10. Graph to show mean days taken to adulthood for diamondback moth on plants in no-choice tests. Error bars are ± 95% CL.

There was no difference in the number of adult diamondback moths produced by each plant species ($F_{(4,20)}$ = 0.96, P = 0.449). However, diamondback moth development was delayed on some plant species ($H_{(4)}$ = 11.42, P = 0.022). Subsequent pair-wise testing (Mann-Whitney U) showed that the delay in development was greatest on rocket (Fig 10).

EXPERIMENT 4. COMPANION PLANT TRIALS

Objective

To determine whether companion plants can reduce oviposition by cabbage root fly and diamondback moth and feeding by flea beetles on crop host plants.

Materials and methods

For all three pest species, the following companion plants were selected:

- Sage (*Salvia officinalis*)
- Dill (*Anethum graveolens*)
- Tomato (*Lycopersicon esculentum*; the Amateur)
- Garlic (*Allium sativum*)
- Mint (*Mentha spp*).

These plants were selected from the literature as having the potential to be effective companion plants based on traditional usage rather than as a result of scientific scrutiny. In the case of diamondback moth and cabbage root fly, two additional treatments were included. These consisted of imitation garlic (green plastic) 'planted' at high or low densities (see Appendix).

All experiments were done within a walled garden at Close House Field Station using cauliflower and companion plants that were of the same age (5-6 weeks) as plants used in earlier experiments. In all experiments plant growth parameters (height, leaf number and leaf area) of all plants were measured after use (see Appendix).

Cabbage root fly and diamondback moth

For the diamondback moth and cabbage root fly experiments, three plants of one companion species were planted around a central cauliflower plant. The companion plants were positioned every 120º around the cauliflower plant, leaving a distance of 10 cm between the stem of each companion plant and the cauliflower. The companion plants were planted directly into the soil, but the cauliflower plants were left in their pots and sunk into the soil so that the rim of the pot was level with the soil surface. The surface of the compost surrounding each cauliflower plant was covered with a 1 cm layer of silver sand followed by a thin layer of sieved field soil. The treatments (one replicate of each) were laid out in a randomised block design. The plots used were enclosed in a muslin field cage supported by garden canes. This cage stood 75 cm high and contained eight 75 x 75 cm areas, laid out end to end, into which the treatments were placed. The test insects were the same age as in previous experiments and they were provided with food (10% sucrose solution absorbed on cotton wool). For each run of the experiment fifty moths and forty flies were placed in the same cage. Experiments were done between 12 July and 20 August 2004.

Each run of the experiment tested one replicate of each treatment compared against a bare soil background control. Ten runs were done for diamondback moth and six for cabbage root fly using new insects and plants for each run. For diamondback moth, egg numbers were recorded on companion plants as well as cauliflower plants, whilst for cabbage root fly, oviposition was assessed only on the cauliflower plants. Egg counts were made as in earlier experiments.

For both insect species, the numbers of eggs laid on cauliflower plants were analysed using a Multiway Analysis of Variance to identify differences between treatments, runs of the experiment and positional effects. For diamondback moth, egg laying on the companion plant species was assessed using a Kruskal-Walis Test as data could not be considered as continuous for all treatments. Data from cauliflower and associated companion plants were combined and subjected to the same analysis as oviposition data on cauliflower plants alone. The data on diamondback moth oviposition on cauliflower plants alone and on cauliflower and companion plants combined were log transformed (x+1) prior to analysis. Cabbage root fly data were transformed in the same way.

Flea beetles

The design of the flea beetle companion plant experiments was similar to the host preference experiment with these insects, but used only two (6 x 6) Latin squares as opposed to three. Cauliflower plants were surrounded by three companion plants of a given species and feeding damage on the central cauliflower plants was compared with damage on control cauliflower plants presented in a bare soil background. The companion plants were spaced around the central cauliflower plant as described for cabbage root fly and diamondback moth. All the plants were removed from their pots and planted directly into the soil. The experiment was done between 22 June and 4 July 2004 using plants of a similar age and provenance to those used in companion experiments with the other insect species. Feeding damage was recorded by counting the number of holes in the leaves of the central cauliflower plant in each treatment.

The data were analysed using a Multiway Analysis of Variance that allowed for the effect of row and column to be assessed. To allow for data from the two blocks to be combined (and the effect of block on the data to be considered), plant species was considered as being nested within blocks. Data were square root transformed prior to analysis.

Results

Cabbage root fly

Companion planting had no effect on oviposition by the cabbage root fly ($F_{(7,28)}$ = 1.11, P = 0.383) (Fig. 11). Sizes of companion plant species (leaf area) varied in experiments from being larger or comparable to cauliflower (i.e. high density artificial garlic and tomato respectively) to smaller than cauliflower (all other species) (see Appendix).

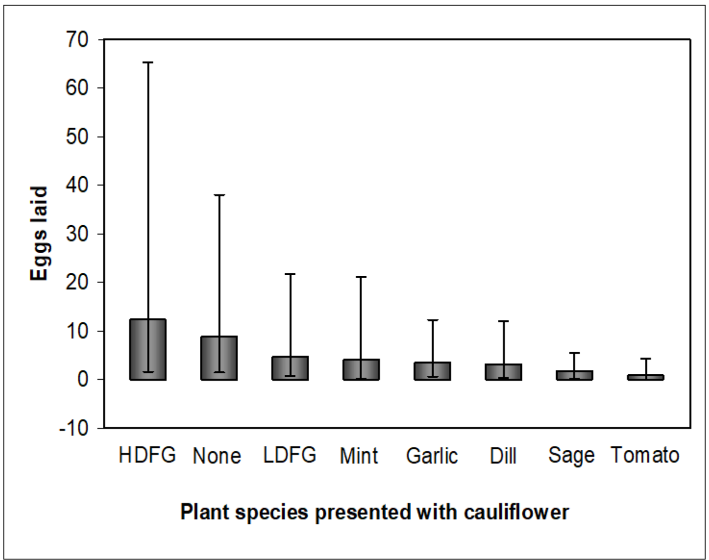

Figure 11. Graph to show mean cabbage root fly oviposition on cauliflower with different companion plants. Error bars are ± 95% CL. Data are back transformed from ANOVA. HDFG /LDFG = High and low density artificial garlic plants respectively.

Diamondback moth

There was no difference between treatments in moth oviposition on cauliflower plants ($F_{(7,56)}$ = 2.13, P = 0.055). There was a statistically significant difference between treatments when considering egg laying on the cauliflower and companion plants combined ($F_{(7,56)}$ = 3.47, P = 0.004), or on the companion plants alone ($H_{(6)}$ = 29.89, P < 0.000) (Fig. 12). Again, the size of different companion plant species relative to the cauliflower plants used varied in the experiment (see Appendix). As in the cabbage root fly experiment companion plant species ranged from being larger or comparable to cauliflower (leaf area) (i.e. high density artificial garlic and tomato respectively) to smaller than cauliflower (all other species) (see Appendix).

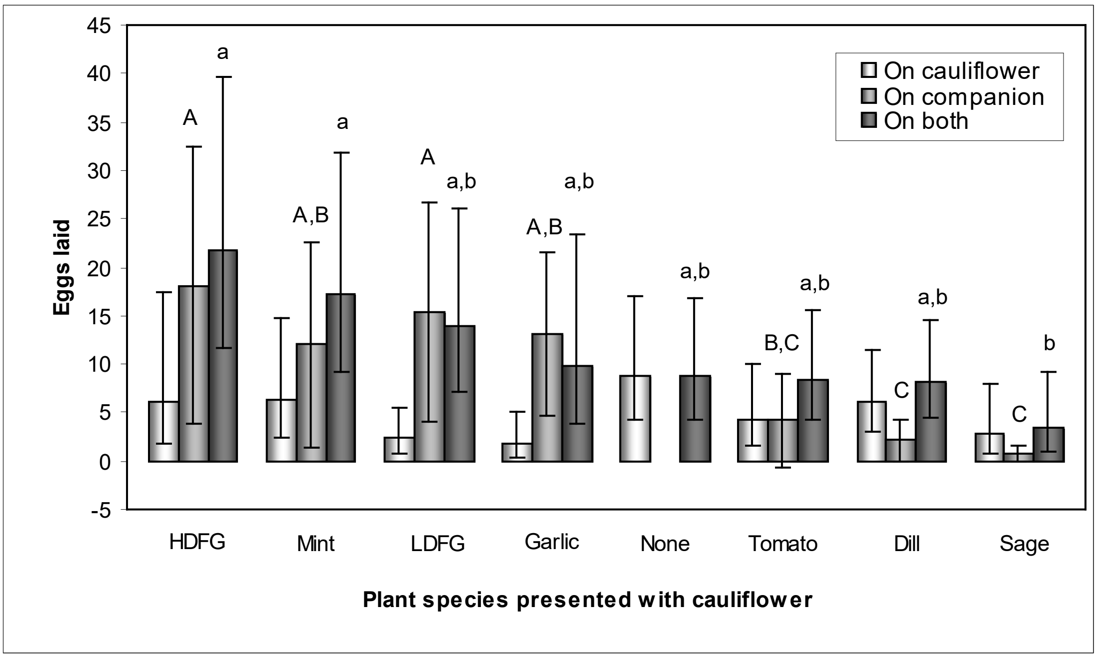

Figure 12. Graph to show mean diamondback moth oviposition on cauliflower and companion plants. Error bars are ± 95% CL. Cauliflower and combined data are back transformed from ANOVA. HDFG/LDFG = High and low density artificial garlic plants respectively.

Flea beetles

Treatment had a statistically significant effect on flea beetle feeding on cauliflower plants ($F_{(5,50)}$ = 3.36, P = 0.011). As a companion plant, tomato reduced feeding damage to the greatest extent (see Fig. 13). Companion plant species varied in size relative to cauliflower plants as in experiments with cabbage root fly and diamondback moth. In the absence of artificial garlic treatments in this experiment, tomato was the only companion plant comparable in size to cauliflower (see Appendix).

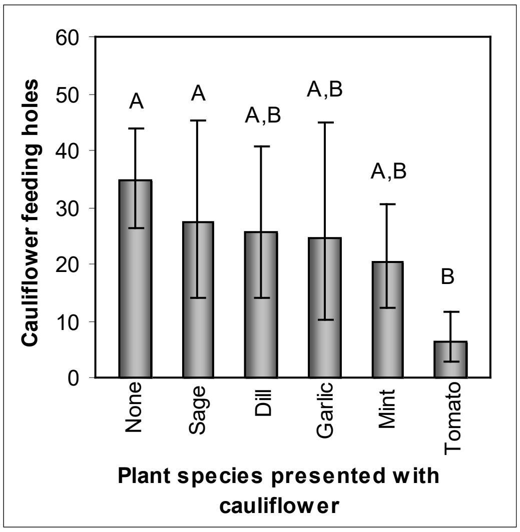

Figure 13. Graph to show mean flea beetle feeding holes on cauliflower with different companion plants. Error bars are ± 95% CL. Data are back transformed from ANOVA.

CONCLUSIONS

EXPERIMENT 1. HOST PLANT PREFERENCE

When presented with a choice, all three of the pest species studied demonstrated clear preferences for certain plants compared with cauliflower. In the case of the cabbage root fly this difference was only statistically significant in comparison with yellow mustard. Nevertheless, the less clear-cut results with the other trap species suggested that they were also preferred by the cabbage root fly (clear differences in means and *P*-values below 0.1). It is likely that increased replication would have led to these preferences becoming statistically significant.

The degree of pest insect preference for trap plants is a critical factor in trap crop design and function (Banks & Ekbom, 1999). The preferences observed suggest that trap cropping using one or more of these species might be a viable control method for the pest species studied. Furthermore, the tendency for both cabbage root fly and diamondback moth to lay most of their eggs soon after contact with a host plant may also lend itself to control using trap crops. Such behaviour suggests that trap plants would need only to retain the insects for a relatively short time early in their reproductive life-cycle when they are highly fecund.

The poor performance of collards as trap plants for diamondback moth may have been due to their weakness and small size, which was the result of poor germination and delayed development. The variety of collard used may also be important as diamondback moth shows clear preferences for certain varieties of this plant over others (Badenes *et al.*, 2004). Larger plants might also have been more effective since plant size is as an important factor in host plant selection by pest insects (Finch & Collier, 2000). This may explain why collards appeared to be relatively unattractive to diamondback moth, despite their having been used successfully as a trap crop for this pest elsewhere (Mitchell *et al.*, 2000).

Indiscriminate oviposition by diamondback moth females on plant pots and non cruciferous plants suggests that, even in the absence of preferred host plants, many eggs may be laid. Interestingly, diamondback moth females laid relatively more eggs on other sites (flower pots etc) in the presence of a cruciferous host that was less preferred. This intriguing behaviour remains unexplained. Although oviposition by cabbage root fly was restricted to cruciferous plants, in the absence of a choice of host plant, females laid all their eggs on what appeared to be a less-preferred host in no-choice tests.

It is likely that broccoli was not preferred for flea beetle feeding in this study as the plants were too old (5-6 weeks) to be attractive when used. Younger plants (at the cotyledon stage) have been shown to be preferred, but this preference diminishes as the plants age (Paliniswamy & Lamb, 1992). Turnip and turnip rape plants were the largest host plants tested in this experiment and this may have contributed to their being the most attractive for flea beetle feeding.

The results described above highlight the importance of not only selecting the appropriate trap crop species (one that is attractive), but also the appropriate age and variety of plant to be used.

EXPERIMENT 2. BEHAVIOUR ON TRAP AND NON-TRAP PLANTS

From this experiment, it appears that the host preferences found in experiment 1 were because the trap plants were more attractive landing sites than cauliflower. In addition, insects seemed to spend longer on the trap plants once they had landed.

Most of the trap plants were considerably larger than the test cauliflower plants (with the exception of collard in diamondback moth experiments) and thus offered an increased visual stimulus to the insects. This could well explain the increased number of landings on the trap plants in line with Finch & Collier's 'appropriate/inappropriate landings' hypothesis (2000). Such a hypothesis would explain also why diamondback moths made relatively few landings on the smaller collard plants.

It is likely that increased residence times on trap plants resulted from their being attractive to the insects, probably based on plant contact chemistry, although this cannot be confirmed by the current work and other factors such as plant size may have played a role. Interestingly, it is also thought to be the case that insects spend longer on non-host plants than standard hosts (Finch *et al.*, 2003). It is probable that insects spend longer on non-hosts as they are confused by inappropriate contact stimuli having landed in response to appropriate visual stimulus.

The rate of re-landing and the percentage of time spent actively moving did not vary on different plant species for either cabbage root fly or diamondback moth. This suggests that the behaviour of these pests post-landing was similar on all plants, but that this behaviour was condensed into a shorter time scale on the less preferred cauliflower hosts leading to them being less attractive for oviposition. However, actual behaviours (e.g. what individual insects were doing when actively moving or stationary) were not considered and may have varied between plant species.

EXPERIMENT 3. PERFORMANCE ON TRAP AND NON-TRAP PLANTS

It would appear that certain trap plants, namely salad rocket in this study, could be selected to minimise pest population growth. However, the effect of the plant species tested here was to reduce the rate of insect development rather than reduce the numbers of insects surviving to adulthood. This is in contrast to earlier studies using a different type of rocket (yellow rocket, *Barbarea vulgaris*) which showed that survival of diamondback moth was reduced (Idrid & Grafius, 1994, Shelton & Nault, 2004). It is likely that the differences found are due to differences in the type of rocket plants used. Nevertheless, using either type of rocket as a trap crop, irrespective of its effect on pest development, could reduce the problems of pest build-up on trap crops and subsequent overspill of pests onto the main crop. In the present study, salad rocket seemed to be the best plant species for achieving this effect with diamondback moth although development times on collard were also longer than on cauliflower.

EXPERIMENT 4. COMPANION PLANT TRIALS

It is possible that companion plants might have the potential to improve trap crop efficiency in a 'push-pull' approach to pest management. This will be dependent on selection of an appropriate companion plant species as not all were successful in reducing pest oviposition/feeding on associated host plants.

The present study suggests that with flea beetles, the largest companion plants may be the most effective. Indeed, tomato, as the only companion plant comparable in size to the cauliflower plants used, was the only companion plant to significantly reduce flea beetle feeding on cauliflower significantly. This agrees with the results of previous studies on other pests (Finch & Collier, 2000, Finch *et al.*, 2003).

Indiscriminate oviposition behaviour by female diamondback moths may make it more difficult to use companion plants as they may be used as oviposition sites from which newly-hatched larvae could migrate. In this instance larger companion plants, often thought of as the most effective, may attract more moths to the area by offering increased visual landing stimuli (Finch & Collier, 2000) and also provide them with additional oviposition sites near to a host plant. Few studies on companion planting have considered oviposition on the companion plants themselves as a potential threat to the crop plants. Thus, caution must be advised in using companion planting to manage pests such as the diamondback moth without evaluating them as alternative oviposition sites. Nevertheless, some companion plants may harbour few diamondback moth eggs and still offer some protection to associated hosts by reducing egg laying on them. Sage appeared to do just this in the current work. Sage was by no means the largest of companion plants tested however, suggesting that plant chemistry, or at least some other aspect aside from plant size, may have a role in making this species a potential companion plant for use with diamondback moth. This was not the case for all companion plants however, as in many cases the effect of imitation companion plants was comparable to that of the real ones.

In this study, the companion plants tested did not reduce oviposition by the cabbage root fly. This may have been due to companion plant architecture and/or size. This is unlikely however as several of the companion plants tested were at least as large as the cauliflower plants in all aspects of their morphology that were measured (see Appendix) and so would have been expected to be suitable companion plants for this pest (Finch *et al.*, 2003). More probable is that no effect of companion planting was found due to the low numbers of insects used in these experiments. As a consequence the data values had extremely large variances making meaningful analysis of the results impossible. Nevertheless, experiments conducted elsewhere (Finch *et al.*, 2003) show promise for companion planting in the control of cabbage root fly, provided that suitable companion plants are used. According to Finch *et al.* (2003) this means selecting the largest (green) companion plants, as were most successful with flea beetles in the current work.

TECHNOLOGY TRANSFER

Various parts of this work have been presented and discussed:

- Abstract presented at Warwick HRI postgraduate forum, Warwick, Nov. 2003.
- Poster presentation given at Royal Entomological Society (RES) meeting in York, July 2004.
- Poster presentation given at RES postgraduate forum, Newcastle, Oct. 2004.
- Oral presentation given at the University of Newcastle's postgraduate conference, Newcastle, June 2004.
- Oral presentation given at RES postgraduate forum, Newcastle, Oct. 2004.
- Oral presentation given to BGA committee, Nov. 2004.

A summary of this project has also been presented to growers through HDC News (see issue 104, page 37).

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Appendix. Physical characteristics of plants used in experiments.

All data are presented as mean values with corresponding standard errors.

Experiment 1. Host plant preference

	HEIGHT	LEAF No.	LEAF AREA
CAULIFLOWER	19.85 ± 0.48	6.67 ± 0.19	13864.67 ± 834.29
CHINESE CABBAGE	20.01 ± 0.27	9.42 ± 0.23	43088.33 ± 1298.37
YELLOW MUSTARD	37.57 ± 1.67	10.50 ± 0.16	31958.17 ± 1589.11
INDIAN MUSTARD	24.33 ± 0.47	8.88 ± 0.18	46073.83 ± 1981.56
TURNIP	23.83 ± 0.65	7.29 ± 0.09	42420.33 ± 1507.77

Table 1.1. Physical characteristics of plants used (height/cm, leaf area/square mm, leaf number) in no-choice experiments with cabbage root fly.

	CAULIFLOWER			TRAP SPECIES		
	Ht.	LEAF No.	LEAF AREA	Ht.	LEAF No.	LEAF AREA
CAULIFLOWER + YELLOW MUSTARD	18.76 ± 0.39	5.83 ± 0.11	13074.83 ± 1078.93	37.84 ± 2.12	10.33 ± 0.28	32046.33 ± 2601.15
CAULIFLOWER + CHINESE CABBAGE	19.45 ± 0.36	6.08 ± 0.19	13341.50 ± 631.72	19.38 ± 0.46	8.75 ± 0.39	41570.67 ± 1052.67
CAULIFLOWER + INDIAN MUSTARD	20.13 ± 0.41	6.00 ± 0.21	16795.17 ± 858.33	23.78 ± 0.77	8.92 ± 0.26	42019.17 ± 1365.52
CAULIFLOWER + TURNIP	17.90 ± 0.45	5.67 ± 0.19	13631.67 ± 1211.06	24.03 ± 0.71	7.33 ± 0.14	41779.50 ± 1696.86

Table 1.2. Physical characteristics of plants used (height/cm, leaf area/square mm, leaf number) in choice experiments with cabbage root fly.

	HEIGHT	LEAF No.	LEAF AREA
CAULIFLOWER	19.65 ± 0.50	6.71 ± 0.15	15601.92 ± 916.74
WHITE MUSTARD	48.48 ± 1.44	11.63 ± 0.31	37549.83 ± 1139.21
INDIAN MUSTARD	24.41 ± 0.51	8.83 ± 0.16	44969.83 ± 1079.37
ROCKET	24.67 ± 0.48	11.83 ± 0.30	31148.00 ± 799.34
COLLARD	15.78 ± 0.35	5.63 ± 0.19	8201.92 ± 407.93

Table 1.3. Physical characteristics of plants used (height/cm, leaf area/square mm, leaf number) in no-choice experiments with diamondback moth.

	CAULIFLOWER			TRAP SPECIES		
	Ht.	LEAF No.	LEAF AREA	Ht.	LEAF No.	LEAF AREA
CAULIFLOWER + WHITE MUSTARD	18.88 ± 0.51	5.92 ± 0.19	11431.00 ± 1158.54	50.14 ± 1.94	11.17 ± 0.30	36441.00 ± 2033.65
CAULIFLOWER + INDIAN MUSTARD	20.62 ± 0.29	5.92 ± 0.23	14963.67 ± 643.56	24.53 ± 0.62	9.25 ± 0.25	46869.00 ± 1248.15
CAULIFLOWER + ROCKET	18.28 ± 0.39	5.75 ± 0.18	12997.17 ± 511.65	24.83 ± 0.51	11.58 ± 0.42	30572.33 ± 730.81
CAULIFLOWER + COLLARD	22.56 ± 0.41	7.50 ± 0.26	28134.08 ± 804.77	17.86 ± 0.72	5.42 ± 0.23	9416.92 ± 528.32

Table 1.4. Physical characteristics of plants used (height/cm, leaf area/square mm, leaf number) in choice experiments with diamondback moth.

	HEIGHT	LEAF No.	LEAF AREA
CAULIFLOWER	24.30 ± 0.30	6.87 ± 0.44	28904.93 ± 1890.26
BROCCOLI	28.50 ± 0.77	7.13 ± 0.16	26493.53 ± 1276.72
RADISH	25.03 ± 3.29	8.33 ± 0.60	27277.07 ± 2083.88
TURNIP	25.46 ± 0.92	6.73 ± 0.31	42033.43 ± 2196.43
TURNIP RAPE	25.13 ± 0.95	8.93 ± 0.69	54702.73 ± 3664.86

Table 1.5. Physical characteristics of plants used (height/cm, leaf area/square mm, leaf number) in experiments with flea beetles.

Experiment 2. Behaviour on trap and non-trap plants.

	HEIGHT	LEAF No.	LEAF AREA
CAULIFLOWER	17.91 ± 0.65	5.75 ± 0.16	7967.00 ± 758.99
CHINESE CABBAGE	19.44 ± 0.43	9.88 ± 0.23	40425.75 ± 1739.68
YELLOW MUSTARD	26.08 ± 2.45	9.38 ± 0.42	23036.88 ± 3149.65
INDIAN MUSTARD	23.11 ± 0.61	8.00 ± 0.33	39649.50 ± 3315.67
TURNIP	23.34 ± 0.40	8.13 ± 0.30	35845.25 ± 1911.55

Table 2.1. Physical characteristics of plants used (height/cm, leaf area/square mm, leaf number) in no-choice experiments with cabbage root fly.

	CAULIFLOWER			TRAP SPECIES		
	Ht.	LEAF No.	LEAF AREA	Ht.	LEAF No.	LEAF AREA
CAULIFLOWER + YELLOW MUSTARD	21.08 ± 0.67	6.25 ± 0.35	17889.50 ± 23.82	47.90 ± 0.84	12.75 ± 0.49	49296.00 ± 24.24
CAULIFLOWER + CHINESE CABBAGE	22.34 ± 0.38	7.00 ± 0.45	21265.50 ± 26.09	22.15 ± 0.56	11.25 ± 0.35	69580.00 ± 38.57
CAULIFLOWER + INDIAN MUSTARD	22.15 ± 0.51	7.00 ± 0.45	22043.25 ± 19.88	23.33 ± 0.46	9.00 ± 0.45	48019.50 ± 20.27
CAULIFLOWER + TURNIP	21.88 ± 0.59	6.50 ± 0.38	21234.25 ± 24.68	23.05 ± 0.60	8.00 ± 0.59	52436.25 ± 41.12

Table 2.2. Physical characteristics of plants used (height/cm, leaf area/square mm, leaf number) in choice experiments with cabbage root fly.

	HEIGHT	LEAF No.	LEAF AREA
CAULIFLOWER	18.36 ± 0.27	5.50 ± 0.19	7786.00 ± 438.96
WHITE MUSTARD	38.96 ± 2.66	10.13 ± 0.40	29378.88 ± 1385.78
INDIAN MUSTARD	24.15 ± 0.75	8.75 ± 0.37	45591.63 ± 1675.99
ROCKET	22.23 ± 0.69	11.00 ± 0.50	27385.00 ± 715.29
COLLARD	15.39 ± 0.67	6.00 ± 0.33	7939.63 ± 670.83

Table 2.3. Physical characteristics of plants used (height/cm, leaf area/square mm, leaf number) in no-choice experiments with diamondback moth.

	CAULIFLOWER			TRAP SPECIES		
	HEIGHT	LEAF No.	LEAF AREA	HEIGHT	LEAF No.	LEAF AREA
WHITE MUSTARD	20.45 ± 0.68	6.25 ± 0.25	16538.25 ± 1212.02	58.08 ± 1.41	12.25 ± 1.18	36551.25 ± 3728.74
INDIAN MUSTARD	22.50 ± 0.56	7.25 ± 0.25	21603.50 ± 1479.93	23.23 ± 0.45	9.75 ± 0.85	45501.00 ± 2838.53
ROCKET	22.65 ± 0.77	6.50 ± 0.29	20521.25 ± 1622.22	22.73 ± 0.78	12.00 ± 1.00	29986.25 ± 3650.16
COLLARD	23.78 ± 0.44	8.25 ± 0.25	33886.75 ± 1642.91	17.1 ± 0.78	5.50 ± 0.29	9885.50 ± 1406.41

Table 2.4. Physical characteristics of plants used (height/cm, leaf area/square mm, leaf number) in choice experiments with diamondback moth.

Experiment 3. Performance on trap and non-trap plants

Plant growth variables not recorded but amount of plant tissue available for feeding was never limiting.

Experiment 4. Companion plant trials.

All tables show data for cauliflower under different treatments in standard text and data for companion plants in italics.

	HEIGHT	LEAF No.	LEAF AREA
CONTROL (NONE)	*24.5 ± 0.81* NA	*7.67 ± 0.21* NA	*37329.67 ± 2036.72* NA
TOMATO	24.22 ± 0.89 *33.76 ± 1.16*	7.67 ± 0.21 *8.56 ± 0.47*	37556.83 ± 2535.08 *35949.67 ± 3745.80*
SAGE	23.85 ± 0.49 *12.82 ± 0.66*	8.00 ± 0.26 *12.56 ± 1.82*	37379.83 ± 797.66 *4834.22 ± 540.33*
GARLIC	24.98 ± 0.51 *31.37 ± 2.36*	8.00 ± 0.26 *23.22 ± 2.31*	39552.50 ± 2856.23 *8171.33 ± 878.65*
DILL	24.33 ± 0.80 *51.94 ± 3.82*	7.67 ± 0.21 *7.22 ± 0.36*	36154.50 ± 1891.82 *4470.00 ± 866.46*
MINT	23.80 ± 1.03	7.67 ± 0.21	33520.00 ± 6286.49

	12.32 ± 0.81	*80.50 ± 9.68*	*13518.33 ± 1299.25*
LDFG	24.48 ± 0.33 *20.00 ± 0.00*	7.83 ± 0.31 *16.00 ± 0.00*	43089.33 ± 3396.56 *8288.00 ± 0.00*
HDFG	23.48 ± 0.59 *20.00 ± 0.00*	7.50 ± 0.22 *160.00 ± 0.00*	38303.17 ± 1778.76 *82880.00 ± 0.00*

Table 4.1. Physical characteristics of plants used (height/cm, leaf area/square mm, leaf number) in experiments with cabbage root fly. HDAG/LDAG = high and low density artificial garlic respectively.

	HEIGHT	LEAF No.	LEAF AREA
CONTROL (NONE)	*23.84 ± 0.64* NA	*7.67 ± 0.17* NA	*35110.0 ± 1829.78* NA
TOMATO	23.87 ± 0.62 *33.51 ± 1.57*	7.44 ± 0.24 *8.67 ± 0.38*	36209.00 ± 2024.24 *34982.19 ± 2713.99*
SAGE	23.27 ± 0.50 *13.03 ± 0.58*	7.78 ± 0.22 *13.74 ± 1.67*	35129.00 ± 1623.92 *5203.04 ± 489.16*
GARLIC	24.38 ± 0.45 *31.74 ± 1.86*	7.67 ± 0.24 *22.89 ± 1.76*	36962.44 ± 2312.35 *8339.37 ± 696.37*
DILL	23.44 ± 0.77 *50.96 ± 2.82*	7.33 ± 0.24 *7.33 ± 0.36*	33418.44 ± 2378.15 *4078.44 ± 659.97*
MINT	23.14 ± 0.80 *12.55 ± 0.65*	7.56 ± 0.18 *90.52 ± 11.34*	32597.56 ± 4246.42 *14939.56 ± 1723.05*
LDFG	23.70 ± 0.52 *20.00 ± 0.00*	7.56 ± 0.29 *16.00 ± 0.00*	39651.89 ± 2865.13 *8288.00 ± 0.00*
HDFG	23.09 ± 0.43 *20.00 ± 0.00*	7.33 ± 0.24 *160.00 ± 0.00*	36112.22 ± 1671.38 *82880.00 ± 0.00*

Table 4.2. Physical characteristics of plants used (height/cm, leaf area/square mm, leaf number) in experiments with diamondback moth. HDAG/LDAG = high and low density artificial garlic respectively.

	HEIGHT	LEAF No.	LEAF AREA
CONTROL (NONE)	22.72 ± 0.61 NA	8.58 ± 0.26 NA	40294.08 ± 1811.58 NA
TOMATO	23.74 ± 0.44 *29.29 ± 0.39*	8.36 ± 0.23 *7.25 ± 0.14*	37142.00 ± 2555.22 *26763.92 ± 763.15*
SAGE	22.29 ± 0.61 *12.78 ± 0.21*	8.36 ± 0.15 *18.03 ± 0.84*	34343.18 ± 1638.12 *6140.22 ± 238.25*
GARLIC	22.88 ± 0.36 *30.72 ± 0.63*	8.64 ± 0.43 *4.64 ± 0.16*	34357.55 ± 1640.88 *2737.69 ± 137.05*
DILL	22.60 ± 0.37 *65.09 ± 0.82*	8.27 ± 0.29 *8.08 ± 0.19*	34315.91 ± 1603.36 *5160.53 ± 291.09*
MINT	23.48 ± 0.53 *7.22 ± 0.32*	8.18 ± 0.25 *11.47 ± 0.82*	34636.64 ± 1478.69 *2579.14 ± 243.58*

Table 4.3. Physical characteristics of plants used (height/cm, leaf area/square mm, leaf number) in experiments with flea beetles.