**Report prepared for the Horticultural Development Council**

# CP 21

# Quantitative application of trap plants for pest control in field vegetables

**Annual Report 2005**

By

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| **Project title:** | Quantitative application of trap plants for pest control in field vegetables |
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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.

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### GROWER SUMMARY



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## GROWER SUMARY

## HEADLINE

- Diamondback moth adults showed consistent preferences for white mustard over cauliflower as an egg laying site, regardless of the age of these plants.
- At a constant age, white mustard plants were preferred to cauliflower plants regardless of whether the mustard plants were made to be smaller than, similar to or larger than the cauliflower plants in size. However, the percentage of eggs laid on the mustard plants was greater when they were larger than cauliflower plants.

  This suggests that it may not be necessary to use older, larger plants as trap crops for diamondback moth. However, larger trap crop plants are likely to maximise the effectiveness of trap cropping in attracting and retaining pest insects.
- For both diamondback moth and flea beetle, leaving a gap of 3 m or more of bare soil between the trap crop and main crop plants increased the percentage of eggs laid/damage on the trap crop. Leaving a gap between the trap crop and main crop plants is therefore likely to increase the effectiveness of border trap crops in pest management.
- Small scale field experiments with flea beetle suggest that there is no pest control benefit of 1:1 substitutive companion planting with tomato in cauliflower plots. Furthermore, planting tomato with a turnip rape trap crop in a ‘push-pull’ approach to flea beetle management was no more effective than using the trap crop alone.

  Both a turnip rape trap crop alone, and in conjunction with tomato as a companion plant, reduced flea beetle damage on cauliflower when compared with plants grown in monoculture or with companion plants. This was only the case in the latter stages of the trial, however, suggesting that the benefits of trap cropping may not be immediately apparent in the field situation.

## 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 inter-sown with a crop. For the control of pest insects, the trap crop and crop plants are 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 crop 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 either 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

### YEAR ONE (See Annual Report, 2003-4, for full details)

- The scientific literature was reviewed and a number of potential trap crop and companion plant 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 females 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 crop plants were almost exclusively larger than cauliflower plants when used in experiments, the only exception being the collards (*Brassica oleracea*; Champion) used in the diamondback moth experiments.
- Although female 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 crop plants than on the cauliflower
- Once they had landed, adult cabbage root flies and adult diamondback moths spent longer on the leaves of trap plants than on those of cauliflower.
- For flea beetle, 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 because of its size.

- 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 these differences were statistically significant. The plants that caused the greatest reduction in egg laying were sage and garlic. Dill and mint were 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.

**YEAR TWO**

- When given a choice between white mustard plants and cauliflower plants of varying ages (4, 5 or 6 weeks old), diamondback moth females oviposited at a similar rate on mustard, regardless of whether these plants were older, younger or the same age as the cauliflower used. As in experiments in year one, the mustard was always preferred for oviposition, typically attracting 85-95% of eggs. Even when 4 weeks old, the mustard plants were at least comparable in size to 6 week old cauliflower plants.
- When given a choice between white mustard plants of a fixed age (5-6 weeks) made to be smaller than, similar to or larger in size than cauliflower plants of the same age, diamondback moth females always preferred to oviposit on the mustard. However, larger mustard plants attracted a significantly higher percentage of oviposition than smaller plants (93% as compared to 68%).
- The above suggests that plant size may be important in trap cropping because larger plants are likely to be more attractive to/preferred by pests and thus presumably work better as trap crops. However, as smaller trap plants may still be preferred to main crop plants, it may not be essential to use larger trap

crop plants *per se*. Nevertheless, using large trap crop plants should maximise the ability of trap crops to relieve pest pressure on the main crop.

Plant age appears less important in determining the ability of trap plants to attract high levels of oviposition away from nearby main crop plants. This statement is, however, based on the assumption that even when younger than main crop plants, trap plants are still at least comparable to them in size. Consequently, plant age is likely to be more important in governing trap crop effectiveness if, when younger than the main crop plants, trap crop plants are also smaller than them.

- In small scale field cage experiments, trap crops effectively reduced flea beetle feeding damage and diamondback moth oviposition on cauliflower compared with using no trap crop at all. However, trap crops were no more effective at lowering damage on protected cauliflower than an outer row of cauliflower itself. This was in spite of trap crop plants attracting far greater levels of feeding/egg laying than comparably-situated exterior cauliflower plants in monoculture.
- Field cages were used to simulate a section of a trap crop system. For flea beetle, leaving a gap of at least 3 m between a trap crop of turnip rape and a main crop of cauliflower increased the percentage feeding damage on the trap crop. The same was true for diamondback moth oviposition but in this case using white mustard as the trap crop. For both pests, the actual damage/number of eggs on the cauliflower was also reduced by separating the cauliflower plants from the trap crop plants by at least 3 m.
- Small scale field experiments were used to test whether trap crops of turnip rape would protect cauliflower from flea beetle feeding damage when planted as an external border. Substitutive companion planting with tomato plants (at a 1:1 ratio with cauliflower) was also assessed as a method of pest control, as was a combination of companion planting and trap cropping. Plants were transplanted into the field when 4-5 weeks old and monitored regularly for damage over a further two months. Only trap cropping, and trap cropping and companion planting combined, resulted in lowered feeding damage to cauliflower plants compared with the monoculture control. Even then, this reduction in feeding damage was not apparent until one month into the study for trap cropping alone, and seven weeks into the study for trap cropping and

companion planting combined. At, and after one month, trap cropping, alone and in combination with companion planting, was also more effective in reducing flea beetle feeding damage on associated cauliflower plants than companion planting alone.

At the end of the study period, the leaf areas of the cauliflower plants in the centre of each plot were assessed. Only the combined trap crop/companion plant treatment reduced cauliflower leaf area significantly compared with the cauliflower plants grown as a monoculture. This is probably because the cauliflower plants had to compete with both the tomato and turnip rape plants. As turnip rape plants grew relatively big during the study, it is likely that they were able to influence even the central cauliflower plants in this small scale experiment. There was no effect of treatment on the height of the cauliflower plants in the centre of each plot.

**FINANCIAL BENEFITS**

- On average a 10-30% overall increase in net profits is reported where trap crops are used (Hokkanen, 1991). This results primarily from the reduced need to control pests on the main crop.
- Trap cropping is a relatively simple technique that requires no specialist machinery or knowledge outside of that needed for 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.

**ACTION POINTS FOR GROWERS**

- If considering the use of border trap cropping to manage flea beetle damage in brassicas, leaving a gap of 3 m or more between the trap and main crop should increase the effectiveness of the trap crop.
- If considering the use of trap cropping, it is advisable to ensure that trap plants are larger, although not necessarily older, than the main crop plants they are protecting.

## 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, multiple retailers are imposing further restrictions on pesticide use. For example, the Co-operative group have banned the use of more than twenty pesticides, mostly organochlorines and organophosphates, on their products. More than one quarter of the pesticides they banned were still permitted for use in the UK at the time of the ban in 2001. 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 phytophagous 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, mechanically, biologically, or by using pesticides, so that damage to the main crop is prevented.

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

- The greater relative attractiveness of the trap crop plants versus those of the main crop (Potting *et al*., 2005). This may depend not only on plant species or cultivar, but also on plant size and age (Bender *et* al., 1999, Robinson, 2001).
- 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 sufficiently to degrade the trap crop, resulting in the spilling over of individuals onto the main crop at high pest 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) found that trap strips of early-planted susceptible corn not only offered protection from pest damage to another corn crop, 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 planting 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 current project also aims to test this hypothesis.

*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.

A brief review of the results of this work can be found in the 'Grower Summary' of this report with full details in the HDC Annual Report for Year 1.

*The objectives of the research done in Year 2 were as follows:*

- To assess the importance of the relative ages of trap crop and main crop plants, in influencing pest preference for trap crop plants.
- To assess the importance of the relative sizes of the trap crop and main crop plants, in influencing pest preference for trap crop plants.
- To assess whether border trap crops are any more affective than borders of main crop plants in reducing pest damage on the main crop.

- To determine the effect of separating a trap crop and main crop, by a distance of up to 6 m, on pest preference for the trap crop plants and the effectiveness of the trap crop to reduce pest damage to the main crop plants.
- To investigate, in small scale field experiments, the potential of trap cropping, companion planting and a combination of the two techniques, for reducing pest damage on associated main crop plants compared with main crop plants grown in monoculture.

## EXPERIMENT 1. THE EFFECT OF HOST PLANT AGE ON DIAMONDBACK MOTH PREFERENCE FOR WHITE MUSTARD OR CAULIFLOWER.

*Objective*

To assess the importance of the relative ages of trap crop and main crop plants in influencing pest preference for trap crop plants.

*Materials and methods*

Choice tests were used to investigate the oviposition preferences of diamondback moth for main crop plants, cauliflower (*Brassica oleracea*; Lateman) and potential trap crop plants, white mustard (*Brassica hirta*), of different ages. White mustard was identified as a preferred host in Year 1 of the project.

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 4-6 weeks old when used in the experiments and varied in size, with the mustard plants typically being larger than cauliflower plants of a similar age (see Appendix).

Diamondback moths were reared at 20ºC (18:6 light:dark cycle) on Chinese cabbage (with 10% sucrose solution absorbed on cotton wool supplied as adult food) at Newcastle University. The moths were obtained originally in 2003 from a culture maintained at Warwick HRI. The experiment was done in a laboratory at Newcastle University at 20ºC with a 18:6 light:dark cycle

Two cauliflower plants of a given age and two white mustard plants of a given age were placed into a wooden frame cage (75 x 50 x 50 cm) with a fine mesh lid to provide access. Ten moths (five males and five females, 1-3 days old) were used in each run of the experiment and each run recorded oviposition over 48 hours. The test plants were left in their pots during the study period and the numbers of eggs laid on the plants and the pots were recorded. Moths were provided with food (10% sucrose solution absorbed on cotton wool) during each experiment.

The treatment combinations are shown in Table 1. Each treatment was repeated once in each of nine runs, hence there were nine replicates.

| | | WHITE MUSTARD | | |
|---|---|---|---|---|
| | AGE / WKS | 4-5 | 5-6 | 6-7 |
| CAULIFLOWER | 4-5 | TREATMENT 1 | TREATMENT 2 | TREATMENT 3 |
| | 5-6 | TREATMENT 4 | TREATMENT 5 | TREATMENT 6 |
| | 6-7 | TREATMENT 7 | TREATMENT 8 | TREATMENT 9 |

**Table 1. Treatments used for oviposition preference experiments with diamondback moth using plants of varying ages.**

At the end of each experimental run, plant growth parameters (height, leaf number and leaf area) were measured. Leaf area was measured using a ‘Delta T Leaf Area Meter’ from Delta T Devices.

Data from the two mustard and cauliflower plants in each replicate were combined to give one value for mustard and one for cauliflower. Paired t-tests (on square root $(x + 0.5)$ transformed data) were used to determine whether there were oviposition preferences for mustard in any treatment combination (data analysed consisted of the numbers of eggs on plants, on pots and the two records combined). The total number of eggs laid was compared between treatments (on plants, pots and the two combined) using 2-way ANOVA (on square root transformed data) to look for differences between replicates as well as treatments. The percentage oviposition on mustard was also assessed in this way (having first subjected the data to the arcsine square root transformation). Where ANOVA identified statistically significant differences between means, the Tukey Test was used to identify differences between pairs of means. To determine the relationship between plant size and oviposition preference, Spearman’s Rank analysis was used to determine if there was any statistically significant correlation between the percentage of eggs laid on plants and plant growth parameters (i.e. the percentage of total within-cage plant height, leaf number or leaf area taken up by the plant species being considered).

Where transformed data were used in any analysis, back transformed means and confidence limits are displayed.

*Results*

**Key to graphs:**

Graphs may show symbols or letters to indicate statistically significant differences between treatment means. The symbols */**/*** indicate significant differences 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.

Diamondback moth eggs were laid on the mustard and cauliflower plants and also on the pots containing the plants. In all treatments, more eggs were laid on the mustard plants than on the cauliflower plants ($T_{(1,8)}$ = 5.75-11.25, $P < 0.001$ in all cases) (Fig 1a). When oviposition near to (on pots), as well as on plants, was considered, this strong preference was maintained ($T_{(1,8)}$ = 4.65-8.78, $P < 0.01$) in all cases except for 4-week old mustard vs 6-week old cauliflower, where the size of the preference was reduced, although still significant ($T_{(1,8)} = 2.39$, $P < 0.05$) (Fig 1c). Oviposition on plant pots tended not to differ between the mustard and cauliflower in any treatment ($T_{(1,8)}$ = -1.98-2.26, $P \geq 0.54$, for 7 out of the 9 treatments) (Fig 1b). However, for the 4- and 5-week old mustard vs 6-week old cauliflower treatments, more eggs were laid on the pots containing the cauliflower plants ($T_{(1,8)} = -5.52$, $P < 0.001$ and $T_{(1,8)} = -2.63$, $P < 0.05$ respectively).

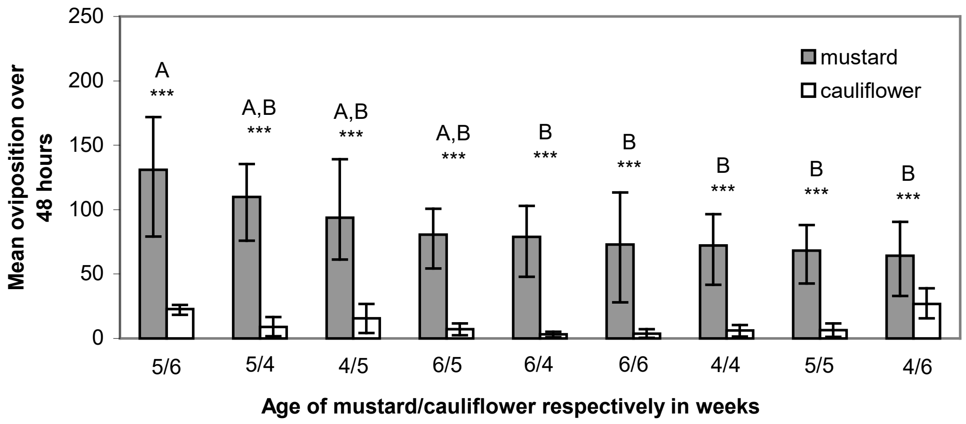



**Fig. 1a. Oviposition on plants**

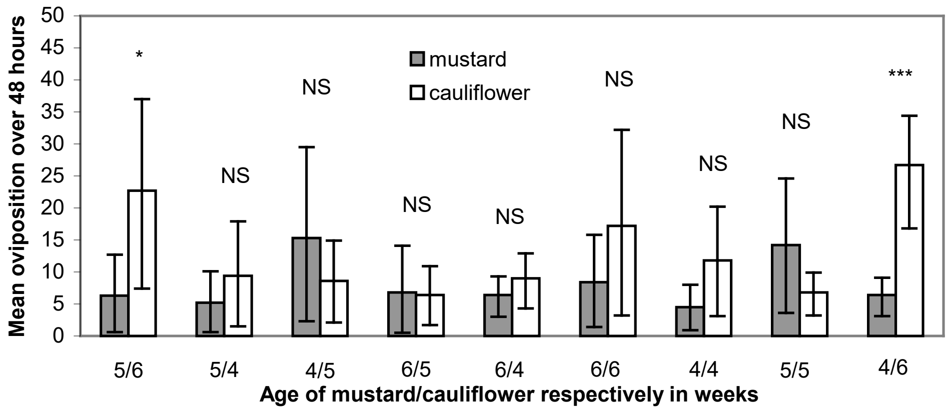



**Fig. 1b. Oviposition on plant pots**

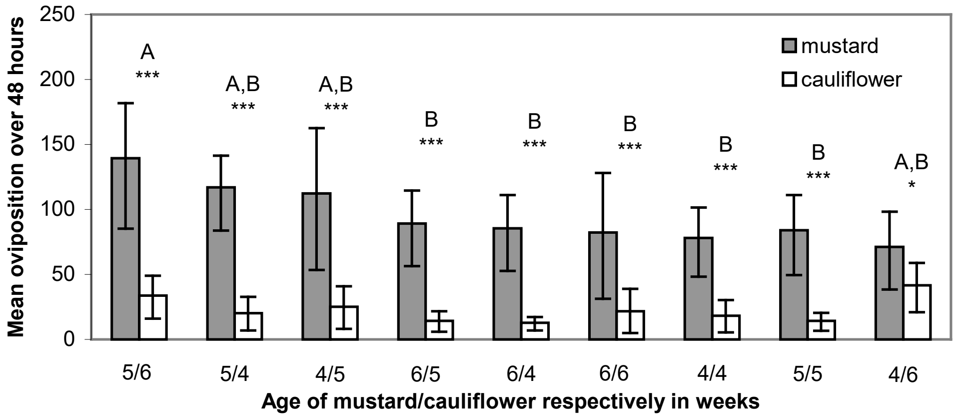



**Fig. 1c. Oviposition on plants and pots combined**

**Fig. 1. The mean number of eggs laid by diamondback moth on mustard and cauliflower plants of various ages (error bars show 95% confidence limits). All data are back-transformed from ANOVA. Treatments not sharing a common letter denote significant differences ($P$ < 0.05) between treatments in the total oviposition on both mustard and cauliflower plants.**

The total numbers of eggs laid differed significantly whether considering oviposition on plants or plants and pots combined ($F_{(8,64)} = 3.47$, $P < 0.01$ and $F_{(8,64)} = 3.29$, $P < 0.01$ respectively). In both the case of oviposition on plants and plants and pots combined, this was due to higher egg laying in the 5-week old mustard vs 6-week old cauliflower treatment, compared with most other treatments (Fig. 1a and c). Total oviposition on pots only did not differ significantly between treatments ($F_{(8,64)} = 2.05$, $P = 0.054$).

In all cases (eggs on plants, pots and the two combined), total oviposition was significantly affected by replicate run ($F_{(8,64)} = 6.44$, 3.87 and 6.57 where $P < 0.001$, in all cases). *Post hoc* testing found that for oviposition on plants, there was significantly lower egg laying during run 1, compared with runs 3 ($P < 0.05$), 4 ($P < 0.05$), 5 ($P < 0.05$), 6 ($P < 0.001$) and 9 ($P < 0.001$), and run 2, compared with runs 6 ($P < 0.05$) and 9 ($P < 0.001$). For counts on pots, significantly lower oviposition was found during run 1, compared with run 5 ($P < 0.01$), and run 3 compared with runs 5 ($P < 0.001$) and 8 ($P < 0.05$). For oviposition on plants and pots combined, oviposition was lower during run 1, compared with runs 4 ($P < 0.01$), 5 ($P < 0.001$), 6 ($P < 0.001$), 8 ($P < 0.05$) and 9 ($P < 0.001$), run 2, compared with runs 6 ($P < 0.05$) and 9 ($P < 0.05$) and run 3, compared with run 9 ($P < 0.05$).

When considering the percentage of eggs laid on the mustard plants, there was no significant difference between treatments ($F_{(8,64)} = 1.65$, $P = 0.128$) (Fig 2). The same was true of the percentage of eggs laid on the pots containing mustard plants ($F_{(8,64)} = 1.63$, $P = 0.133$) (Fig 2). However, when the percentage of eggs laid on mustard plants and pots combined was considered, there was a significant difference between treatments ($F_{(8,64)} = 2.67$, $P < 0.05$) (Fig 2). A lower percentage of eggs was laid on the mustard plant/pot complex in the 4-week old mustard vs 6-week old cauliflower treatment compared with the 5-week old mustard vs 5-week old cauliflower treatment, and all other treatments where the mustard was older than the cauliflower. In no case did replicate have an effect on these data.

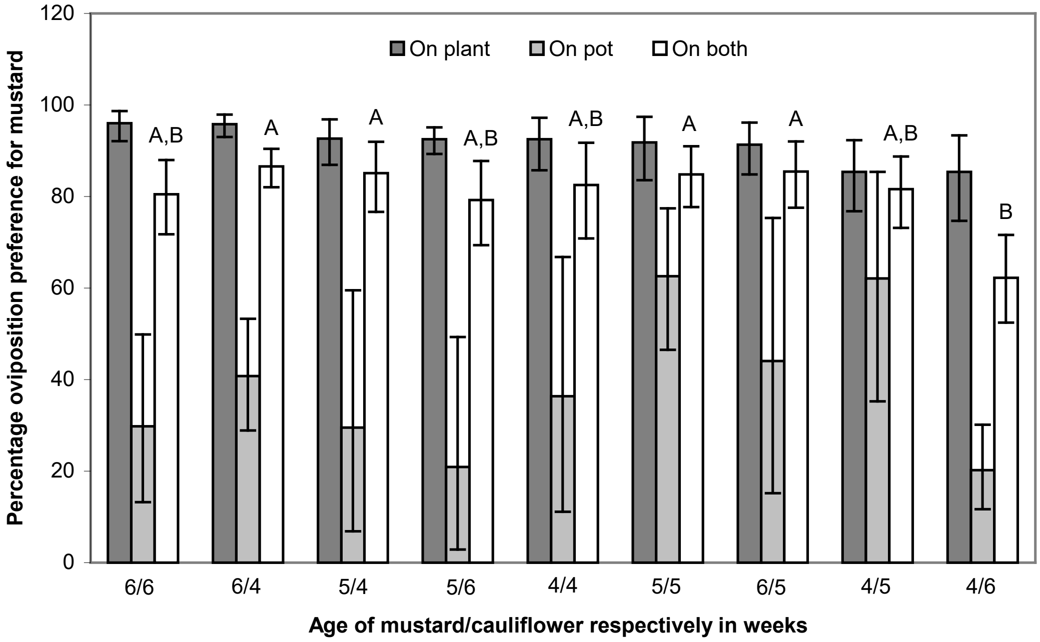



**Fig. 2. The percentage of eggs laid by diamondback moth on mustard plants of various ages presented together with cauliflower plants of various ages (error bars show 95% confidence limits). All data are back-transformed from ANOVA.**

Finally, the percentage of oviposition on the mustard plants was significantly and positively correlated with the percentage of the total within-cage plant height occupied by the mustard plants (combined height of the mustard plants divided by the combined height of all plants) ($R_{(81)} = 0.29$, $P < 0.01$). The same was true of the percentage oviposition on mustard plant pots with respect to leaf area ($R_{(81)} = 0.27$, $P < 0.05$) and percentage oviposition on mustard plants and pots combined with respect to all measured mustard plant variables (height; $R_{(81)} = 0.35$, $P < 0.001$, leaf area $R_{(81)} = 0.39$, $P < 0.001$, leaf number; $R_{(81)} = 0.316$, $P < 0.01$).

## EXPERIMENT 2. THE EFFECT OF TRAP PLANT SIZE, RELATIVE TO THE MAIN CROP, ON DIAMONDBACK MOTH PREFERENCE FOR WHITE MUSTARD OVER CAULIFLOWER.

*Objective*

To assess the importance of the relative sizes of the trap crop and main crop, in influencing pest preference for trap crop plants and oviposition on main crop plants.

*Materials and methods*

The method used in this choice experiment was similar to that used in Experiment 1. However, the cage was modified to allow the height of the white mustard plants to be altered, whilst keeping plant age constant (Fig 3) This modification involved cutting circular holes in the base of the cage to allow mustard plants to be lowered through the cage floor. Their height within the cage could then be varied. The cage stood on a wooden frame constructed to give support to the plants once they had been lowered through the cage floor. Once lowered through these holes, thin plywood base plates were fitted around the plant stems to seal the holes in the cage floor. Plant pots were then fitted around the lower portion of the plant that was protruding into the cage. Each of these pots was fitted with a cardboard support that rested on the lip of the pot and allowed for a thin layer of sieved compost to be placed on the support surface surrounding the plant stem, which protruded through the centre of the cardboard support. In this way all plants appeared to be potted in the cage when used.

Three treatments were used in total, using one replicate of each treatment in each of eight runs. Hence each treatment was replicated eight times. Plants were always 5-6 weeks old when tested. The height of the cauliflower plants was never manipulated. White mustard plants were used when larger than the cauliflower plants (normal size), or when their size within the cage was adjusted so that to the moths in the cage they appeared comparable to cauliflower plants in size, or smaller than cauliflower plants (see Appendix).

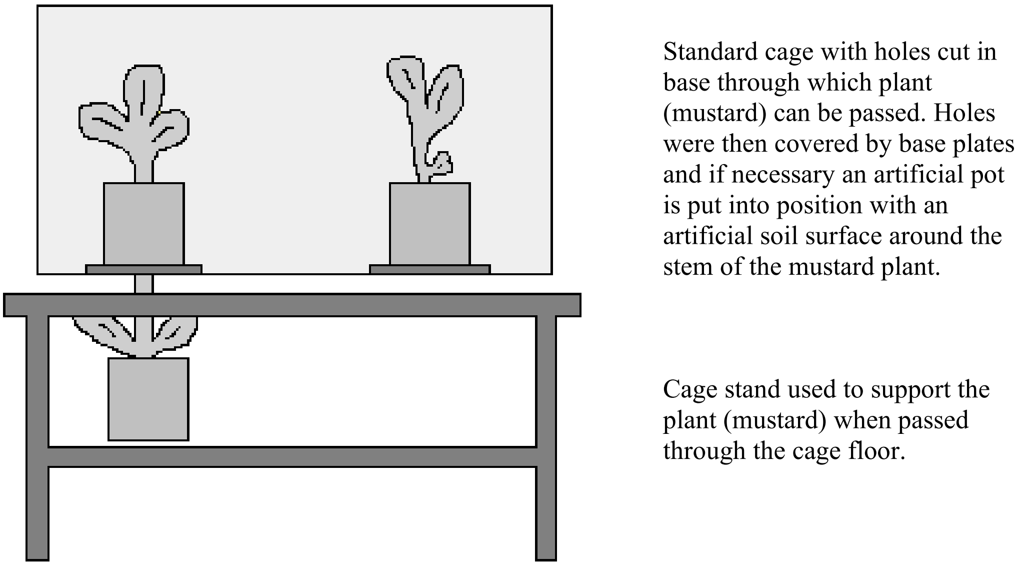


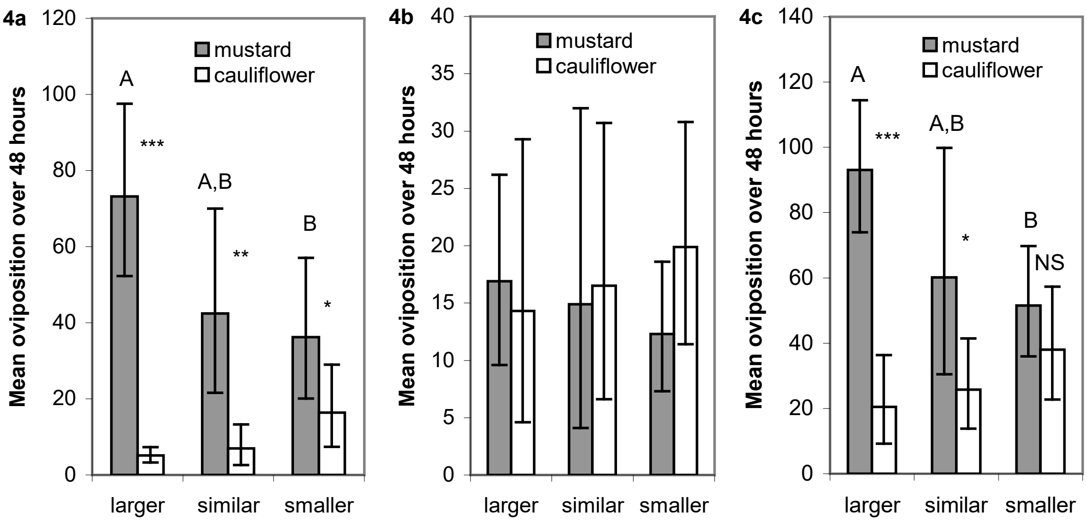

**Fig. 3. Diagram of the cage set-up used to manipulate the size of mustard plants in experiments.**

Data were analysed in the same manner as Experiment 1. Differences between oviposition on cauliflower and mustard plants between treatments were also assessed by 2-way ANOVA to consider the effect of both treatment and run.

*Results*

When considering the levels of oviposition on the cauliflower, there was a significant difference between treatments in the numbers of eggs laid on plants ($F_{(2,14)} = 3.82$, $P < 0.05$), but not on pots or plants and pots combined ($F_{(2,14)} = 0.25$ and 1.18, $P = 0.783$ and 0.335 respectively). Tukey tests could not identify any differences between the mean numbers of eggs laid on the cauliflower plants, although more eggs were clearly laid in the presence of the smallest mustard plants (Fig 4a). For oviposition on the mustard there were also significant differences between treatments with regard to the numbers of eggs laid on plants ($F_{(2,14)} = 5.48$, $P < 0.05$) and also eggs laid on plants and pots combined ($F_{(2,14)} = 4.66$, $P < 0.05$) (Fig 4a and 4c). In both cases this resulted from significantly higher oviposition on the largest mustard plants as compared to the smallest ($P < 0.05$ in both cases). Run had no affect on any of the oviposition data for cauliflower, but did so for oviposition on mustard plants and plants and pots combined ($F_{(7,14)} = 3.95$ and 4.66 respectively, $P < 0.05$ in both cases). For oviposition on mustard plants, this resulted from increased egg laying during run 4 as compared to runs 6 and 7 ($P < 0.05$ in both cases). For egg laying on the plants and pots, Tukey Tests were unable to identify any significant pair-wise differences between means.

In all treatments, diamondback moth females preferred to oviposit on the mustard plants rather than the cauliflower (Fig 4a). This preference was most pronounced when the mustard was larger than the cauliflower plants ($T_{(1,7)} = -8.14$, $P < 0.001$), but persisted when the mustard was similar in size to the cauliflower ($T_{(1,7)} = -4.69$, $P < 0.01$) and when it was smaller ($T_{(1,7)} = -2.66$, $P < 0.05$). For oviposition on the pots alone there was never a statistically significant difference in oviposition between mustard and cauliflower in any treatment ($T_{(1,7)} = -0.47$, 0.20 and 1.22 where $P = 0.654$, 0.845 and 0.263 respectively for mustard larger than, similar to and smaller than cauliflower respectively) (Fig 4b). When considering the combined data from plants and pots, mustard was still preferred for oviposition, but this was only statistically significant when mustard plants were larger or similar in size to co-presented cauliflower ($T_{(1,7)} = -6.17$, $P < 0.001$ and $T_{(1,7)} = -3.00$, $P < 0.05$, respectively). When mustard was smaller than cauliflower, there was no significant difference in oviposition on plants and pots combined between the two plant species ($T_{(1,7)} = -1.31$, $P = 0.232$) (Fig 4c). Neither was there any difference in the total eggs laid per treatment between treatments for any measured oviposition response (i.e. eggs on plants, pots and the two combined were respectively $F_{(2,14)} = 1.48$, 0.08 and 0.58 and $P = 0.262$, 0.923 and 0.571). Furthermore, these data were unaffected by replicate ($F_{(7,14)} = 2.45$, 0.70 and 1.36 where $P = 0.072$, 0.671 and 0.295 for eggs on plants, pots and the two combined respectively).




**Relative size of mustard as compared to cauliflower**

**Fig. 4. The mean number of eggs laid by diamondback moth on mustard and cauliflower a). plants, b). plant pots and c). plants and pots combined, of various relative sizes (error bars show 95% confidence limits). All data are back-transformed from ANOVA.**

There was a significant difference between treatments in the percentage of the total eggs laid on the mustard plants ($F_{(2,14)} = 6.43$, $P < 0.01$) (Fig 5). A higher percentage of eggs were laid on mustard plants that were larger than cauliflower compared with mustard plants that were smaller ($P < 0.01$). There was no significant difference between treatments in the percentage of eggs laid on plant pots ($F_{(2,14)} = 1.02$, $P = 0.385$) (Fig 5). When data from plants and pots were combined, however, the percentage of eggs laid on mustard differed between treatments ($F_{(2,14)} = 7.67$, $P < 0.01$), again because a higher percentage of eggs was laid on the mustard that were larger than cauliflower, compared with mustard that were smaller ($P < 0.01$) (Fig 5). Replicate did not influence the numbers of eggs laid on plants or pots alone ($F_{(7,14)} = 1.36$ and 1.54 where $P = 0.294$ and 0.232 respectively), but did so when the two were combined for analysis ($F_{(7,14)} = 2.77$, $P < 0.05$). This resulted from a higher preference for the mustard in replicate 7 compared with 4 ($P < 0.05$).

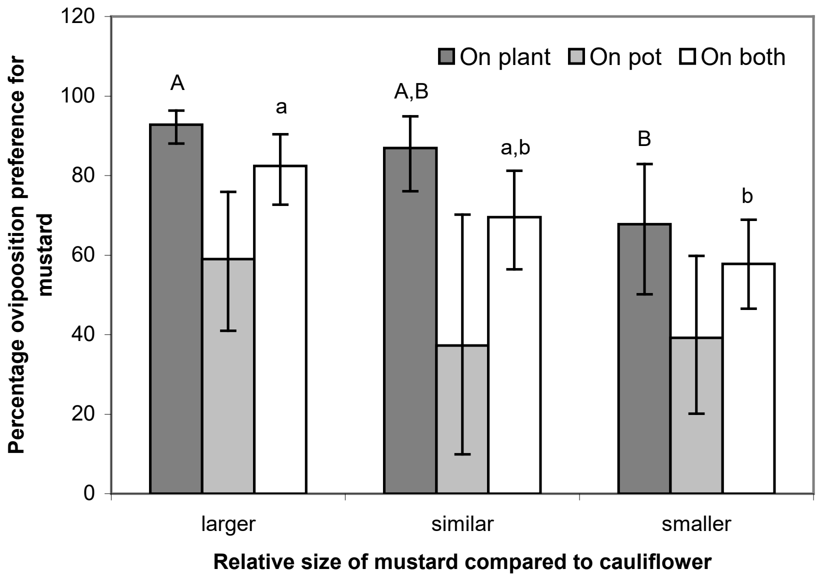



**Fig. 5. The percentage oviposition preference of diamondback moth for varying sizes of mustard over a constant size of cauliflower (error bars show 95% confidence limits). All data are back-transformed from ANOVA.**

Using correlation analysis it was found that the percentage of eggs laid on mustard plants in all treatments was positively and significantly correlated with the percentage of the within-cage height, leaf number and leaf area occupied by the mustard ($R_{(24)}$ = 0.557, 0.467 and 0.571 where $P < 0.01$, 0.05 and 0.01 respectively). Oviposition preference for the pots containing the mustard plants was not correlated with any of these plant parameters ($R_{(24)}$ = 0.362, 0.300 and 0.286 where $P = 0.082$, 0.154 and 0.176 respectively for plant height, leaf number and leaf area). When oviposition on the plants and pots was combined, however, all measured plant parameters were again positively and significantly correlated with oviposition preference for mustard (percentage of total within-cage plant height, leaf number and leaf area vs percentage oviposition preference for mustard plants and pots combined; $R_{(24)}$ = 0.581, 0.425 and 0.462 where $P < 0.01$, 0.05 and 0.05 respectively).

## EXPERIMENT 3. THE EFFECT OF SEPARATING TRAP CROPS AND MAIN CROPS ON PEST CONTROL.

*Objective*

The objective of this experiment was to determine whether trap crop effectiveness (in protecting main crop plants from pest attack) could be enhanced by separating trap and main crop plants by distances of up to 6 m.

*Materials and methods*

This experiment was done using long cages (tunnels) covered in fine mesh netting to model a 'slice' through a trap crop system as it would typically be used in the field. The same technique was used to study both diamondback moth and flea beetles.

*Diamondback moth*

Moths and plants were reared/grown as described for Experiment 1 and insects and plants of similar age to those used in previous experiments were tested (i.e. 1-3 day old moths and 5-6 week old plants).

The experiments were done between 18 April and 19 May 2005 in tunnels erected within a greenhouse at Close House Field Station, Heddon-on-the-Wall, Northumberland. Within this greenhouse, climatic conditions could be partially controlled, so that the minimum temperature was 10ºC and the maximum temperature approximately 30ºC.

Within the greenhouse, three fine mesh netting tunnels were erected on each of three metal benches (87 cm high and measuring 8.5 x 0.92 m). The walls and ceilings of these cages were of 'Enviromesh®' ('Ultrafine' from Agralan), whereas the floor of each cage comprised the bench surface covered with brown/grey shingle. Each cage measured 92 x 80 cm and was 8.5 m in length and supported by nine equidistant 15 mm diameter bamboo canes along each side of the cage (fixed to the bench legs). The netting was fixed to these canes using electrical cable ties. Along both ends and one side of each cage, the netting was covered with shingle to seal the tunnel. On the other side of each cage, the netting was fixed to the floor of the bench using clothes pegs, to allow access to the cage interior.

To vary the distance between the trap and main crop plants, six trap crop plants (white mustard) were placed in two grey gravel trays (24 x 37 cm x 5 cm deep), three per tray, these trays being placed side by side filling the width of the cage at varying distances from six main crop plants (cauliflower) arranged in the same way. For any run of the experiment, one cage housed a control treatment (trap and main crop plant trays adjacent), one cage housed a treatment where main crop plant trays were separated from the trap crop plant trays by 3 m, and the final cage contained main crop plant trays located 6m from the trap crop plant trays.

In each cage, a space of 1 m was left at the front of the cage (in front of the trap crop plants) and 1 m was left at the end of the cage (behind the main crop plants). The space at the front of the cage was left to allow moths to settle when placed into the cage. At the rear of the cage a large (50 x 50 cm) Perspex sheet coated on both sides with 'Tangle Trap' (from 'The Tanglefoot Company', USA) was erected to capture moths that had travelled to the far end of the tunnel, thus minimising of the number of moths that flew back onto the nearby cauliflower plants. Treatments were allocated to cages at random and the arrangement of plants within the cage was always rotated by 180º between one run of the experiment and the next. Eight runs were conducted, so that each treatment was tested eight times.

Thirty moths (1:1 sex ratio) were used in each run of the experiment and each run lasted 48 hours, after which oviposition on all plants was recorded. Moths were released in the front of the cage (the end not containing the sticky trap) by opening the 20 ml plastic 'Sterilin' tube in which they had been transported to the study site. Moths were then left to disperse unaided. Moths were always released between 1200 and 1400 hours. The plants remained in their pots during the experiment and oviposition on the pots was recorded as previously. The moths were not provided with food during experiments as this might have influenced their movement within the cage. The plants were watered at the onset of any experiment by filling the gravel trays with approximately 3 cm of water. To stop moths from drowning in the gravel trays, approximately 1.25 L of 'Hydroleca' (from Silvaperl) was added to each tray.

At the end of any experimental run, plant growth parameters (height, leaf number and leaf area) were measured, although leaf area was only assessed for every other run, due to time constraints. As previously, the mustard plants were larger than cauliflower plants when used (see Appendix).

*Flea beetles*

The experiments with flea beetles were done in a walled garden at Close House between the 1-14 June 2005 (to coincide with the emergence of the first generation of beetles). All plants were 5-6 weeks old when used and put out into the field from 1500 hours onwards.

The experiment was similar to the experiment with diamondback moth, except that 10 replicates were run concurrently. Cages were arranged in a randomised design, with the position of any treatment being allocated at random in each repeated set of three different treatments. Two sets of five replicates were aligned in opposite directions (Fig 6). As in the experiments with the moths, the plants remained in their pots during the study period and these were placed into gravel trays containing 'Hydroleca' and maintained under conditions of continuous water availability. Six previously identified trap crop plants (Turnip rape (*Brassica rapa*; Pasja), see Annual Report, year one), and six cauliflower (main crop) plants were used per cage as in the experiment with the moths. Unlike the moth experiment, the six trap crop or cauliflower plants were placed in a single tray (in two lines of three plants spaced equidistantly). The cages were constructed from the same 'Environmesh' as previously used with the moths, supported by bamboo canes to which the mesh was secured using electrical cable ties. The cages differed in length according to treatment, being 1 m longer than the treatment they contained (i.e. 1 m for the 0 m treatment, 4 m for the 3 m treatment and 7 m for the 6m treatment). All cages were 1 m high by 60 cm wide and open to the front to allow flea beetle access. Cages were closed to the rear, where a water trap was placed (24 x 37 cm x 5 cm deep) to minimise the number of beetles that returned through the cage. The water traps were approximately 50 cm away from the cauliflower plants at the rear of the cage. All cages were 50 cm apart and the whole plot was surrounded by a buffer of at least two rows of potato plants.

Plants were monitored for damage (feeding holes) every few days. When a measurable level of damage was attained, plants were brought in from the field and stored at 5ºC until the damage could be assessed in the laboratory.

Weather conditions (average (with standard errors) maximum and minimum daily temperatures (ºC) and average daily rainfall (mm) respectively) were as follows; $15.07 \pm 0.82$, $8.00 \pm 0.67$ and $1.36 \pm 0.51$. Exactly half of the study days were totally rain free.

At the end of the experiment, plant growth parameters (height, leaf number and leaf area) of a randomly selected turnip rape or cauliflower plant from each replicate (of each treatment) were measured. As previously, the trap crop plants were larger than cauliflower plants when used (see Appendix).

Data from trap crop and cauliflower plants were grouped per replicate for moth and flea beetle experiments. Paired t-tests were used to assess oviposition (data square root transformed) or feeding preference (data log transformed) within treatments, for diamondback moth and flea beetles respectively.

ANOVA was used to compare the extent of oviposition and feeding damage on the cauliflower plants between treatments (on square root and log transformed data respectively), and on the mustard plants between treatments (again on square root and log transformed data respectively). For diamondback moth a 2-way analysis was done to assess the effect of run as well as treatment. For flea beetles a 3-way analysis was used to look for the effect of cage aspect and row as well as treatment. The same analyses were used to look for differences between total within-cage oviposition or feeding damage. Diamondback moth total oviposition data were square root transformed prior to this analysis but the flea beetle feeding-hole data were not transformed. The percentage preference of both pests for the trap plants was also compared across treatments in the same way. All data were arcsine square root transformed prior to this analysis. As previously, diamondback moth oviposition on plants, plant pots and the two combined was considered in all analyses. Where ANOVA identified statistically significant differences between means, the Tukey Test was used to identify differences between pairs of means.

Where transformed data were used for analysis, these data are back-transformed when displayed.

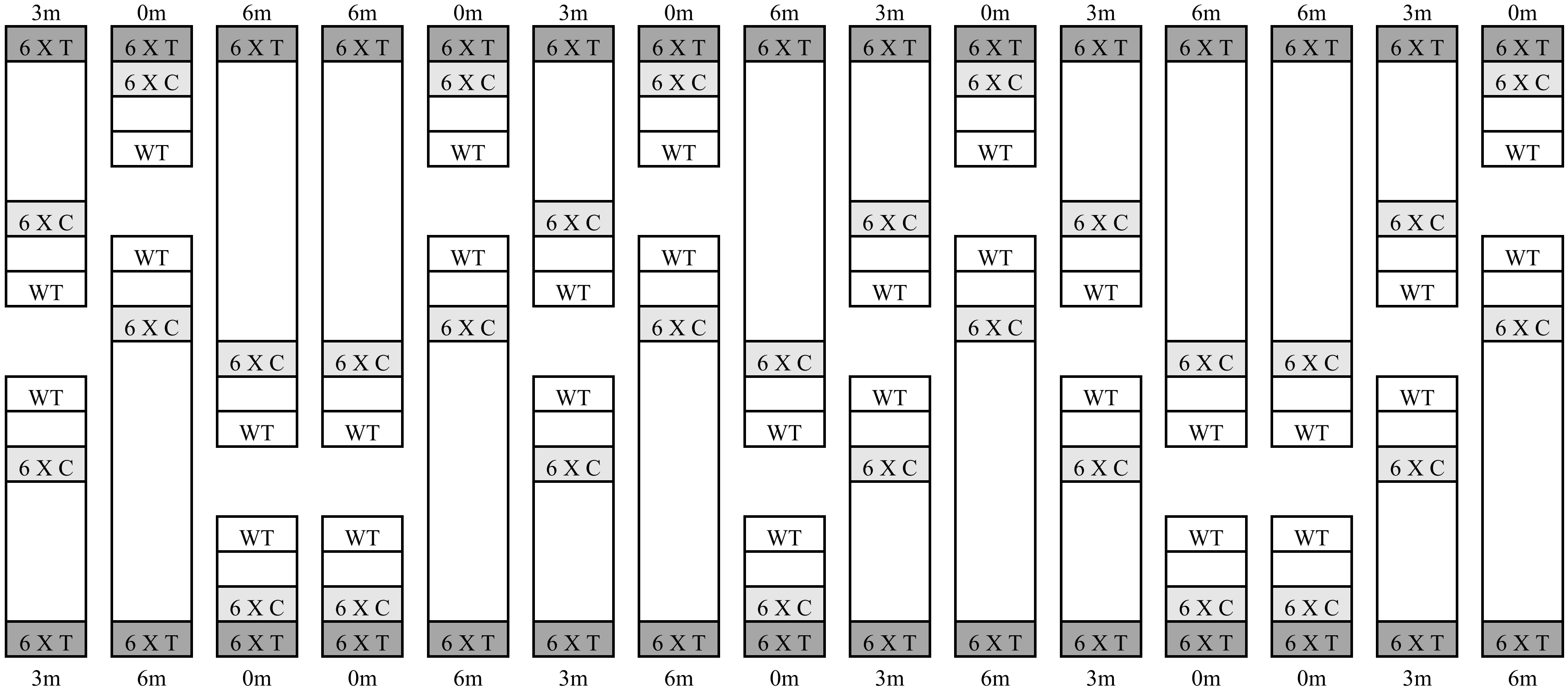



**Fig. 6. Layout of flea beetle trap crop distance experiment. T = trap crop plant, C = cauliflower plant, WT = water trap, χm = treatment.**

*Results*

*Diamondback moth*

When considering the number of eggs laid on the cauliflower plants, there was a significant difference between treatments for counts on plants (Fig 7a) and plants and pots combined (Fig 7c) ($F_{(2,14)} = 5.98$, $P < 0.05$ and $F_{(2,14)} = 6.64$, $P < 0.01$, respectively). In both cases this resulted from higher egg loads on the cauliflower in the 0 m separation treatment than both the 3 and 6 m separation treatments ($P < 0.05$ in all cases). There were no other differences between pairs of means. Run did not affect the data from plants alone, but did so when this was combined with counts from pots ($F_{(7,14)} = 5.93$, $P < 0.01$). This resulted from levels of oviposition that were higher during runs 1 and 2 than runs 3, 7 and 8 ($P < 0.05$ in all cases). For eggs on the mustard, there was no significant difference between treatments for eggs on plants, pots or the two combined ($F_{(2,14)} = 0.77$, 0.55 and 0.89, $P = 0.483$, 0.589 and 0.431 respectively) (Fig 7). Run influenced the data for oviposition on mustard plants ($F_{(7,14)} = 5.63$, $P < 0.01$) and plants and pots combined ($F_{(7,14)} = 5.39$, $P < 0.01$). In both cases this was due to lower levels of oviposition during run 3 as compared to runs 5 and 7 ($P < 0.05$ in all cases, except for eggs on plants and pots, run 3 vs run 5, where $P < 0.01$).

In all treatments, significantly more eggs were laid on the mustard plants than on the cauliflower plants ($T_{(1,7)} = 9.64$, 7.31 and 9.61, $P < 0.001$, (for all) for 0 m, 3 m and 6 m treatments respectively) (Fig 7a). There was no significant difference between the numbers of eggs laid on the mustard and cauliflower pots within any treatment ($T_{(1,7)} = -1.95$, 0.73 and 0.34, $P = 0.093$, 0.487 and 0.745 for 0 m, 3 m and 6 m treatments respectively) (Fig 7b). When oviposition data from pots were combined with oviposition on plants, the mustard plant/pot complex was significantly preferred over that of the cauliflower in all treatments ($T_{(1,7)} = 9.72$, 5.69 and 8.15, $P < 0.001$, (for all) for 0 m, 3 m and 6 m treatments respectively) (Fig 7c).

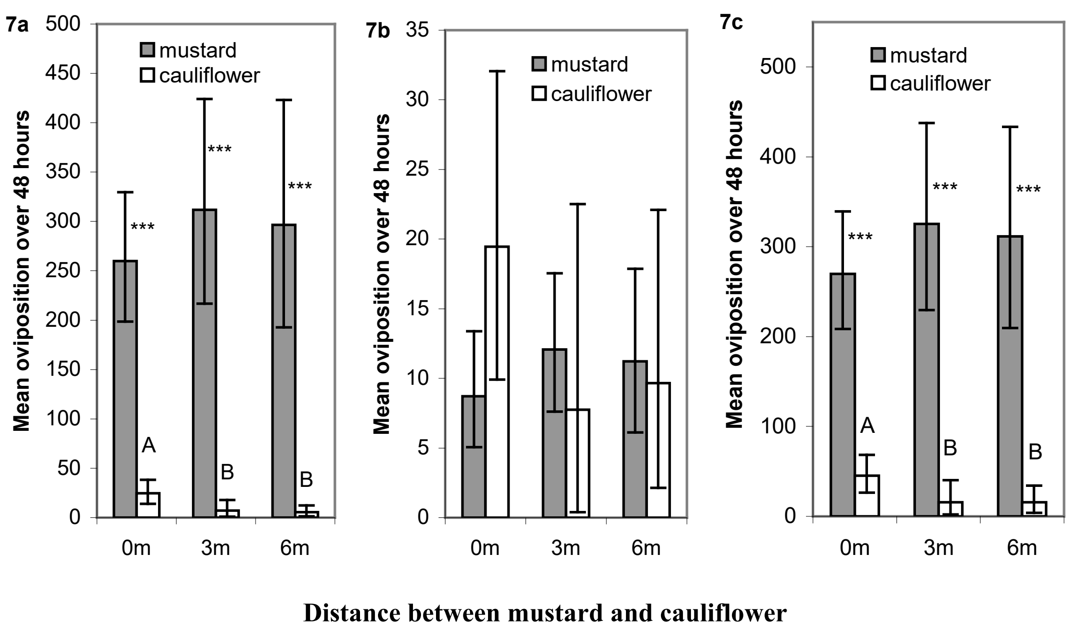



**Figure 7. Number of diamondback moth eggs on cauliflower a). plants, b). pots and c). plants and pots combined, separated from mustard trap crop plants by varying distances (error bars show 95% confidence limits). All data are back-transformed from ANOVA.**

There was a significant difference in the percentage of oviposition that occurred on the mustard plants between treatments (Fig 8). For oviposition on plants and plants and pots combined this difference was most pronounced ($F_{(2,14)} = 6.32$ and 5.48, where $P < 0.05$ for both). In both cases this result occurred due to significantly higher percentages of eggs laid on the mustard plants in the 3 m and 6 m separation treatments, as compared to those laid on mustard in the 0 m separation treatment ($P <$ 0.05 in all cases). Experimental run had a significant effect on the data in both the case of percentage oviposition on mustard plants ($F_{(7,14)} = 2.99$, $P < 0.05$) and mustard plants and pots combined ($F_{(7,14)} = 5.77$, $P < 0.05$). In the case of both data from plants and the combined plant/pot complex, higher levels of preference for the mustard were observed in run 1 as compared to run 7 ($P < 0.05$ and 0.01 respectively), and in the case of oviposition on plants and pots combined preference for mustard was also greater in run 1 than runs 3 and 8 ($P < 0.01$ in both cases). There was also a difference in the data between treatments when considering oviposition on plant pots alone ($F_{(2,14)} = 4.08$, $P < 0.05$). This was probably due to similar pair-wise differences, as for oviposition on plants or the plant/pot complex, although no significant differences between pairs of means could be identified through Tukey Testing. These data were not affected by experimental run ($F_{(7,14)} = 2.40$, $P = 0.077$).

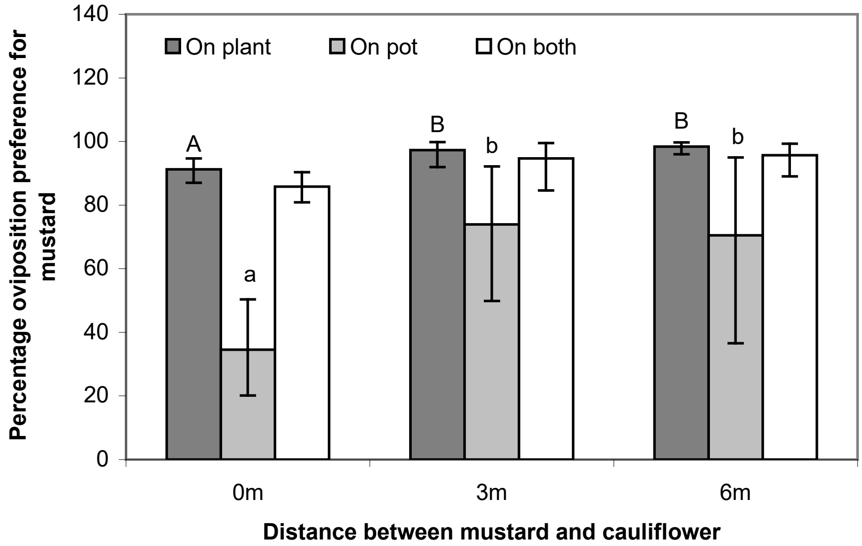



**Fig. 8. The percentage oviposition preference of diamondback moth for mustard positioned at varying distances from cauliflower (error bars show 95% confidence limits). All data are back-transformed from ANOVA.**

When considering the total egg laying that occurred in the cages, there was no difference between treatments for egg laying on plants ($F_{(2,14)} = 0.36$, $P = 0.705$), pots ($F_{(2,14)} = 0.78$, $P = 0.477$), or the two combined ($F_{(2,14)} = 0.38$, $P = 0.693$). Experimental run did significantly affect these data in all cases ($F_{(7,14)} = 4.85$, 6.78 and 4.84 where $P < 0.01$, 0.001 and 0.01 for total oviposition on plants, pots and the two combined respectively). Pair-wise differences are shown in Table 4.

| OVIPOSITION MEDIA | RUN COMPARISON | P-VALUE |
|---|---|---|
| PLANT | 1 vs 5 & 7 | < 0.05 & 0.05 |
| | 3 vs 5 & 7 | < 0.01 & 0.05 |
| POT | 3, 6, 7 & 8 vs 1 | < 0.01, 0.05, 0.01 & 0.05 |
| | 3 vs 2, 7 & 8 | < 0.01, 0.05 & 0.05 |
| PLANT AND POT COMBINED | 1 vs 5 | < 0.05 |
| | 3 vs 5 & 7 | < 0.01 & 0.05 |

**Table 4. *P*-values for runs in which significantly greater total oviposition occurred on plants, pots and the two combined. The run in which the greater oviposition occurred is presented first in the 'run comparison'.**

*Flea beetles*

There was a significant difference between treatments in the number of feeding holes in the cauliflower ($F_{(2,22)} = 17.60$, $P < 0.001$) (Fig. 9). More holes were found in cauliflower adjacent to the trap crop plants than 3 or 6 m away from them ($P < 0.01$ and 0.001 respectively). There were also more holes in cauliflower 3 m away from the trap crop plants than cauliflower 6 m away from the trap crop plants ($P < 0.05$). Neither cage aspect nor row influenced these data. There was no significant difference in the number of holes in the turnip rape between treatments ($F_{(2,22)} = 0.56$, $P = 0.576$). Aspect had no effect on these data, although row did ($F_{(2,22)} = 3.40$, $P < 0.05$) where the only significant difference between pairs of means came from feeding levels being higher in row 1 as compared to row 5 ($P < 0.05$).

In all treatments (0 m, 3 m and 6 m separation between trap and cauliflower plants), more holes were found in the turnip rape trap plants than the protected cauliflower ($T_{(1,9)} = 14.86$, 33.34 and 17.54 respectively where $P < 0.001$ in all cases) (Fig 9).

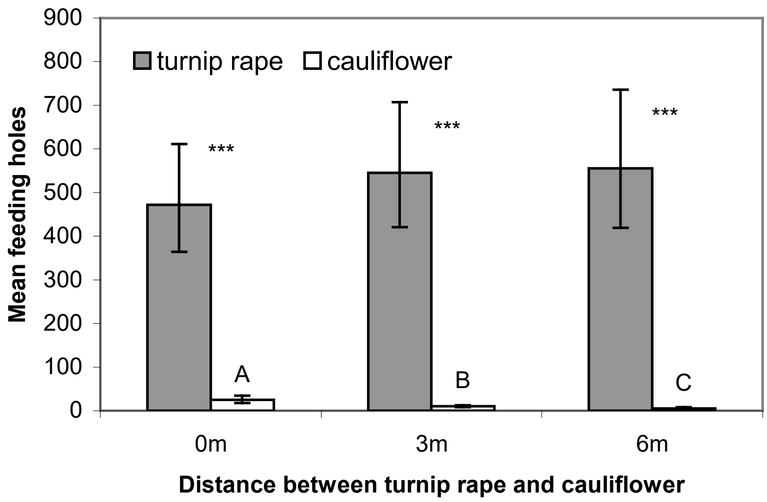



**Fig. 9. Number of flea beetle feeding holes on cauliflower and trap crop plants separated by varying distances (error bars show 95% confidence limits). All data are back-transformed from ANOVA.**

There was no significant difference between treatments regarding the total number of feeding holes in the rape and cauliflower plants combined ($F_{(2,22)} = 0.36$, $P = 0.704$). Cage aspect did not significantly affect these data although row did ($F_{(4,22)} = 2.90$, $P < 0.05$). Tukey tests could not identify any significant differences between pairs of means although feeding appeared higher in rows 1 and 3 as compared to row 5.

There was a highly significant difference between treatments in the percentage of feeding holes found in the turnip rape trap plants ($F_{(2,22)} = 16.88$, $P < 0.001$) (Fig 10). This was found to result from significantly lower percentage feeding on trap plants in the 0 m separation treatment as compared to in the 3 m ($P < 0.001$) and 6 m ($P < 0.001$) treatments. Neither aspect nor row significantly affected these data.

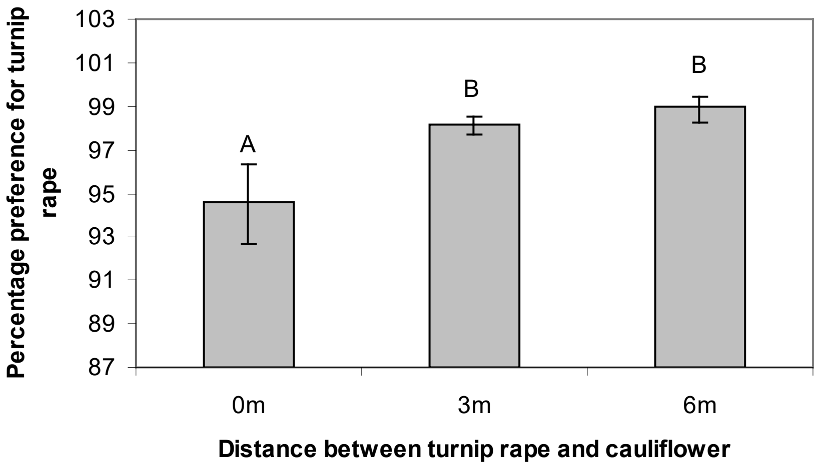



**Fig. 10. The percentage feeding preference of flea beetles for turnip rape positioned at varying distances from cauliflower (error bars show 95% confidence limits). All data are back-transformed from ANOVA. NB: y-axis shown starts at 87% and not 0% to make presentation of the results clearer.**

## EXPERIMENT 4. TRAP CROP EFFECTIVENESS IN PEST CONTROL.

*Objective*

The objective of this experiment was to determine whether the trap crops used in Experiment 3 offered any protection to the main crop plants compared with using no trap crop at all or a buffer zone of main crop plants.

*Materials and methods*

This experiment was done using the same cages as Experiment 3. The same technique was used to study diamondback moth and flea beetles.

*Diamondback moth*

This experiment was conducted in the same cages used for moths in Experiment 3 under similar greenhouse conditions between 25 Oct and 24 Nov 2005. Plants were positioned in gravel trays and watered in the same way as for Experiment 3, but different treatments were used. The three treatments consisted of; (i) six trap crop and six adjacent cauliflower plants, (ii) twelve cauliflower plants (in two adjacent blocks of six plants each) and (iii) six cauliflower plants (Fig 11). These treatments were positioned in the centre of the cage. Treatments were allocated to cages at random and the arrangement of plants within the cage was always rotated by 180º between one run of the experiment and the next. Eight runs were conducted, so that each treatment was tested eight times. Moths were released at the front of the cage (the end nearest to the trap crop plants) and at the rear, the same Perspex trap as used previously was positioned.

Once again, thirty moths were used in each run of the experiment and oviposition on plants and pots was assessed for all plants after 48 hours. Moths were released in the same way as in the previous experiment and at the same time of day.

Plant growth parameters (height, leaf number and leaf area) were assessed for all plants after runs 2, 4 and 6. These data are given in the Appendix where it is shown that the mustard was larger than cauliflower when used.

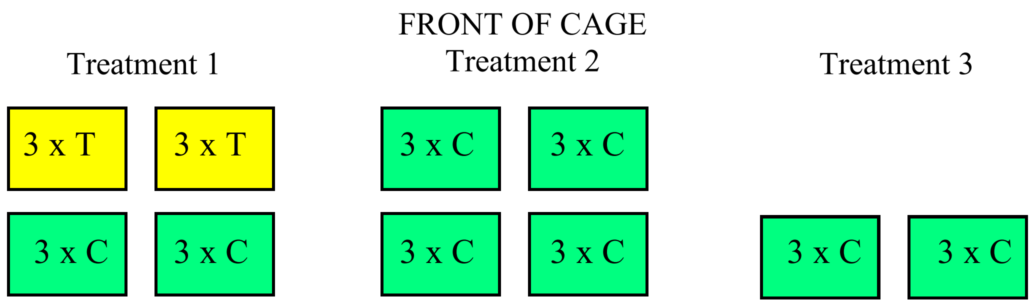



**Fig. 11. Treatments used to test effectiveness of trap crops with Diamondback moth. T = trap crop plant, C = cauliflower plant. Each rectangle represents a gravel tray. For the flea beetle experiment only one gravel tray was used, instead of two, to house six cauliflower or trap crop plants.**

*Flea beetles*

The experiment on the effectiveness of trap crops with flea beetles was conducted at the same field site as Experiment 3 and using the same cages, but with all cages reduced to 1 m in length. The experiment ran from 3-10 Aug 2005 (to coincide with the emergence of the second, over-wintering generation of beetles. The same treatments as in the experiment with diamondback moth were used (Fig 11), although any set of six trap crop or cauliflower plants were positioned in a single gravel tray. Cages were again open at the front end and closed at the rear where a water trap was placed. Cages remained 50 cm apart and the plot was still surrounded by a buffer zone of at least two rows of potatoes during the experiment. Treatments were positioned at random as with the flea beetle trap crop distance experiment. All plants were put out into the field from 15:00 hours onwards.

Plants were watered as needed and monitored every few days to assess flea beetle damage. Once a measurable level of damage was observed, plants were retrieved from the field and stored at 5ºC. Flea beetle feeding holes in all plants could then be assessed in the laboratory where measurements of plant height, leaf number and leaf area were also made.

Weather conditions (average (with standard errors) maximum and minimum daily temperatures (ºC) and average daily rainfall (mm) respectively) were as follows; 17.13 ± 1.38, 9.63 ± 0.78 and 1.38 ± 0.63. Exactly half of the study days were totally rain free.

At the end of the experiment, plant growth parameters (height, leaf number and leaf area) were measured for a single randomly chosen turnip rape and cauliflower plant from each replicate of all treatments. These data are given in the Appendix where it is shown that the turnip rape was larger than cauliflower when used.

Data from trap crop and 'external' and 'internal' cauliflower plants were grouped per replicate for moth and flea beetle data. 'External' plants were those that were protecting other plants, (nearest the front of the cage). 'Internal' plants were those being protected, (further towards the rear of the cage, including the cauliflower treatment with no external plants). Paired t-tests were used to assess oviposition or feeding preference within treatments where external and internal plants could be compared. In all cases data were square root transformed for this analysis.

ANOVA was used to compare feeding on turnip rape or oviposition on mustard to that on external cauliflower. As previously, 3-way ANOVA was used on flea beetle data and 2-way ANOVA on the moth data (to look for differences in the same variables). Data were square root transformed in both cases. This same analysis was done to investigate differences between treatments in the number of feeding holes or eggs found on the internal cauliflower. Again data were square root transformed in both cases prior to this analysis. Where ANOVA identified statistically significant differences between means, the Tukey Test was used to identify differences between pairs of means.

As previously, diamondback moth oviposition on plants, plant pots and the two combined was analysed.

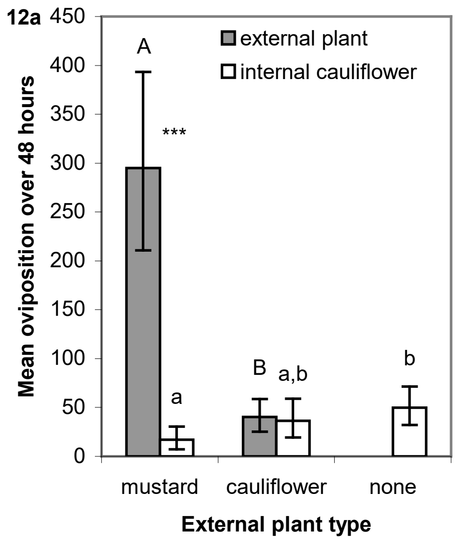
Where transformed data were used for analysis, these data are back-transformed when displayed.

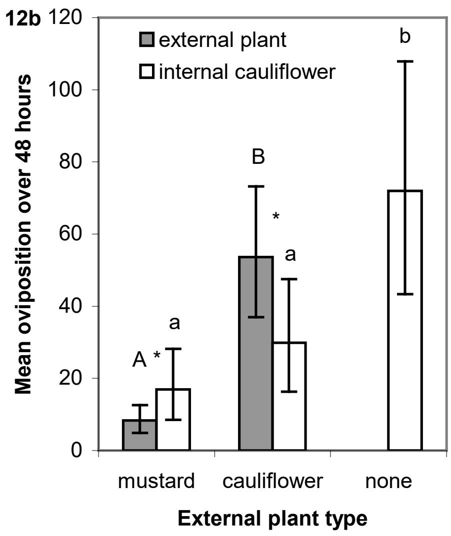
*Results*

*Diamondback moth*

There was a significant difference between treatments in the numbers of eggs laid on the internal cauliflower plants ($F_{(2,14)} = 5.88$, $P < 0.05$) (Fig 12a). More eggs were laid on internal plants protected by no external trap or cauliflower plants compared to those protected by mustard plants as a trap crop ($P < 0.05$). Tukey testing found no other differences between pairs of means, including the numbers of feeding holes in internal cauliflower protected by an external trap crop (mustard) or external cauliflower plants ($P = 0.485$). Experimental run had no significant effect on the data ($F_{(7,14)} = 2.52$, $P = 0.067$). There was also a difference between treatments when considering eggs laid on the pots of the internal cauliflower ($F_{(2,14)} = 10.595$, $P < 0.01$) (Fig 12b). More eggs were laid on these pots when mustard was present compared to when no external plants were used ($P < 0.001$), and fewer eggs were laid on the pots of internal cauliflower when no external cauliflower plants were present as compared to when they were ($P < 0.05$). Run had no effect on these data ($F_{(7,14)} = 1.89$, $P = 0.148$). When egg counts on plants and pots were combined, there remained a significance difference between treatments ($F_{(2,14)} = 8.19$, $P < 0.01$) (Fig 12c), again caused by higher oviposition on the internal cauliflower presented with no external plants as compared to when protected by mustard trap crop plants ($P < 0.01$). There were again no other pair-wise differences between treatments, including where the external mustard plant treatment was compared to the external cauliflower treatment ($P = 0.231$). Run did not influence the data ($F_{(7,14)} = 1.60$, $P = 0.214$).



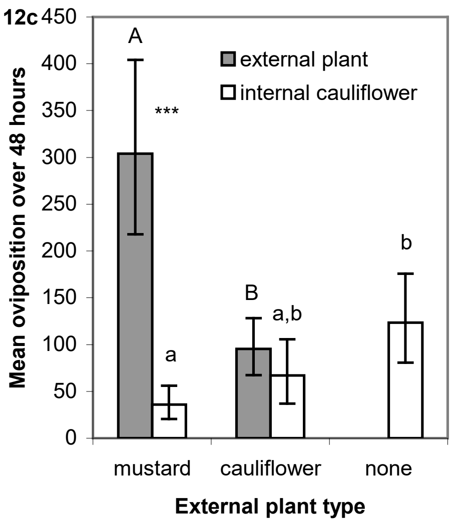




**Figure 12. Number of diamondback moth eggs on cauliflower a). plants, b). pots and c). plants and pots combined surrounded by different external plant barrier types (error bars show 95% confidence limits). All data are back-transformed from ANOVA.**

When comparing the two treatments with external plants, external mustard plants attracted higher levels of moth oviposition than the internal cauliflower they were protecting ($T_{(1,7)}$ = 10.71, $P$ < 0.001), but external cauliflower plants did not ($T_{(1,7)}$ = 0.46, $P$ = 0.660) (Fig 12a). For data on plant pots, fewer eggs were laid on the pots of mustard than those of the cauliflower they were protecting ($T_{(1,7)}$ = -2.65, $P$ < 0.05), with the opposite being true of the external cauliflower treatment, where fewer eggs were laid on the pots of the internal plants ($T_{(1,7)}$ = 2.42, $P$ < 0.05) (Fig 12b). When plant and pot data were combined, there was no difference between the numbers of eggs laid on external and internal cauliflower for the double cauliflower treatment, although more eggs were still laid on the mustard compared to the cauliflower in the trap crop treatment ($T_{(1,7)}$ = 9.69, $P$ < 0.001) (Fig 12c). As expected, more eggs were recovered from external mustard plants than external cauliflower plants ($F_{(1,7)}$ = 92.67, $P < 0.001$) (Fig 12a) and plants and pots combined ($F_{(1,7)}$ = 43.51, $P < 0.001$) (Fig 12c), although the opposite was true for data on pots ($F_{(1,7)}$ = 40.00, $P < 0.001$) (Fig 12b). Run did not affect these data in any instance.

*Flea beetles*

There was a significant difference between treatments in the number of flea beetle holes in the leaves of the internal cauliflower plants ($F_{(2,22)}$ = 5.21, $P < 0.05$) (Fig 13). More holes were present in internal plants protected by no external plants as compared to those protected by turnip rape plants as a trap crop ($P < 0.05$). As with the moths, there were no other differences between treatment means, including between cauliflower protected by a turnip rape trap crop and that protected by external cauliflower ($P = 0.103$). Both cage aspect and row had significant effects on the data ($F_{(1,22)}$ = 5.14, $P < 0.05$ and $F_{(4,22)}$ = 5.62, $P < 0.01$ respectively). Greater levels of feeding were observed in cages that faced east, out onto the bulk of the walled garden as opposed to those that faced west, out onto a smaller area of garden bordered by a conifer hedge. Greater levels of feeding were also observed in row 2 ($P < 0.01$) and row 4 ($P < 0.01$) as compared to row 1.

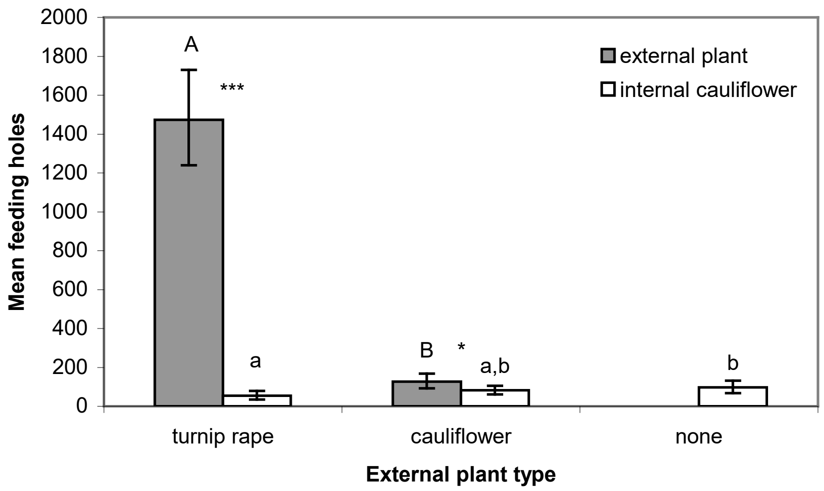



**Figure 13. Number of flea beetle feeding holes in cauliflower plants and the different external 'trap crop' types used to protect them (error bars show 95% confidence limits). All data are back-transformed from ANOVA.**

When comparing the two treatments with external plants, both external turnip rape plants and external cauliflower plants attracted higher levels of flea beetle feeding than the internal cauliflower they were protecting ($T_{(1,9)}$ = 27.38 and 2.63 where $P < 0.001$ and 0.05 respectively) (Fig 13). Nevertheless, there was a significant difference between absolute number of feeding holes in turnip rape as compared to those in external cauliflower plants ($F_{(1,13)} = 362.84$, $P < 0.001$) (Fig 13). More holes were found in the rape. Aspect did not significantly effect these data although row did ($F_{(4,13)} = 4.16$, $P < 0.05$), with higher levels of feeding damage in row 4 as compared to row 1 ($P < 0.05$).

## EXPERIMENT 5. THE POTENTIAL OF TRAP CROPPING, COMPANION PLANTING AND A COMBINATION OF THE TWO, IN REDUCING PEST DAMAGE ON ASSOCIATED MAIN CROP PLANTS RELATIVE TO MONOCULTURE.

*Objective*

The objectives of this experiment were to determine (i) whether border trap cropping on a small scale would be effective in managing flea beetle damage on cauliflower over a season (ii) whether trap cropping would be more effective in pest control than companion planting and (iii) whether using the two techniques combined, in what has been termed a 'push-pull' approach, would offer any further advantage for controlling flea beetle damage than any one technique alone.

*Materials and methods*

This experiment was conducted within the walled garden at Close House between 16 June and 14 Aug 2005.

Prior to the start of the experiment, all plants used were grown in plugs of John Innes No. 2 compost until they were 4.5 weeks old when they were transferred to the field.

Four treatments were used to simulate the way in which border trap crops/companion plants are commonly deployed in the field (Fig 14). These treatments were originally set out in a Latin square design, but due to suspected zinc contamination in one corner of the plot, one replicate of each treatment was lost and the design was analysed as a randomised block with three replicates of each treatment

(Fig 15). These treatments were a cauliflower monoculture (49 plants in a 7 x 7 block), cauliflower (25 plants) with 50% substitutive trap crop (turnip rape) border (24 plants), cauliflower (25 plants) with 50% substitutive companion plants (24 tomato plants (*Lycopersicon esculentum*; the Amateur), intercropped) and cauliflower (13 plants) and companion plants (12 plants, intercropped) with 50% substitutive trap crop border (24 plants). Tomato had been found previously to be an effective companion plant for use with flea beetles (see Annual Report, year one).

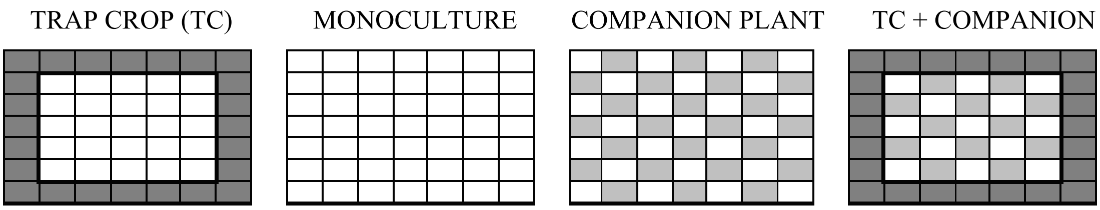



**Fig. 14. Treatments to be used for experiment. One square = one plant. Key: dark grey = trap crop plant, white = cauliflower plant, light grey = tomato (companion) plant.**

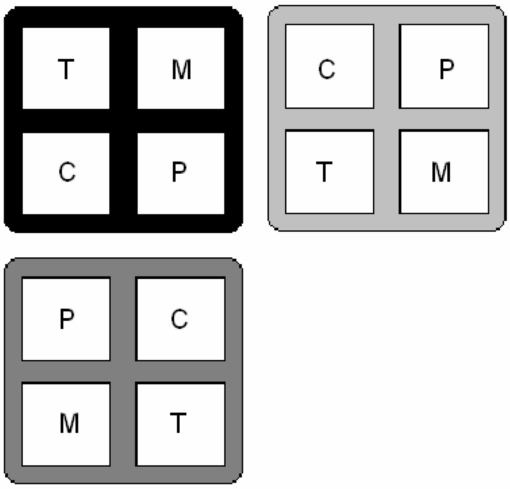



**Fig. 15. Layout of treatments in randomised block design Key: black = block 1, dark grey = block 2, light grey = block 3, M = monoculture, C = companion plant, T = trap crop, P = trap cropping and companion planting combined (push-pull).**

Each individual plant was set in its own space measuring 25 x 25 cm and a gap of 2 m of bare soil surrounded any treatment. To aid establishment, plants were watered as necessary by a sprinkler system for the first three weeks in the field. After this time plants were adequately established as to require no further artificial irrigation. Plots and spaces between plots were kept weed free by a combination of rotovation and hand weeding.

In each treatment, eight peripheral host (trap crop or cauliflower) plants were randomly selected for monitoring, as were eight internal cauliflower plants and eight tomatoes. The heights and leaf numbers of all plants were assessed on 19 June and those of the cauliflower at least one row from the edge of the plots, again on 14 August. At this time, four internal cauliflower plants (two from rows adjacent to the outer-most row of plants and two from rows further into the centre of each plot) were harvested to gather leaf area data (see Appendix). Flea beetle feeding damage (number of holes per plant) was assessed on all selected host plants on 19, 22, 25 June and 15 July which equate to 3, 6, 9 and 29 days after transplanting. A further count of damage, to internal cauliflower plants only, was made on 4 August, 49 days after transplanting. Although the cauliflower was still immature at the end of the experiment, plants had started to head and would probably have been harvestable shortly after the final data collection date.

High levels of slug/pigeon damage were observed on the plants in the early stages of the experiment. To combat the slug damage 'Chicken Layers Mash' was applied in a band (5 cm thick) around each treatment on 17 June, a zinc strip was set in the lower end of the plot (where slugs were suspected to enter the plots) on 29 June and the spaces between treatments were rotovated on 30 June to kill any slugs present in the surface layer of the soil. Bird netting was used to cover the entire plot area between 1 July and 3 August to prevent further damage by pigeons and allow the plants to grow to a size where pigeons would no longer feed upon them.

The average daily maximum and minimum temperatures during the experiment were 18.50 (± 0.45 SE) ºC and 11.53 (± 0.32 SE) ºC respectively. A daily average of 2.78 (± 0.70) mm of rain fell during the experiment with 54% of all days being rain free.

Flea beetle feeding damage data from the first sampling date, 3 days after plants were transferred to the field, were not analysed because levels of flea beetle damage were very low at this time.

Flea beetle damage data from internal cauliflower plants were analysed by Nested ANOVA (where plants were nested within replicate blocks), having square root transformed the data first (adding 0.5 to all data collected 6 and 9 days after transplanting the plants in the field). Block was considered as a factor in this analysis.

Data from external plants, and the total number of feeding holes per treatment for all plants, could not be made to conform to the assumption of equal variances for a Nested ANOVA. Instead, the numbers of feeding holes were grouped per replicate per treatment and subjected to 2-way ANOVA to look for differences between treatments and blocks. Data were square root transformed prior to this analysis. Where ANOVA identified statistically significant differences between means, the Tukey Test was used to identify differences between pairs of means.

Leaf number data were not analysed as they were non-continuous and so could not be subjected to a Nested ANOVA. Leaf area data (non-transformed) were analysed by Nested ANOVA. Cauliflower plants from the middle of plots and rows adjacent to the external row of plants were analysed separately. Plant height data were analysed in the same way. Data from the most central 3 plants (at least two rows from the external plants) were considered separately from data from the other 5 plants which were adjacent to the external row. This was done as in trap crop and ‘push-pull’ treatments turnip rape grew large enough to have affected the growth of any plants further toward the plot exterior and this may have biased the data.

*Results*

*Flea beetle feeding*

On internal cauliflower plants, there was no significant difference in flea beetle feeding holes between treatments when plants were sampled 6 or 9 days after transplanting ($F_{(3,84)} = 1.48$, $P = 0.227$ and $F_{(3,84)} = 0.35$, $P = 0.788$ respectively) (Fig 16). There was no effect of block 6 days after transplanting (DAT) data ($F_{(8,84)} = 1.70$, $P = 0.110$) but block did have a significant effect for the 9 DAT data ($F_{(8,84)} = 3.54$, $P < 0.001$). The only pair-wise difference between means showed that there were more holes in companion plant treatments in block 2 than block 3 ($P = 0.008$).

After 29 days in the field, there was a significant difference between treatments in the number of flea beetle feeding holes in internal cauliflower plants ($F_{(3,84)} = 16.43$, $P < 0.001$) (Fig 16). There were more holes in cauliflower plants in monoculture compared to the trap crop treatments ($P < 0.001$), and more holes in the companion-planted cauliflower than the trap-cropped cauliflower ($P < 0.001$), or cauliflower grown under a ‘push-pull’ regime ($P < 0.05$). There were also fewer holes in trap-cropped cauliflower than cauliflower grown with the trap crop and companion plants together ($P < 0.01$). Block significantly affected these data ($F_{(8,84)} = 2.84$, $P <$

0.01). The only pair-wise difference (between like treatments) was for monocultured cauliflower, where more holes were found in plants in block 1 as compared to block 3 ($P < 0.05$).

After 49 days there were again significant differences between treatments in the number of feeding holes in internal cauliflower plants ($F_{(3,84)} = 35.42$, $P < 0.001$) (Fig 16). There were more feeding holes in internal cauliflowers grown as either a monoculture or with companion plants, compared to cauliflowers grown with trap crops or trap crops and companion plants combined ($P < 0.001$ in all four cases). Block did not have a significant effect on these data ($F_{(8,84)} = 1.70$, $P = 0.111$).

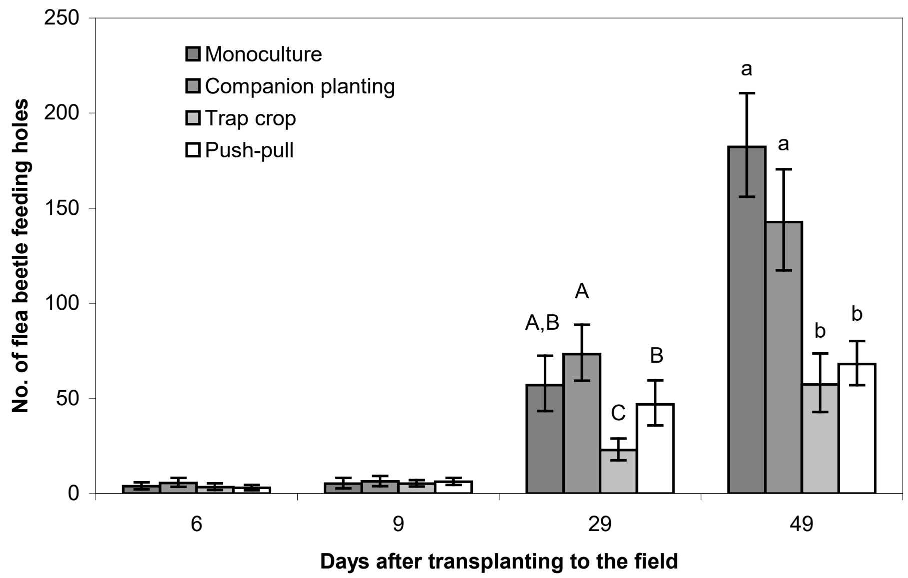



**Fig. 16. Mean flea beetle feeding holes recovered from cauliflower plants under different treatments at varying times after transplanting (error bars show 95% confidence limits). All data are back-transformed from ANOVA. Push-pull = trap cropping and companion planting combined.**

Feeding holes in external plants were assessed 6, 9 and 29 DAT only. There were significant differences between treatments on all sampling dates (6 DAT; $F_{(3,6)} = 12.19$, $P < 0.01$, 9 DAT; $F_{(3,6)} = 11.37$, $P < 0.01$, 29 DAT; $F_{(3,6)} = 82.95$, $P < 0.001$). In all cases more holes were found in turnip rape plants (in trap crop and 'push-pull' treatments) than similarly situated cauliflower plants in treatments lacking trap crops (monoculture and companion plant treatments) (Table 5). Block did not affect the data on any sampling date.

When considering the total holes made in all plants of a single treatment, there were significant differences between treatments on all sampling dates (6 DAT; $F_{(3,6)}$ = 9.43, $P < 0.05$, 9 DAT; $F_{(3,6)}$ = 9.69, $P < 0.01$, 29 DAT; $F_{(3,6)}$ = 52.65, $P < 0.001$). In all cases, on all sampling dates, this was because there were significantly more holes in plants in the trap crop or 'push-pull' treatments as compared to the monoculture or companion plant treatments (Table 5). Block never affected these data (6 DAT; $F_{(2,6)}$ = 0.48, $P = 0.639$, 9 DAT; $F_{(2,6)}$ = 0.43, $P = 0.669$, 29 DAT; $F_{(2,6)}$ = 0.15, $P = 0.865$).

| | DAYS AFTER TRANSPLANTING | | |
|---|---|---|---|
| TREAT | 6 | 9 | 29 |
| MONO | 48.21 (+7.09, -6.61)$^{A}$<br>88.18 (+19.08, -17.21)$^{a}$ | 66.28 (+29.29, -23.94)$^{A}$<br>123.92 (+34.14, -29.99)$^{a}$ | 448.04 (+294.78, -220.66)$^{A}$<br>930.51 (+586.81, -444.05)$^{a}$ |
| COMP | 58.58 (+31.45, -24.72)$^{A}$<br>115.46 (+22.97, -20.88)$^{a}$ | 65.45 (+49.10, -35.45)$^{A}$<br>127.63 (+73.83, -57.05)$^{a}$ | 587.75 (+288.18, -230.88)$^{A}$<br>1206.91 (+435.40, -368.47)$^{a}$ |
| TRAP | 521.29 (+116.22, -104.53)$^{B}$<br>557.79 (+130.10, -116.48)$^{b}$ | 704.04 (+212.57, -184.57)$^{B}$<br>753.51 (+200.64, -176.98)$^{b}$ | 6882.49 (+687.02, -654.34)$^{B}$<br>7081.98 (+731.40, -695.46)$^{b}$ |
| PUSH | 527.69 (+474.71, -323.71)$^{B}$<br>557.49 (+496.70, -339.80)$^{b}$ | 858.43 (+792.78, -535.76)$^{B}$<br>918.03 (+787.37, -545.48)$^{b}$ | 8815.71 (+2275.86, -2014.82)$^{B}$<br>9223.74 (+2378.16, -2105.70)$^{b}$ |

**Table 5. Means and 95% confidence limits for flea beetle feeding holes recovered from external trap crop or cauliflower plants and from all plants of a given treatment. External plant values are presented first and total plant values second. TREAT = treatment, MONO = monoculture, COMP = companion planting, TRAP = trap crop, PUSH = trap crop and companion planting combined (push-pull). All data are back-transformed from ANOVA.**

*Plant growth*

There was no difference in cauliflower plant height between treatments at the end of the study period for plants in the centre of the plots ($F_{(3,24)}$ = 1.05, $P = 0.389$). Block did not affect these data ($F_{(8,24)}$ = 2.13, $P = 0.073$) (Fig 17a). For plants in the row adjacent to the external row of plants, there was a significant difference between treatments ($F_{(3,48)}$ = 14.76, $P < 0.001$) (Fig 17a). Plants were significantly taller in monoculture as compared to trap crop ($P < 0.001$) and 'push-pull' ($P < 0.001$) treatments, Plants were also significantly taller in companion plant treatments, again as compared to trap crop ($P < 0.01$) and 'push-pull' ($P < 0.001$) treatments. Block had no effect on these data ($F_{(8,48)}$ = 1.06, $P = 0.408$).

There was a difference in cauliflower leaf area between treatments at the end of the study ($F_{(3,12)} = 5.78$, $P < 0.05$ for the internal plants (those at least 2 rows from the plot edges) and $F_{(3,12)} = 17.01$, $P < 0.001$ for plants in the rows adjacent to the external row) (Fig 17b). For the internal plants, smaller leaf areas were recorded from plants in the ‘push-pull’ treatments as compared to the monoculture and companion plant treatments ($P < 0.01$ and 0.05 respectively). For the cauliflower in rows adjacent to the external row, plants had lower leaf areas under both trap crop and ‘push-pull’ treatments as compared to both monoculture and companion plant treatments (monoculture vs trap crop; $P < 0.01$, monoculture vs ‘push-pull’; $P < 0.05$, companion plant vs trap crop; $P < 0.001$, companion plant vs ‘push-pull’; $P < 0.001$). Block did not affect data for the internal cauliflower leaf areas ($F_{(8,12)} = 1.63$, $P = 0.215$), but did so for the more external plants ($F_{(8,12)} = 6.45$, $P < 0.01$). The only difference within treatments was for companion plants where leaf areas were higher in block 1 than 2 ($P < 0.001$).

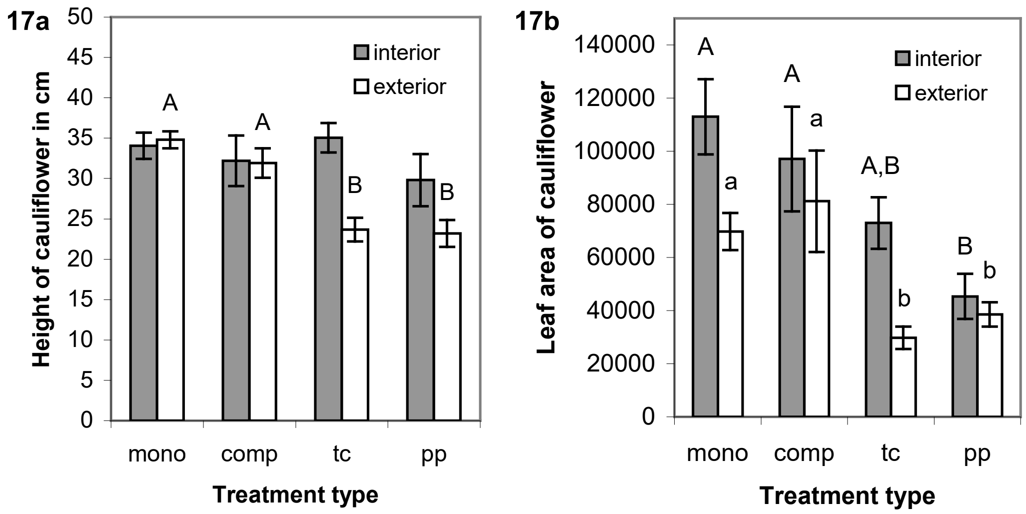



**Fig. 17. The mean a). heights and b). leaf areas of cauliflower plants in different positions under different treatments at the end of the study period (error bars show standard errors). Internal = plants in the centre of plots, at least two rows from the external most plants. External = plants in the row adjacent to the external most plants. Mono = monoculture, comp = companion planting, tc = trap crop, pp = trap crop and companion plant combined (push-pull).**

## CONCLUSIONS

### EXPERIMENT 1. THE EFFECT OF HOST PLANT AGE ON DIAMONDBACK MOTH PREFERENCE FOR WHITE MUSTARD OVER CAULIFLOWER.

Diamondback moth preferred mustard of all ages as an oviposition site compared with cauliflower, regardless of whether the mustard was older, younger or the same age as the cauliflower.

A preference for white mustard *per se* is not surprising. In both earlier experiments (see Annual Report, year one) and work elsewhere (Paliniswamy & Gillott, 1986) white mustard was an attractive host plant of diamondback moth and has been recommended for use in trap cropping to manage this pest (Talekar & Shelton, 1993). However, what was more unexpected was that young mustard plants were still preferred to older, larger cauliflower plants. Both Bender *et al.* (1999) and Srinivasan & Krishna Moorthy (1991) for example, suggested seeding a mustard trap crop for diamondback moth fifteen days before the main crop (in this case cabbage). However, the moths did not display a greater preference for the relatively older mustard plants in the current work unless both plants and plant pots were considered as a single sampling unit. In this instance the data fitted well with the assumption that relatively older plants would be preferred to a higher degree, with mustard two weeks younger than cauliflower being less preferred than mustard which was older than the cauliflower when used. That the same pattern of host preference was not found on the plants alone may have arisen from the fact that even when younger than cauliflower plants, mustard was still at least comparable to these plants in size, with the importance of trap crop plant size highlighted both elsewhere (Robinson, 2001) and in the next section.

In summary, the results suggest that plant age may not be a crucial factor governing trap crop success in the field. This is the case as the results presented here show that older trap plants need not be more preferred by pests than trap crop plants of the same age, or even younger, than the main crop plants. However, as trap crop plants were always at least comparable in size to the main crop plants in the present study, this may not be the case when trap crop plants that are younger than the main crop plants, are also notably smaller than them.

EXPERIMENT 2. THE EFFECT OF TRAP PLANT SIZE, RELATIVE TO THE MAIN CROP, ON DIAMONDBACK MOTH PREFERENCE FOR WHITE MUSTARD OVER CAULIFLOWER.

Regardless of whether the mustard plants were larger, smaller or similar in size to the cauliflower used, they were always preferred for diamondback moth oviposition. This may seem surprising since trap plants larger than the main crop are often recommended (Robinson, 2001). Larger plants might be expected to make more effective trap crops since plant size is an important factor in host plant selection by pest insects, with larger plants being more attractive as landing sites (Finch & Collier, 2000). Nevertheless, whilst mustard of all sizes was preferred over cauliflower *per se*, this preference was not equal across the treatments considered. When larger than co-presented cauliflower plants, mustard was relatively more preferred than when smaller, this being the case for both data from plants alone and plants and pots combined. Furthermore, when considering combined plant and pot data, diamondback moth displayed no significant preference for the mustard when these plants were smaller than the co-presented cauliflower. This suggests that trap crop plant size is important in ensuring pest preference for trap crop plants.

The above suggests that there may indeed be a benefit in using larger plants as trap crops as they are relatively more preferred and should therefore theoretically attract and retain pests more efficiently than a trap crop composed of plants smaller than, or similar in size to, those in the main crop. Nevertheless, this work also suggests that trap crop plants can still be preferred by pests when smaller or similar in size to main crop plants. Thus, it is unlikely that using larger trap crop plants (compared to main crop plants) is critical for trap crops to work *per se*, but it is likely to improve their effectiveness by maximising pest preferences for them.

EXPERIMENT 3. THE EFFECT OF SEPARATING TRAP CROPS AND MAIN CROPS ON PEST CONTROL.

No matter how attractive or preferred the trap crop, it is likely that some pests will by-pass, or pass through it, and onto the main crop plants. Therefore, any means by which the trap crop plants can be made to attract and retain greater numbers of pests can only improve the ability of trap crops to relieve pest pressure on the main crop.

It appears from the results that one way of achieving this is to separate the trap and main crop plants by an area of bare soil 3 m or more in width. In experiments with both diamondback moth and flea beetles, doing so resulted in an increased percentage of oviposition on the trap crop plants (although in all treatments the trap crop plants were preferred) and fewer feeding holes/eggs on the cauliflower plants. This probably resulted from a greater proportion of the pest insects being unable to locate the cauliflower plants, when these were placed further away from the trap crop plants that they presumably encountered first. For diamondback moth there appeared to be no advantage in leaving a larger gap of 6 m compared to a smaller one of 3 m. However, for flea beetles the number of feeding holes in cauliflower was further reduced by increasing the space between these plants and the trap crop from 3 to 6 m. This probably reflects the stronger flying tendency/ability of the moths, where covering a distance of 6 m of bare soil to locate a host is only a little more difficult than covering 3 m to do so. Flea beetles, on the other hand, seemed to find it harder to travel this extra 3 m and hence caused less damage on cauliflower plants 6 m from the trap crop than those 3 m from it.

Separating trap and main crops in the field would probably prove wasteful to the grower. Large tracts of land would need to be left bare between the trap and main crop, which could otherwise be used to increase the main crop growing area. In certain circumstances however, growers are required to leave unsprayed buffer zones of up to 5 meters anyway, these being necessary to protect landscape features such as dykes, ditches and hedges, and/or non-target arthropod species from pesticide drift. If trap crops were unsprayed, they could be cited on the outer edge of these buffer zones and leaving gaps of several meters between the trap and main crop would not prove as wasteful, assuming some amount of pesticide would need to be applied to the main crop even in the presence of the trap crop, and that there were no restrictions in place to prevent the buffer zone from being used in this way (see DEFRA & RPA, 2006 'Single Payment Scheme – Cross Compliance Handbook for England', paragraphs 93 and 101) . In these instances however, it would be difficult to control trap crop pest numbers to prevent pest over-spill onto the main crop. Such over-spill might be reduced by leaving a gap between the trap and main crop anyway, and alternatives to chemical trap crop pest control, such as reseeding of the trap crop, could be sought to limit over-spill.

Depending upon the pesticides used, their mode of application, the surrounding landscape and the results of certain risk assessments, the size of these buffer zones may be greatly reduced, or they may not be needed at all. In these circumstances, separating trap and main crops could still prove wasteful. Even where buffer zones are not required however, the removal of a small number of external main crop rows where a trap crop is used would probably not reduce the main crop yield by much as main crop plants adjacent to the typically larger trap crop plants may suffer competition effects (see Experiment 5). Further study is needed, however, to assess whether trap crop and main crop separations of a few rows (i.e. less than 3 m) would also be effective in improving trap crop efficiency. Also, it is possible that where pest control is concerned these spaces might be better used to accommodate additional trap crop plants or even companion (or other non-host) plants. This too needs to be considered in future work.

EXPERIMENT 4. TRAP CROP EFFECTIVENESS IN PEST CONTROL.

This experiment demonstrated that trap crops can effectively reduce pest feeding damage on a main crop. This is in agreement with work on flea beetles by Parker *et al.* (2002) who also found main crop damage to be reduced with trap cropping. Interestingly however, using a trap crop of highly preferred plants was statistically no more effective in controlling flea beetle damage or diamondback moth oviposition on cauliflower than using a peripheral planting of cauliflower. This peripheral cauliflower even acted as a trap crop for the flea beetles by attracting greater levels of feeding damage than the other cauliflower plants, further towards the cage rear, which the peripheral plants were protecting. However, the presence of peripheral cauliflowers did not reduce damage to the internal main crop cauliflower relative to the treatment containing no external trap crop or cauliflower plants, whereas a turnip rape trap crop did, and a far greater number of holes were recovered from the turnip rape relative to the internal main crop cauliflower. This suggests that the trap crop effect of peripheral cauliflower may not have been as strong as that of turnip rape. Nevertheless, that peripheral cauliflower was even slightly effective as a trap crop suggests that the trap crop may have been functioning at least partially through a simple interception effect and need not necessarily be composed of highly attractive, preferred plants to function. However, as was demonstrated by the results of

Experiment 5, the pest control benefits of trap cropping may take time to manifest themselves. Thus, it may have been the short-term nature of Experiment 4 that led to trap cropping with preferred plants being no more effective than 'trap cropping' with cauliflower. Given more time, the differences that were beginning to emerge in the results from both pests, i.e. that fewer holes/eggs were recovered from internal cauliflower protected by preferred trap crop plants rather than external cauliflower plants, may have become more significant.

EXPERIMENT 5. THE POTENTIAL OF TRAP CROPPING, COMPANION PLANTING AND A COMBINATION OF THE TWO, IN REDUCING PEST DAMAGE ON ASSOCIATED MAIN CROP PLANTS RELATIVE TO MONOCULTURE.

*Flea beetle feeding*

In the early part of the experiment it was found that none of the treatments used (trap crops, companion plants or the two combined) were able to reduce flea beetle feeding on cauliflower plants relative to a monoculture. This was perhaps surprising in light of the results of the previous experiment, and experiments conducted the previous year (see Annual Report, year one), where respectively, turnip rape trap plants and companion planting with tomato did reduce flea beetle feeding damage on associated cauliflower plants. Flea beetle feeding was relatively light in the early part of the study period however, and this may have resulted in non-significant differences in the levels of feeding in all treatments. When feeding pressure increased later in the season, differences could be seen with respect to feeding damage on cauliflower as this was increased in treatments without a trap crop. A similar pattern of trap crops only becoming beneficial in pest control after a certain time period, or only when the pest pressure is sufficiently high, has been observed for *Lygus* bugs on lettuce in Italy (Accinelli *et al.*, 2005). Akin to the work here, trap cropping (with alfalfa) had no effect on *Lygus* numbers on lettuce until approximately one month into the study period.

It was no surprise that trap cropping and trap cropping and companion planting combined, reduced flea beetle feeding damage on protected cauliflowers. What was not expected, for reasons already given, was that companion planting would have no effect. This was the case both for companion planting on its own, which was no more effective in controlling flea beetle damage than monoculture, and for companion planting combined with trap cropping, which was no more effective in reducing flea beetle damage to cauliflower than trap cropping alone. The companion plants were used in place of cauliflower plants in a substitutive design and so there were half as many cauliflower plants in the companion-planted plots as in the monoculture. Therefore, it is possible that companion planting reduced the number of beetles present, but that damage to individual cauliflower plants remained the same. Whilst using an additive design would have been possible, it is probable that due to the size of the companion plants used, most cauliflower plants would have been heavily out-competed and died. Also, a 1:1 planting ratio as was necessary to make companion plant:main crop plant ratios equal to trap crop plant:main crop plant ratios used (this in itself being fixed by the space and plants available). In these instances then, it appears there is no benefit in using companion planting alone or in conjunction with trap cropping, although the use of trap cropping alone may aid in flea beetle pest management. It may be the case that companion planting is more successful at a higher companion plant to main crop plant ratio. This was indeed the case in experiments done in year one where 3 companion plants were used to every one cauliflower (see Annual Report, year one), and methods such as intercropping and/or undersowing of crop plants with high densities of pest non-host plants such as clover is often successful in pest control (Andow, 1991). However, in any substitutive design, this would greatly reduce the number of main crop plants that could be grown in a set area. Similarly in additive designs, using high densities of non-crop plants means a yield or quality loss in the crop could be expected (see following section on 'plant growth'). The future challenge for companion planting (and indeed intercropping and undersowing in general) may therefore be to over-come the crop yield/quality losses associated with using these techniques additively at high non-crop plant densities (where they may be more effective in pest control).

Even in the relatively effective trap cropping treatments used here, it is true that any reduction in flea beetle feeding damage to the cauliflower observed came at the cost of reducing the number of cauliflower plants grown in a plot. In such small-scale experiments this reduction was notably significant (around 50%). Trap crops typically occupy much less of the field area when used however (10% being the norm, Hokkanen, 1991), which may make any loss in the number of main crop plants economically acceptable when weighed against the levels of pest control achieved by including a trap crop.

*Plant growth*

Many authors have expressed concerns that inter-planting non-host plants with crop plants for pest control may have detrimental effects on the growth of the crop plants (Mwaja *et al.*, 1996, Wiech, 1996, Hooks & Johnson, 2004 and Rivera *et al.*, 2004). This did not appear to be the case here as cauliflower grown with companion plants was not notably smaller (in height or leaf area) than plants grown in monoculture. This again probably reflects the substitutive experimental design where competition from a tomato plant in the companion planting treatment was probably no more severe than competition from a cauliflower plant in monoculture. However, it appears that under the 'push-pull' treatment, even the cauliflower plants in the centre of the plots were negatively affected with regards to their size (leaf area). This probably resulted from the combined competitive pressures of the turnip rape and tomato plants limiting cauliflower growth in this treatment. Turnip rape grew especially large in the experiment and may, in combination with the tomato plants, have influenced the cauliflower plants in the centre of what were relatively small plots. Nevertheless, a turnip rape trap crop on its own, without the added competitive pressure of companion plants, did not reduce cauliflower plant growth in the plot centres. When considering cauliflower plants in the rows adjacent to the trap plants however, it was found that these were always smaller (height and leaf area) than cauliflowers in the treatments without a trap crop.

The combined results of Experiments 3 and 5 therefore suggest that separating trap and main crops by an area of bare soil may not be as economically costly as first thought. If only small gaps need to be used, then it is likely that the main crop plants sacrificed to create the gaps are those which may have had their growth compromised by the trap crop anyway.

ALL EXPERIMENTS

In many of the experiments presented, variables such as replicate run, field cage position or experimental block had a significant affect on the data collected.

In the case of all field and greenhouse experiments done with diamondback moth, it was likely that any difference between runs of a single experiment was caused by variable environmental conditions during the study period. Such factors cannot however explain the differences observed between runs of any laboratory experiment with these moths, where all such conditions were held constant. In these instances it is probable that minor variations in variables such as moth age (where in any one run compared to another more moths at the older or younger end of the chosen age range may have been used), or natural variations in behaviour between one set of moths and the next, can explain the differences found between runs.

Where differences between rows, cage aspects, or experimental blocks were found to significantly affect flea beetle data in a single experiment, these probably reflected the natural movement patterns of these beetles in the field.

## TECHNOLOGY TRANSFER

Various parts of this work have been presented and discussed:

*Year 1*

- Abstract presented at Warwick HRI postgraduate forum, Warwick, Nov. 2003.
- Poster presentation given at Royal Entomological Society (RES) National Meeting, 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.

*Year 2*

- Oral presentation given at RES postgraduate forum, Newcastle, Oct. 2004.
- Oral presentation given to BGA committee, Nov. 2004.
- Poster presentation given at Warwick HRI postgraduate forum, Warwick, March 2005.
- Poster presentation given at the University of Newcastle's postgraduate conference, Newcastle, July 2005.
- Poster presentation given at RES National Meeting, Sussex, Sept. 2005.
- Oral presentation given at AAB Conference, Sept. 2005.

- Oral presentation given at IOBC Meeting, Ljubljana, Slovenia, Oct. 2005 (publication in Proceedings to follow).

A summary of this project has also been presented to growers through HDC News (George, 2004) (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.

| | PLANT SPECIES | |
|---|---|---|
| | CAULIFLOWER | WHITE MUSTARD |
| 4 WK MUST VS 4 WK CAULI | 15.87 ± 0.32, 5.00 ± 0.16, 5057.06 ± 255.90 | 30.32 ± 0.80, 9.61 ± 0.27, 25990.78 ± 779.71 |
| 5 WK MUST VS 5 WK CAULI | 18.76 ± 0.52, 5.33 ± 0.11, 8520.56 ± 649.29 | 39.70 ± 2.26, 10.28 ± 0.23, 30472.50 ± 1271.97 |
| 6 WK MUST VS 6 WK CAULI | 20.75 ± 0.57, 6.22 ± 0.17, 14075.94 ± 1083.93 | 50.91 ± 2.24, 11.17 ± 0.33, 39227.67 ± 1165.04 |
| 4 WK MUST VS 5 WK CAULI | 14.70 ± 0.33, 5.11 ± 0.11, 4783.06 ± 377.58 | 27.63 ± 0.56, 9.17 ± 0.25, 22806.39 ± 932.87 |
| 4 WK MUST VS 6 WK CAULI | 21.67 ± 0.46, 6.22 ± 0.10, 14544.50 ± 717.15 | 22.47 ± 0.56, 7.94 ± 0.22, 16396.83 ± 844.11 |
| 5 WK MUST VS 4 WK CAULI | 11.14 ± 0.16, 4.11 ± 0.08, 2088.72 ± 90.10 | 30.53 ± 0.89, 9.50 ± 0.26, 27138.89 ± 1705.03 |
| 5 WK MUST VS 6 WK CAULI | 22.32 ± 0.58, 6.83 ± 0.22, 17312.83 ± 987.43 | 43.50 ± 2.27, 10.56 ± 0.25, 28402.00 ± 1260.51 |
| 6 WK MUST VS 4 WK CAULI | 11.93 ± 0.62, 4.44 ± 0.17, 2704.56 ± 330.79 | 59.82 ± 2.40, 11.50 ± 0.23, 36401.44 ± 1257.07 |
| 6 WK MUST VS 5 WK CAULI | 16.58 ± 0.47, 5.56 ± 0.15, 6213.44 ± 406.25 | 55.41 ± 1.74, 11.50 ± 0.35, 38512.72 ± 706.89 |

**Table I. Physical characteristics of plants used (height/cm, leaf number, leaf area/square mm) in Experiment 1. N = 18**

| | RELATIVE SIZE OF MUSTARD COMPARED TO CAULIFLOWER | | |
|---|---|---|---|
| | SMALLER | SIMILAR | LARGER |
| CAULIFLOWER | 18.14 ± 0.62, 5.50 ± 0.16, 8227.56 ± 963.24 | 16.77 ± 0.44, 5.38 ± 0.13, 6890.88 ± 739.50 | 16.75 ± 0.69, 5.44 ± 0.20, 6994.13 ± 567.35 |
| WHITE MUSTARD | 11.38 ± 0.55, 2.75 ± 0.14, 3222.81 ± 319.89 | 16.88 ± 0.91, 3.81 ± 0.16, 7717.63 ± 1155.85 | 36.74 ± 1.85, 10.44 ± 0.33, 33482.75 ± 1976.35 |

**Table II. Physical characteristics of plants used (height/cm, leaf number, leaf area/square mm) in Experiment 2. N = 18.**

| | TREATMENT / M SEPERATION OF TRAP AND MAIN CROP | | |
|---|---|---|---|
| | 0 M | 3 M | 6 M |
| CAULIFLOWER | 20.50 ± 0.18, 6.90 ± 0.10, 17629.39 ± 636.68 | 20.33 ± 0.20, 6.94 ± 0.12, 17835.50 ± 986.03 | 20.51 ± 0.24, 7.02 ± 0.11, 18374.78 ± 816.33 |
| WHITE MUSTARD | 68.26 ± 2.65, 11.98 ± 0.25, 29109.72 ± 1255.48 | 70.73 ± 2.66, 12.50 ± 0.28, 31739.72 ± 1407.40 | 69.25 ± 2.73, 12.64 ± 0.27, 33459.56 ± 2060.04 |

**Table III. Physical characteristics of plants used (height/cm, leaf number, leaf area/square mm) in Experiment 3a with diamondback moth. N = 48 for height and leaf number and 18 for leaf area.**

| | TREATMENT / M SEPERATION OF TRAP AND MAIN CROP | | |
|---|---|---|---|
| | 0 M | 3 M | 6 M |
| CAULIFLOWER | 26.62 ± 0.49, 8.60 ± 0.22, 43738.70 ± 2126.46 | 25.81 ± 0.54, 9.20 ± 0.25, 52399.90 ± 2509.30 | 27.02 ± 0.51, 8.80 ± 0.25, 48710.90 ± 1768.43 |
| TURNIP RAPE | 22.88 ± 0.31, 9.40 ± 0.50, 54913.30 ± 3024.74 | 24.22 ± 1.02, 10.30 ± 0.40, 68527.70 ± 5183.48 | 23.82 ± 1.18, 11.10 ± 0.28, 65094.00 ± 5781.49 |

**Table IV. Physical characteristics of plants used (height/cm, leaf number, leaf area/square mm) in Experiment 3a with flea beetles. N = 10.**

| | TREATMENT TYPE | | |
|---|---|---|---|
| | TRAP CROP OF WHITE MUSTARD | DOUBLE CAULIFLOWER | SINGLE CAULIFLOWER |
| EXTERNAL PLANT | 49.78 ± 1.43, 13.06 ± 0.35, 38238.89 ± 1804.63 | 21.32 ± 0.31, 7.44 ± 0.18, 18906.61 ± 773.95 | NA |
| INTERNAL PLANT | 21.93 ± 0.34, 7.78 ± 0.15, 19701.06 ± 795.88 | 22.12 ± 0.33, 7.94 ± 0.15, 20024.17 ± 887.33 | 21.63 ± 0.31, 7.67 ± 0.14, 20236.33 ± 726.46 |

**Table V. Physical characteristics of plants used (height/cm, leaf number, leaf area/square mm) in Experiment 3b with diamondback moth. N = 18.**

| | TREATMENT TYPE | | |
|---|---|---|---|
| | TRAP CROP OF TURNIP RAPE | DOUBLE CAULIFLOWER | SINGLE CAULIFLOWER |
| EXTERNAL PLANT | 36.94 ± 1.35, 9.80 ± 0.39, 91273.60 ± 8988.56 | 24.39 ± 0.35, 7.70 ± 0.15, 29599.60 ± 815.29 | NA |
| INTERNAL PLANT | 24.36 ± 0.56, 7.60 ± 0.31, 31543.20 ± 1835.41 | 25.07 ± 0.47, 7.50 ± 0.22, 30347.20 ± 1230.16 | 24.45 ± 0.47, 7.80 ± 0.13, 31170.60 ± 1220.32 |

**Table VI. Physical characteristics of plants used (height/cm, leaf number, leaf area/square mm) in Experiment 3b with flea beetles. N = 10.**

| | TREATMENT | | | |
|---|---|---|---|---|
| | MONOCULTURE | COMPANION PLANTING | TRAP CROPPING | PUSH-PULL |
| CAULIFLOWER | 20.07 ± 0.51, 5.25 ± 0.21 | 20.32 ± 0.42, 4.96 ± 0.13 | 21.25 ± 0.40, 5.00 ± 0.19 | 21.42 ± 0.39, 5.04 ± 0.18 |
| TOMATO | NA | 27.37 ± 0.50, 6.17 ± 0.19 | NA | 27.58 ± 0.39, 6.42 ± 0.19 |
| TURNIP RAPE | NA | NA | 22.10 ± 0.51, 5.21 ± 0.20 | 21.72 ± 0.50, 4.83 ± 0.19 |

**Table VII. Physical characteristics of plants used (height/cm, leaf number) at the start of Experiment 4. N = 24.**

| | TREATMENT | | | |
|---|---|---|---|---|
| | MONOCULTURE | COMPANION PLANTING | TRAP CROPPING | PUSH-PULL |
| HEIGHT | 34.80 ± 1.05, *34.06 ± 1.61* | 31.93 ± 1.83, *32.20 ± 3.12* | 23.68 ± 1.46, *35.06 ± 1.81* | 23.19 ± 1.66, *29.80 ± 3.24* |
| LEAF NUMBER | 13.33 ± 0.39, *13.67 ± 0.88* | 11.27 ± 0.73, *11.56 ± 0.60* | 8.73 ± 0.70, *13.11 ± 0.77* | 7.80 ± 0.57, *10.33 ± 1.09* |
| LEAF AREA | 69782.00 ± 6996.86, *112991.50 ± 14157.64* | 81195.00 ± 19099.56, *97053.83 ± 19706.87* | 29741.67 ± 4180.90, *72975.17 ± 9720.62* | 38563.50 ± 4561.69, *45357.17 ± 8439.39* |

**Table VIII. Physical characteristics of internal cauliflower plants (height/cm, leaf number, leaf area/square mm) at the end of Experiment 4.b Figures for plants in rows adjacent to the external row of plants are given in regular text. Figures for plants in rows further toward the plot centres are given in italics. N = 6 for all leaf area data, 9 for all other data from internal most cauliflower plants and 15 for all other data from cauliflower plants adjacent to the external most row of plants.**