Report prepared for the
Horticultural Development Council

FV 222
Brassicas: Biology and Control of Brassica Flea Beetles by Integrating Trap Crops with Insecticide Use

Annual Report 1999/2000

by

Bill Parker, Julia Howard, Stan Finch & Andy Jukes

AUTHENTICATION

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

Dr W E Parker
Principal Research Consultant
ADAS Wolverhampton

Signature .... Date ....

Report authorised by:

Mr R T Granfield
Research Team Manager
ADAS Wolverhampton

Signature .... Date ....

Project Title

Brassicas: Biology and Control of Brassica Flea Beetles by Integrating Trap Crops with Insecticide Use

Project number:	FV 222
Project Leader:	Dr W E Parker, ADAS, Woodthorne, Wolverhampton, WV6 8TQ.
Current report:	Annual Report 1999/2000
Previous reports:	None
Key Workers:	Dr Julia Howard, ADAS Wolverhampton, Mr S Tones, ADAS Exeter, Dr R McKinlay, SAC Edinburgh, Dr S Finch, HRI Wellesbourne, Mr A Jukes, HRI Wellesbourne.
Location of project:	Flights Farm, Ledbury, Herefordshire. Eastacotte Farm, Crediton, Devon. Birnieknowes Farm, Cockburnspath, East Lothian HRI, Wellesbourne,Warks
Project Co-ordinators:	Mr D Simmons, Trewellard Farm, Scorrier, Redruth, Cornwall, TR16 5DH. Mr A Jackson, Kettle Produce Ltd., Balmalcolm Farm, Cupar, Fife, KY15 7TJ.
Project Commence Date:	April 1999
Project Completion Date:	April 2002
Key Words:	Brassicas; flea beetles, *Phyllotreta*, trap crops, insecticides, fipronil, carbofuran, imidacloprid, tefluthrin, lambda-cyhalothrin, deltamethrin, cypermethrin, gamma-HCH.

CONTENTS

PRACTICAL SECTION FOR GROWERS

Project objectives

The brassica flea beetle complex is becoming an increasing problem for vegetable brassica growers during the spring and summer. Attacks occur on both speciality salad vegetables and on drilled brassicas such as swedes. In severe cases, feeding damage can necessitate re-drilling.

The overall aim of this three year project is to reduce the number of insecticide applications made to some crops for flea beetle control, and to identify additional non-chemical means of flea beetle management consistent with the principles of Integrated Crop Management (ICM). The main objectives of the project are:

1. To identifying the main species involved in causing damage at different sites, and the main periods of activity.

2. To develop techniques for managing flea beetles based on the use of novel trap crops and insecticides, used either singly or in combination.

The objectives of the first year's work were:

1. To determine the species of flea beetle responsible for the main damage to vegetable brassicas, and the principal periods of activity.
2. To test the hypothesis that different types of exotic *Brassica* are more attractive to flea beetles then crop plants.
3. To investigate alternatives to current insecticides.

Key results

- *Brassica* flea beetles were found in varying numbers at each of the four monitoring sites. Beetle activity was at a peak for up to four weeks. The timing of the peak varied from May/June at some sites to June/July at others. Beetles were caught at all sites throughout the monitoring periods (May to July at three sites, April to October at one site).
- Species composition varied between sites, with *Phyllotreta undulata* and *P. atra* predominating at the East Lothian and Herefordshire sites, and *P. vitula* and *P. nigripes* predominating at the Devon site. Other non-*Phyllotreta* (non-*Brassica* feeding) species were caught in water traps, but were rarely found on trap crops.
- Of the trap crops tested, Chinese cabbage and summer turnip were found to attract consistently more flea beetles than Indian mustard or Chinese radish. All trap crops attracted more flea beetles than swede.
- Age also affected flea beetle response to trap crops. Trap crops sown up to four weeks in advance of swede were most attractive to flea beetles.
- There was no relationship between the number of beetles found on trap crops and swede and crop damage.
- There was some evidence that different *Phyllotreta* species preferred specific trap crops.

- Four insecticidal seed treatments (carbofuran, imidacloprid, tefluthrin and fipronil) were applied to swede seed. None of the treatments improved plant stand, but carbofuran and imidacloprid reduced the percentage of seedlings damaged by flea beetles by approximately 70% and 60% respectively.
- Foliar treatments with pyrethroids (lambda-cyhalothrin, cypermethrin and deltamethrin) or gamma-HCH marginally improved plant stand of turnip seedlings, and reduced the percentage of seedlings damaged by flea beetles by 25-45%.

Action points for growers:

- Growers with persistent flea beetle problems could consider growing strips of trap crops around their field crops. The most promising trap crops (consistently catching most beetles of all species) were summer turnip and Chinese cabbage. However, further work is required to identify the most effective method of using trap crops.
- Trap crop need to be sown to emerge two to three weeks in advance of the emergence of the field crop. This will ensure that the trap crops are at their most attractive stage relative to the crop during the critical early phases of crop establishment.
- Establishing the predominant *Phyllotreta* flea beetle species present on individual farms would aid effective trap crop selection.
- Seed treatments (carbofuran and imidacloprid) are generally more effective at reducing the percentage of seedling damaged by flea beetles than single pyrethroid sprays. However, none of the seed treatments are currently Approved for use on Brassicas in the UK.

Practical and financial anticipated benefits

Several studies suggest that the use of trap cropping can bring financial benefits. On average, a 10-30% overall increase in net profits, mainly resulting from reduced insecticide use and/or reduced pest attack, has been reported. Reduced insecticide burden on the crop (particularly close to harvest) will also help maintain beneficial insect populations, and reduce the risk of pesticide residue problems occurring in produce. Identification of ways of treating flea beetle populations on trap crops rather than on crops grown for harvest will also lessen the risk of pesticide residues in harvested produce, as well as reducing the overall use of insecticide.

No commercial products are likely to result from the results, but if the trap cropping is successful, a market may develop for UK growers to produce and supply seed to other growers. Trap-cropping results would also be highly appropriate to organic systems, where flea beetle management can be a persistent problem.

EXPERIMENTAL SECTION

General Introduction

The brassica flea beetle complex, (a range of *Phyllotreta* species) is becoming an increasing problem for vegetable brassica growers during the spring and summer. Attacks occur on both speciality salad vegetables and on drilled brassicas such as swedes. Severe attacks can necessitate re-drilling, and even moderate attacks on speciality salads can severely reduce leaf quality. Although effective insecticides are available for flea beetle control (principally pyrethroids such as alpha-cypermethrin and deltamethrin), they are not persistent. Re-invasion of the crop after spraying can be very rapid and even repeated insecticide treatment often fails to give adequate control. Recently, flea beetle control problems have been compounded by the withdrawal (in June 1999) of seed treatments containing the organochlorine compound gamma-HCH.

Other insecticides Approved on brassicas can give incidental control of flea beetles. These include the carbamates aldicarb, carbofuran and carbosulfan, which are used primarily for cabbage root fly (*Delia radicum*) control. However, because of the problems of enhanced degradation, these soil-applied insecticides can only be used once a year in any one field, and not in the same field in consecutive years. In principle, organophosphorous (OP) insecticides could also be used for flea beetle control. However, current consumer and retailer concerns over the use of such products, coupled with their reduced availability because of on-going regulatory reviews, means that the future use of such products is under severe question.

There is therefore an urgent need to identify new effective insecticides for flea beetle management specifically on brassicas. Although some recent work has been done on brassicas (Finch & Edmonds, 1999) and other crops (Oakley *et al*., 1996; Cullis *et al*., 1999), further work is still required.

The increasing emphasis on Integrated Crop Management (ICM) in vegetable production means that growers are under pressure from their major customers to reduce insecticide use, and to integrate insecticidal control with non-chemical methods of pest management. One of the most promising techniques for flea beetle management on brassicas without insecticides is trap cropping (Vargas & Kershaw, 1979; McKeown, pers. comm.). The principle of trap cropping is based on the fact that virtually all pests show a distinct preference for certain plant species, cultivars or crops of a certain age. Therefore, offering pests an attractive ‘alternative’ to the target crop at critical times during the pest’s and/or the crop’s development results in the concentration of the pest on the ‘alternative’ host - the trap crop. Protection is achieved either by preventing the pest from reaching the crop or by concentrating the pest into an area which can be economically treated with an insecticide (Hokkanen, 1991).

To be successful, trap crops must be more attractive to the pest than the main crop. Differences in attractiveness can be achieved in one of two ways. Firstly, by using a preferred plant or cultivar planted alongside the crop. Alternatively, the same crop plant as the main crop can be used, but at a different, more attractive, growth stage than the actual crop. Knowledge of the target pest, including information on overwintering, hibernation sites and the direction of infestation is also important when using trap crops (Hokkanen, 1991).

Work done at the University of Guelph, Ontario, Canada in 1996 identified that certain exotic mustard species were highly attractive to flea beetles. These reduced or in some circumstances eliminated the need for insecticide treatment in brassicas planted alongside strips of trap crops (McKeown, pers.comm.). Given this apparent success, there is clearly a need to investigate the practical use of such trap crops under UK conditions, including the prospect of integrating trap crop use with insecticides.

The scientific objectives of the work done during this first year of the project were therefore:

4. To determine the species of flea beetle responsible for the main damage to vegetable brassicas, and the principal periods of activity.
5. To test the hypothesis that different types of exotic *Brassica* are more attractive to flea beetles then crop plants.
6. To investigate alternatives to current insecticides.

Flea beetle species and activity

Materials and methods

Site Locations

Monitoring was done at three widely separated commercial locations throughout the UK. These were:

1. Birnieknowes Farm, Cockburnspath, East Lothian.
2. Flights Farm, Ledbury, Herefordshire.
3. Eastacotte Farm, Crediton, Devon.
4. HRI, Wellesbourne, Warwickshire

At each site, monitoring was done in a field growing either swedes (Devon and East Lothian) or Brussels sprouts (Herefordshire) in 1999. All sites had a previous history of flea beetle damage to ensure a high chance of a significant infestation developing.

Trapping procedure

Between nine and 12 traps were set out at each site. The traps were spaced at equal distances around the field border, between the edge of the crop and the field margin. Each water trap was three-quarter filled with water containing 'Teepol' surfactant to reduce surface tension. A fibre 'wick' clipped over the edge of the trap with a paper clip to prevent the water trap over flowing.

Beetle monitoring assessments

At Sites 1 to 3 (commercial field sites), beetle activity was monitored at weekly intervals from just prior to the emergence of the field crop until the field crop plants had 12 true leaves (approximately April to July). At Site 4 (HRI), traps were checked daily from mid-April until early October. On each sampling occasion, the contents of the traps were sieved into labeled pots and returned to the laboratory for counting and identification of beetles. Samples not identified immediately were stored in lactic alcohol in labeled pots.

Results

Traps were set out on 10 April and 5, 6 and 18 May 1999, at the HRI, Herefordshire, Devon and East Lothian sites respectively. The overall trapping periods were 26, 13, nine and 10 weeks respectively. Flea beetles were found at all sites throughout these trapping periods.

East Lothian

Total flea beetle numbers trapped increased during the first four monitoring weeks, peaking at a mean of 0.46 per trap on 14 June 1999, six weeks after the field crop was sown (Fig. 1). From 28 June onwards, numbers declined sharply but remained at *c.* 0.1 beetle per trap for the remainder of the monitoring period.

The principal flea beetle species found was *Phyllotreta undulata*, the small striped flea beetle, which accounted for 73% of all flea beetles recorded (Fig. 2). Other, non-*Phyllotreta* flea beetle species accounted for most of the remaining population (26%), with P. *nemorum*, the large striped flea beetle, accounting for only 1% of the population.

Herefordshire

Total flea beetle numbers generally increased during the first six monitoring weeks, peaking at a mean of 2.19 beetles per trap by 22 June 1999, approximately seven weeks after the field crop was sown (Fig. 3). Thereafter, flea beetle numbers declined to 0.19 by 21 July, after which they increased slightly to 0.83 by 4 August, at which point monitoring was discontinued.

The principal brassica flea beetle species found were *P. undulata* (39% of the population and other, non-*Phyllotreta* flea beetles (38%). The other two species of flea beetle found were *P. atra* and *P. nigripes,* comprising 6% and 7% of the population respectively (Fig. 4).

Devon

Total flea beetle numbers increased sharply during the second monitoring week, peaking at a mean of 0.30 beetles per trap by 20 May 1999, one week after the field crop was sown (Fig. 5). Thereafter, flea beetle numbers declined to 0.19 per trap by 15 July 1999.

The principal flea beetle species found in the water traps in Devon were non-*Phyllotreta* species (e.g. *Aphthona* and *Longitarsus* species), comprising 91% of the total population (Fig 6). The other two species of flea beetle found were both *Phyllotreta* spp.; *P. atra* accounting for 6% and *P. vitula* making up the final 3%.

HRI (Warwickshire)

The numbers of flea beetles caught/trap/day at Wellesbourne are shown for the entire season from mid-April until early October. To smooth out the fluctuations that arise as a result of changes in the weather, the results have been plotted as triple-running means (Fig. 7). There appeared to be four periods of beetle activity. These occurred in 1) late April; 2) late May; 3) mid June; and 4) late August/early September, with the main period of beetle activity extending from mid-May to mid-June.

Although the beetles in the samples are still being identified, several species were active during the main period of beetle activity and so the two apparent peaks (Fig. 7) do not simply reflect two different species. For example, in one sample of 34 beetles caught in a trap on 21 May, 18% were *Phyllotreta undulata* Kuts., and the remainder were divided equally between *P. nigripes* F. (42%) and *P. atra* F. (42%). The sample also contained three species of flea beetle that do not feed on cruciferous plants.

Figure 1. Trap catches of all flea beetle species at the East Lothian monitoring site.

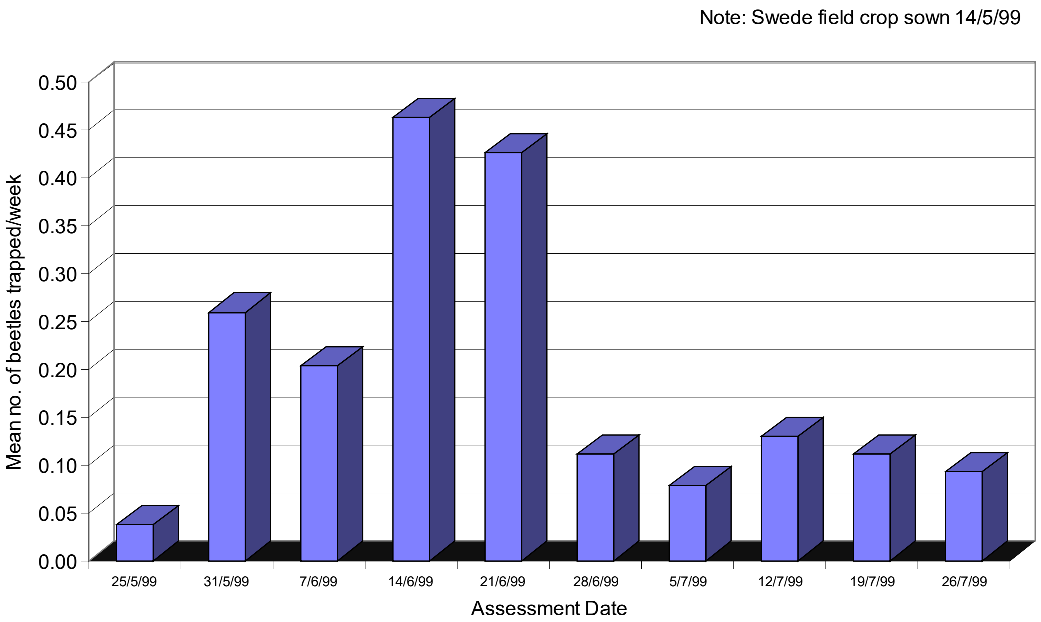


Figure 2. Overall flea beetle species composition at the East Lothian monitoring site.

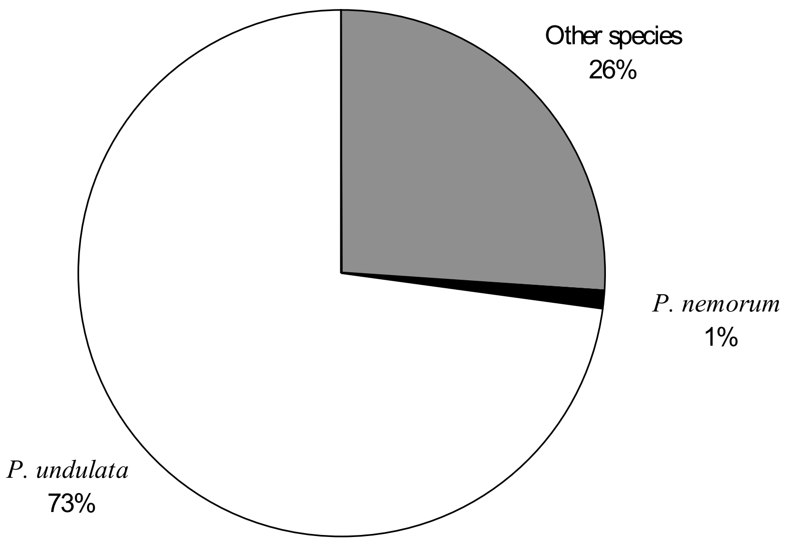


Figure 3. Trap catches of all flea beetle species at the Herefordshire monitoring site.

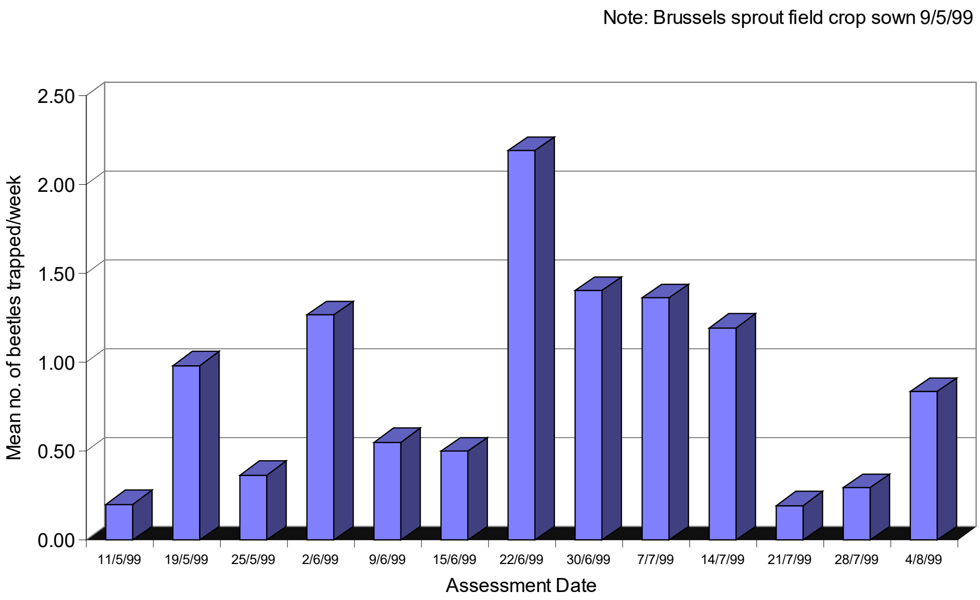


Figure 4. Overall flea beetle species composition at the Herefordshire monitoring site.

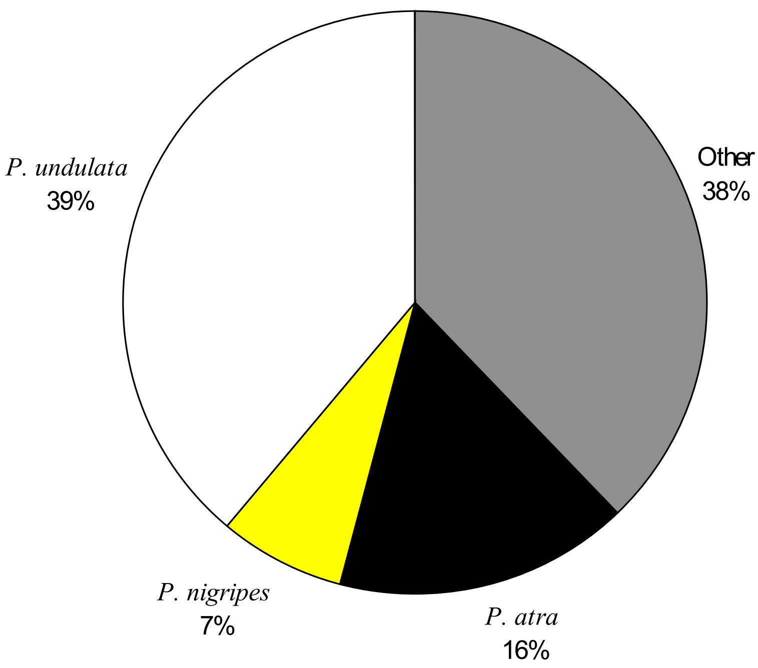


Figure 5. Trap catches of all flea beetle species at the Devon monitoring site.

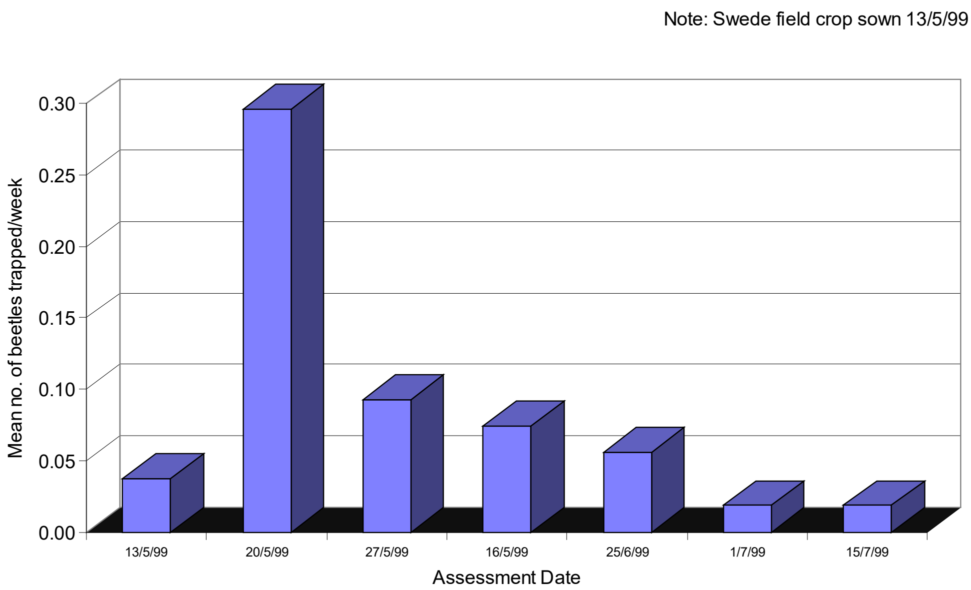


Figure 6. Overall flea beetle species composition at the Devon monitoring site.

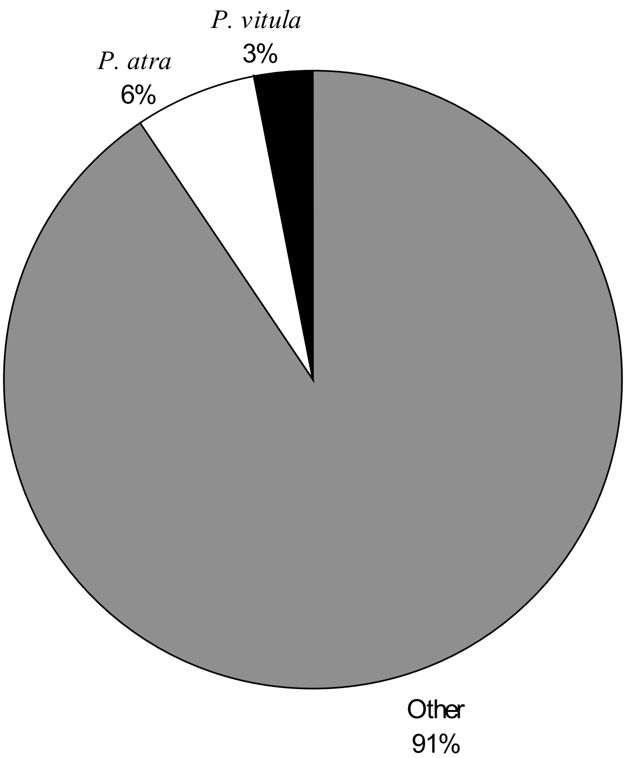
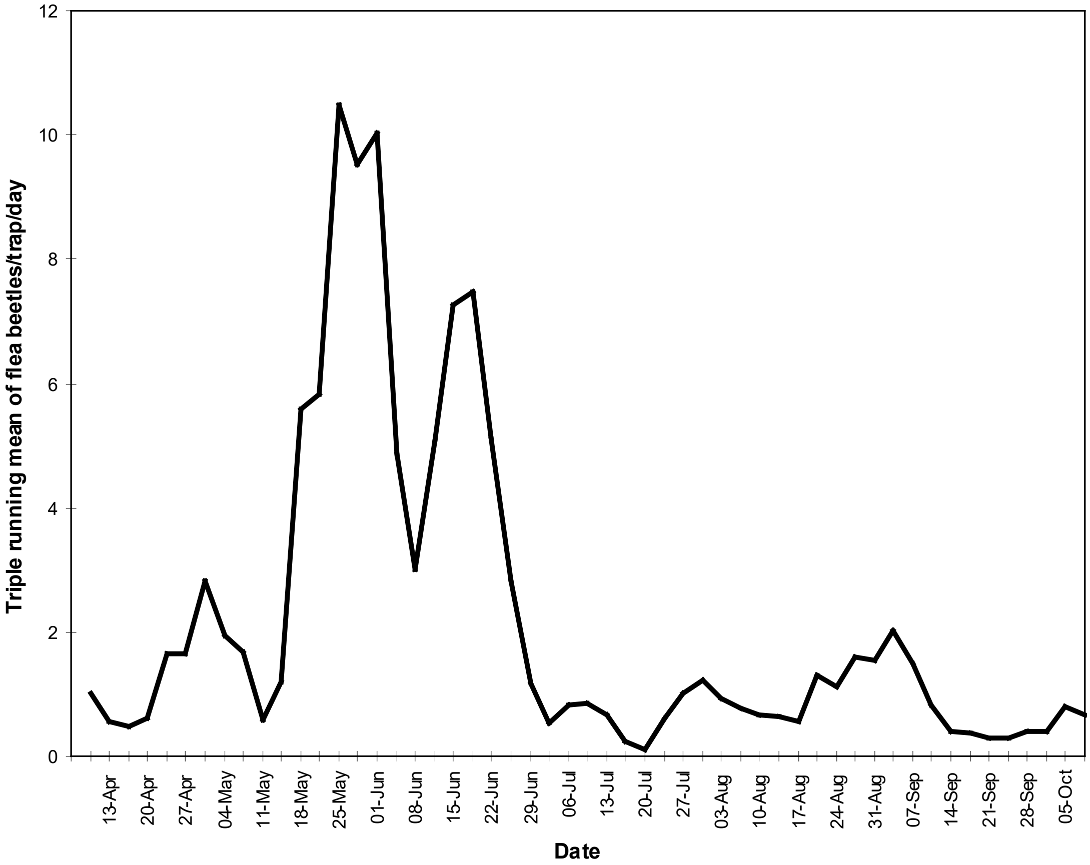


Fig.7. Triple-running means of the numbers of flea beetles caught/trap/day at Wellesbourne during 1999.



Assessment of trap crop attractiveness

Materials and methods

Site location

This experiment was done at two of the three commercial field sites used for monitoring flea beetle activity and species composition. These were:

1. Flights Farm, Ledbury, Herefordshire.
2. Eastacotte Farm, Crediton, Devon.

Trap crop types

Potential trap crop types were selected on the basis of work done at the University of Guelph, Ontario, Canada (McKeown, pers. comm.), that had demonstrated the possibility of using exotic brassica species as potential trap crops for flea beetle management. Four of the most promising trap crops from the Canadian work were selected for inclusion in the current experiments (Table 1).

Table 1. Potential trap crops selected for inclusion in attractiveness experiments.

Common name	**Cultivar**
Summer turnip	White lady
Chinese cabbage	Kasumi
Chinese radish	Lo bok
Indian Mustard (*Brassica juncea)*	Var. *crispifolia*

Swede was selected as the ‘control’ crop.

Trap crop seed was obtained from commercial seed suppliers in Canada (Richters Seeds, Goodwood, Ontario, Canada and Stokes Seeds, St Catherines, Ontario, Canada).

Experimental design and analysis

The experiment was designed to test the interaction between trap crop type and sowing date on attractiveness to flea beetles, using swede as a ‘field crop’ control. The four trap crop types were sown on four different dates. Swedes were sown on the last sowing date only. The formal design of the experiment was therefore a randomised block four x four factorial plus control design, with all ‘treatment’ combinations replicated five times. Each ‘plot’ consisted of a single seed tray of one treatment group (trap crop x sowing date) or control, resulting in a total of 85 trays (i.e. four varieties, replicated five times for four sowing dates, plus the swede control replicated five times for one date only). Raw data from both sites were tested for normality and $\log_{10}(n+1)$ transformed when necessary to achieve a normally distributed data set (note that all data in the Results section are presented as back-transformed means). Analysis of variance was then performed on these data, in which trap crop type, trap crop age, flea beetle species and site were treated as factors. The significance of main effects and interactions were assessed using F (variance ratio) tests. Where F tests were significant, differences between means were tested using least significant differences (LSD) tests at *P*=0.05.

Experimental procedure

Trap crop sowing dates: for the Herefordshire site, sowing dates were 10, 19, 26 May and 2 June 1999, and for the Devon site 30 April, 7, 14 and 21 May 1999. Due to problems with the first assessment at the Devon site (see below), a final sowing date of 6 June 1999 was also included. Swedes were sown on the final sowing date at both sites.

Seed germination and propagation: at each sowing date, five Hassy 104 seed trays were sown, each with 48 seeds per tray for each of the four trap crops. The compost of each tray was then drenched with fungicide (Aliette, 80% w/w fosetyl-aluminium), at 5 g product/100 ml of water per m^2. Thereafter, the trays were watered little but often to keep compost moist. The plants were maintained in a well-vented greenhouse at a constant 18°C ± 2°C. Once germinated and established, the seeds were transferred to ambient temperature. Approximately three weeks after planting, plants were fed with potassium nitrate (0.007 g/l). Once plants had between one and two true leaves a further Aliette treatment was applied where mildew was present using a conventional hydraulic sprayer at a rate of 0.5 g product/100 ml water per m^2. Once plants were established, they were thinned to 40 seedlings per tray.

Field procedure: the trays of plants were set out in the field on 6 June 1999 and 9 June 1999 at the Devon and Herefordshire sites respectively; exactly five weeks after the first batch of trap crop seeds were sown. The trays were spaced at equal distances around three edges of the field in a randomised block design. Each tray was slightly sunk into the soil surface to enhance moisture retention in the seed modules. Additional watering was done as required to keep the compost moist and the plants actively growing. Due to poor weather conditions at the Devon site, the first assessment was abandoned and the start of the experiment was delayed by a week. On the new starting date of 16 June 1999**,** the oldest trays of each trap crop variety were removed and replaced with a new, most recently sown tray. This ensured that the trap crops and the swede control were still no more than four weeks apart in age.

Assessments

Flea beetle numbers: assessments of beetle numbers on each tray of plants were made two and 10 days post planting. At each assessment, each tray was carefully placed inside a large, clear, polythene bag and gently shaken to dislodge any flea beetles. After the assessment at two days, the tray was carefully removed from the bag and returned to its original position. The contents of the bag were emptied into a small, self-sealing bag, labeled with the assessment day and tray number and returned to the laboratory for identification and counting of beetles.

Flea beetle damage: at the assessment 10 days post planting, 20 plants were collected from each tray, returned to the laboratory in labeled polythene bags, and assessed for flea beetle damage. All the leaves from a single plant were removed and the number of flea beetle holes in a 1 cm^2 area recorded for each leaf. Where leaves were less than 1 cm^2, the number of holes in a 0.5 cm^2 area was recorded. Damage caused by pests other than flea beetles (birds/rabbits) was also noted.

Results

Overall, significantly more flea beetles were trapped at the Herefordshire site compared to the Devon site (F=190.45, d.f.=6, 2366, *P*<0.001). The species range also varied between the sites. *P. undulata* was the dominant species present at the Herefordshire site (Figure 8a), followed by *P. atra*, *P. nigripes*, and *P. nemorum*. *P. vitula* was not found. Conversely, *P. vitula* was the dominant species at the Devon site, followed by *P. nigripes*, *P. atra* and *P. nemorum* (Fig. 7b). *P. undulata* was not found. Despite the high numbers of non-*Phyllotreta* species found in the water traps at both sites (particularly in Devon), these species were generally found in only low numbers on the trap crops.

Herefordshire site

Effect of trap crop type: a significant (F=5.6, d.f.=3, 136, *P*<0.001) effect of crop type on the number of beetles attracted (averaged over both assessment dates) was found (Fig. 9). All trap crops attracted significantly more beetles than swede. Trays of Chinese radish, summer turnip and Chinese cabbage attracted a similar number of flea beetles over the experimental period (7.89, 7.36 and 6.28 beetles per tray respectively). Indian mustard (mean of 4.20 beetles per tray) attracted significantly fewer beetles than Chinese radish. Swedes only attracted an average of 1.46 beetles per tray. A significant difference in the number of each species found on all crop types was also found (F=594.37, d.f.=6, 816, *P*<0.001), with *P. undulata* being predominantly attracted, followed by *P. atra*, *P. nigripes*, other non-*Phyllotreta* flea beetles and finally a small number of *P. nemorum*. This generally reflected the relative abundance of *Phyllotreta* species found in the water traps (Fig. 4); very few non-*Phyllotreta* species were found on the trap crops relative to the number found in water traps.

A significant interaction (F=3.02, d.f.=18, 816, *P*<0.001) was found between flea beetle species attracted and crop type (Fig. 10). Chinese radish, summer turnip and Chinese cabbage primarily attracted *P. undulata* and *P. atra*. Indian mustard tended to attract fewer *P. undulata* compared with the other trap crops. Swede attracted fewer beetles of all species, but tended to attract relatively more *P. nigripes*.

Effect of trap crop age: crop age (in weeks from sowing) had a significant effect on overall flea beetle attraction (F=3.15, d.f.= 3, 1182, *P*=0.024). Four-week-old trap crops attracted more beetles than crops sown later (Fig. 11). There was also a significant (F=2.61, d.f.=18, 816, *P*<0.001) interaction between crop age and flea beetle species attracted (Fig.12). The oldest trap crops (4 weeks) consistently trapped the greatest numbers of all flea beetle species. However, the two-week-old crops appeared to be less attractive to *P. undulata* than to *P. atra.* With the exception of *P. undulata*, one-week-old crops were the least attractive to all species.

Devon site

Effect of trap crop type: a significant (F=4.24, d.f.=3, 136, *P*<0.01) effect of crop type on the number of beetles attracted (averaged over both assessment dates) was found (Fig. 13). Summer turnip and Chinese cabbage attracted the most beetles (means of 0.089 and 0.082 beetles per tray respectively). Indian mustard and Chinese radish tended to attract fewer beetles (means of 0.032 and 0.029 beetles per tray respectively). Swede did not attract any beetles at this site. A significant difference in the number of each species found on all trap crops was also identified (F=13.57, d.f.=6, 816, P<0.01). *P. vitula* and *P. nigripes* were the dominant species, followed by *P. atra* and *P. nemorum.* Despite the high numbers of non-*Phyllotreta* species found in the water traps, none were found on the trap crops.

There was a significant (F=3.45, d.f.=18, 816, *P*<0.01) interaction between crop type and flea beetle species (Fig. 14). *P. nigripes* had a strong tendency to prefer Chinese cabbage and Summer turnip, whereas *P. vitula* tended to be attracted to Indian mustard and Summer turnip.

Effect of trap crop age: crop age (in weeks from sowing) had a significant (F=8.36, d.f.= 3, 1182, *P*<0.001) effect on overall flea beetle attraction (Fig. 15). As at the Herefordshire site, four-week-old crops attracted more beetles than those sown later. There was also a significant (F=2.68, d.f.=18, 816, *P*<0.01) interaction between flea beetle species and trap crop age (Fig. 16). One, two and four-week old crops attracted generally similar proportions of all species (four-week-old crops were most attractive), but the proportions of *P. atra* and *P. vitula* attracted by three-week-old trap crops were low relative to other species.

Damage assessments

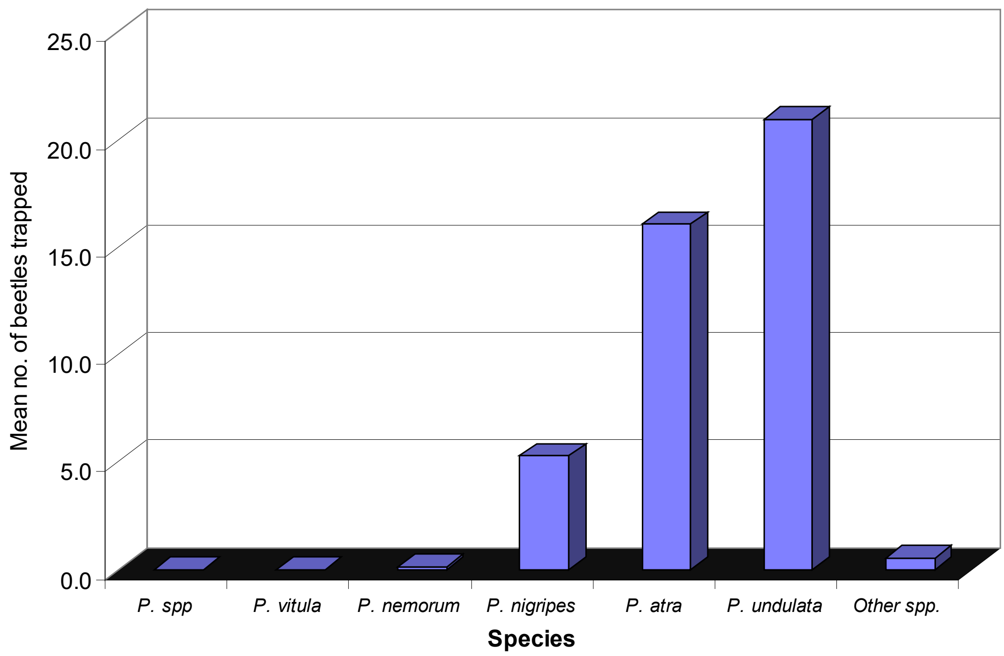
Analysis of the Herefordshire data was based on the *mean* number of holes per cm^2 for each plant. However, analysis of the damage data from the Devon site was based on the *total* holes per cm^2 for each plant and therefore does account for plant size. These latter data should therefore be treated more cautiously.

Herefordshire site: *c*rop type significantly (F=12.10, d.f.=3, 68, P<0.001) affected the amount of crop damage (Fig. 17). Most damage occurred on swede (mean of 18.9 holes/cm^2/leaf) despite being the least attractive crop to flea beetles (Fig. 9). Chinese cabbage suffered the least damage (8.28 holes/cm^2) despite being moderately attractive to flea beetles (Fig. 8). However, there was no direct relationship between flea beetles numbers found on trap crops and leaf damage levels. Trap crop age also significantly (F=24.38, d.f.=3, 68, P<0.001) affected flea beetle damage (Fig. 18). Again, in contrast to the flea beetle population assessments, damaged decreased with increasing crop age.

Devon site: Damage levels at this site were generally lower than in Herefordshire. Trap crop type did not significantly affect the level of damage (F=0.91, d.f.=3, 68, *P*=0.440) and there was no relationship between the amount of damage and flea beetle numbers. Trap crop age (Fig. 20) did not significantly affect the level of flea beetle damage (F=2.67, d.f.=3, 68, *P*=0.054).

Fig. 8. Relative numbers of different flea beetle species found on trap crops at experimental sites.

a) Herefordshire



b) Devon

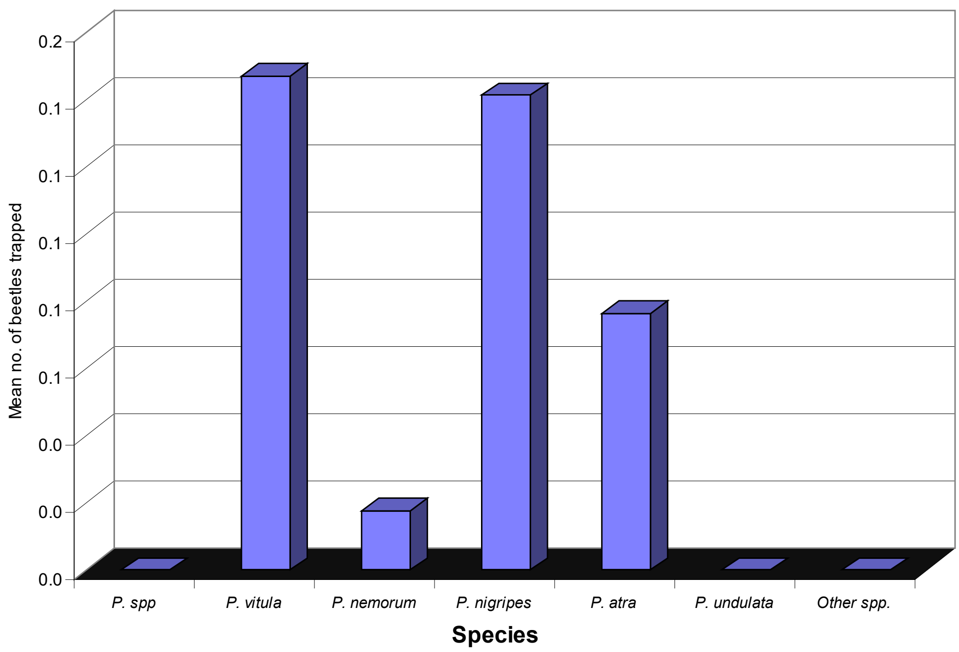


Fig. 9. Overall mean number of flea beetles attracted to individual trap crops and swede (control) at the Herefordshire experimental site.

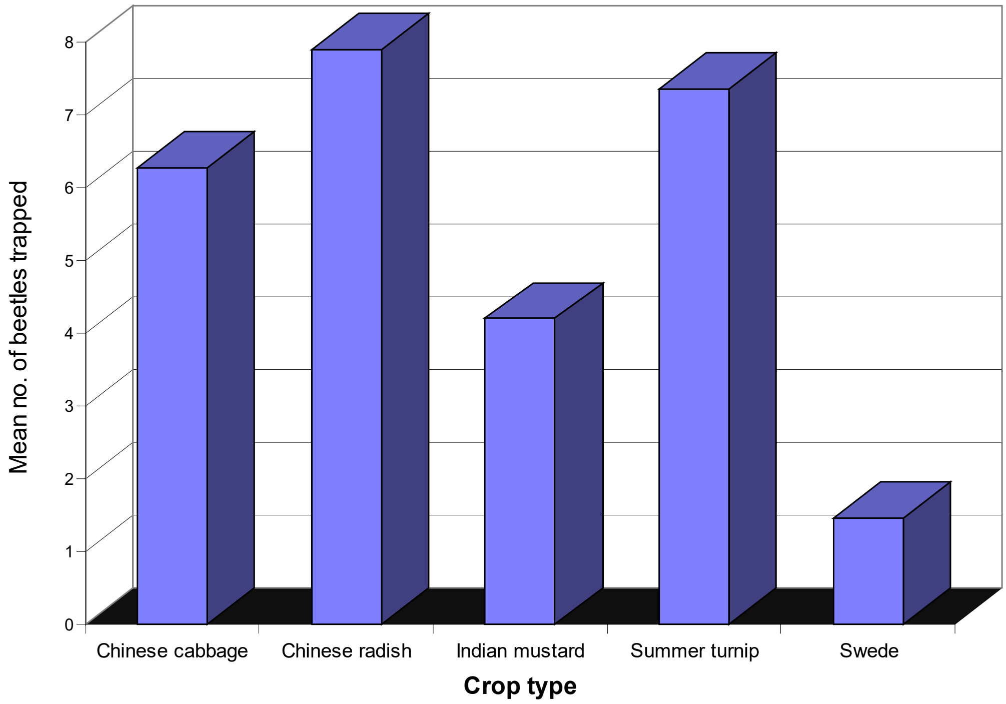


Figure 10. The interactions between flea beetle species attracted and trap crop type at the Herefordshire experimental site.

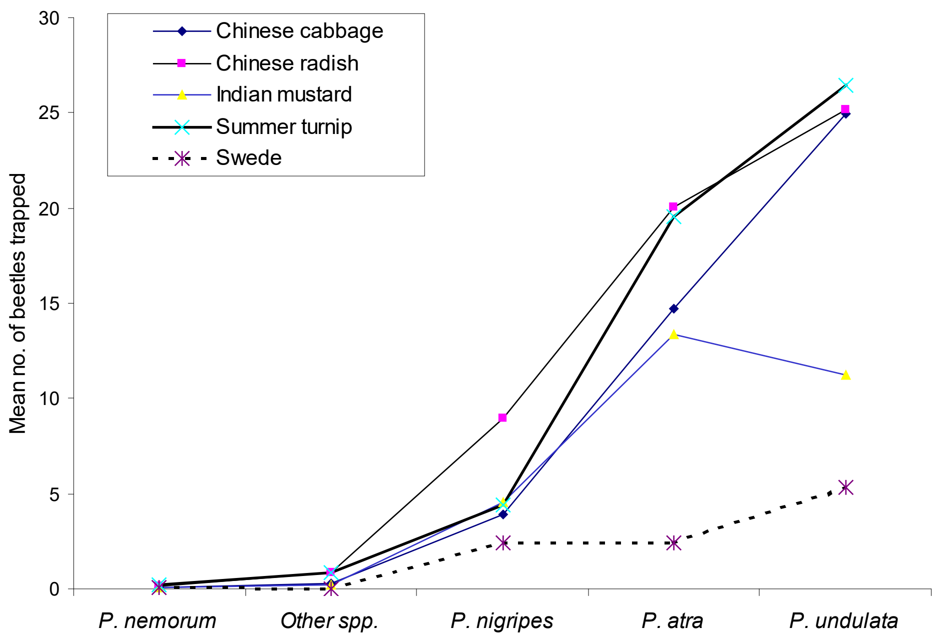


Fig. 11. Overall mean number of flea beetles attracted to trap crops (data for all crops pooled) of different ages at the Herefordshire experimental site.

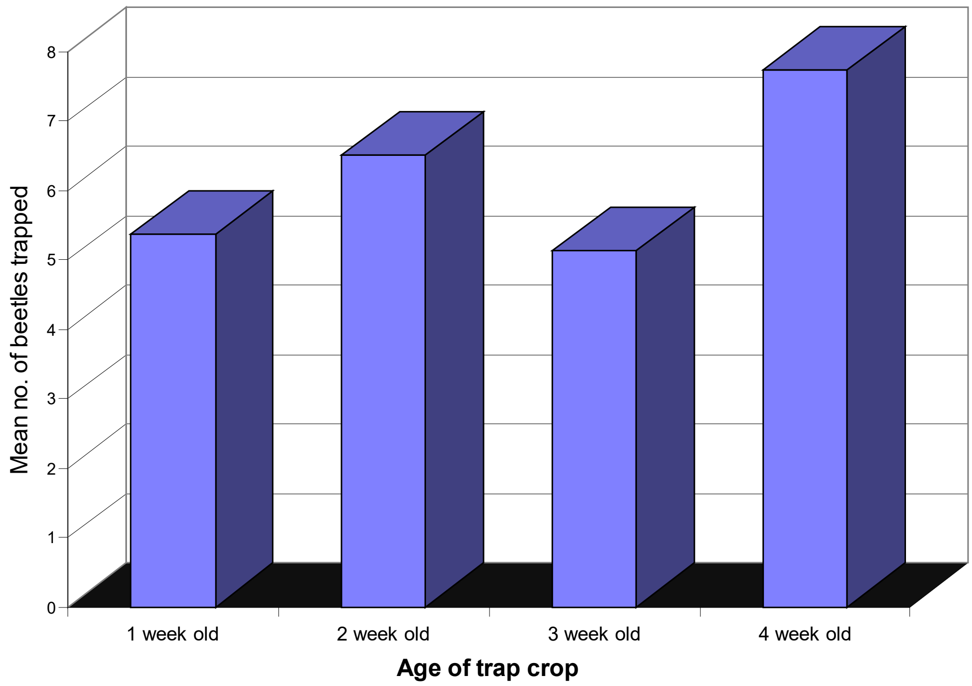


Fig. 12. The interactions between flea beetle species attracted and trap crop age at the Herefordshire experimental site.

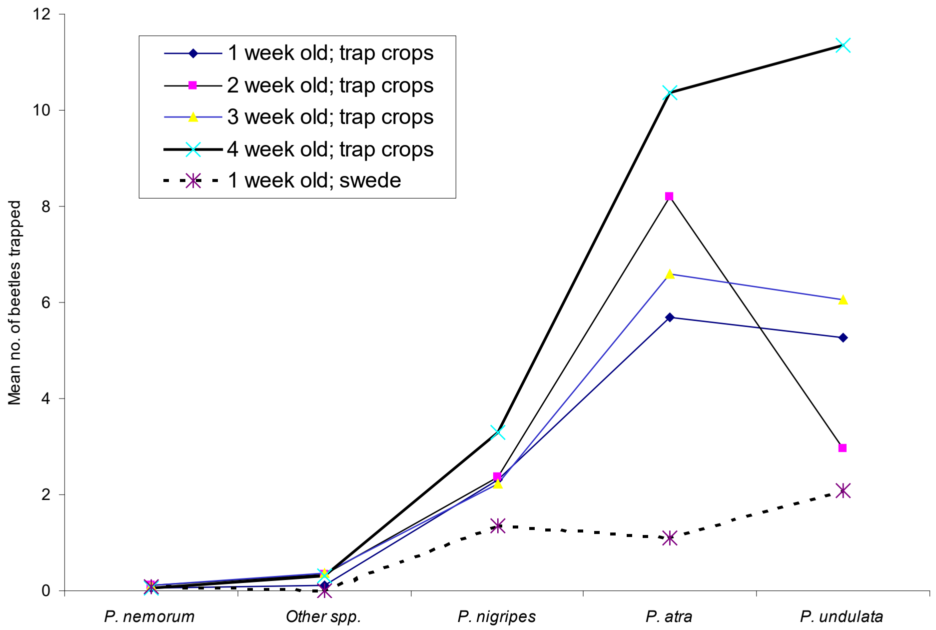


Fig. 13. Overall mean number of flea beetles attracted to individual trap crops and swede (control) at the Devon experimental site.

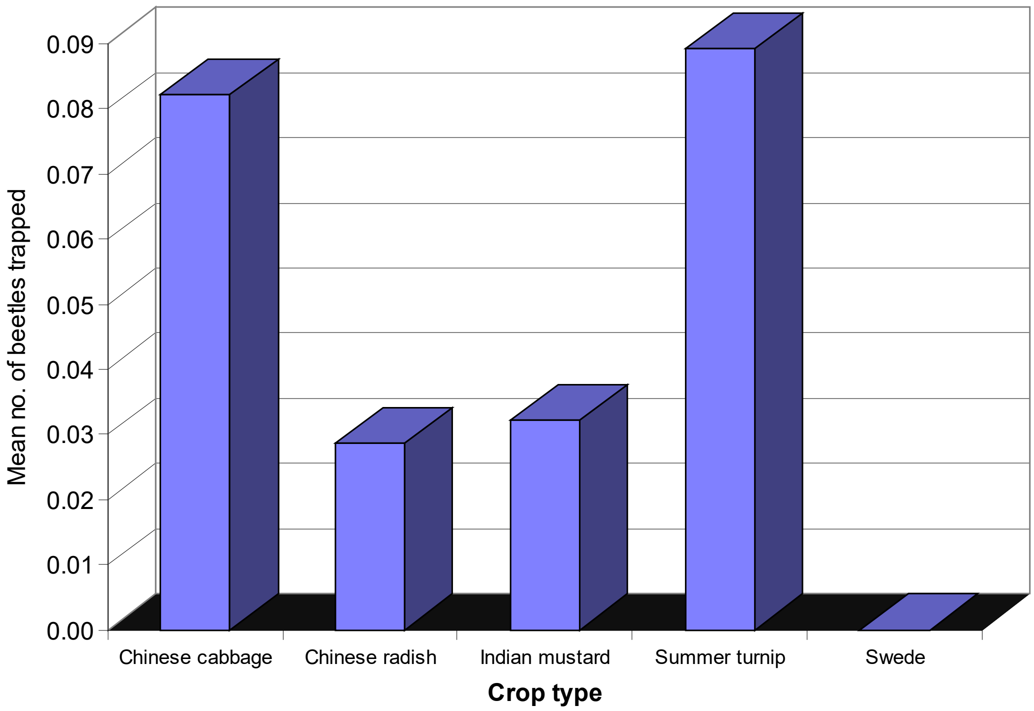


Fig. 14. The interactions between flea beetle species attracted and trap crop type at the Devon experimental site.

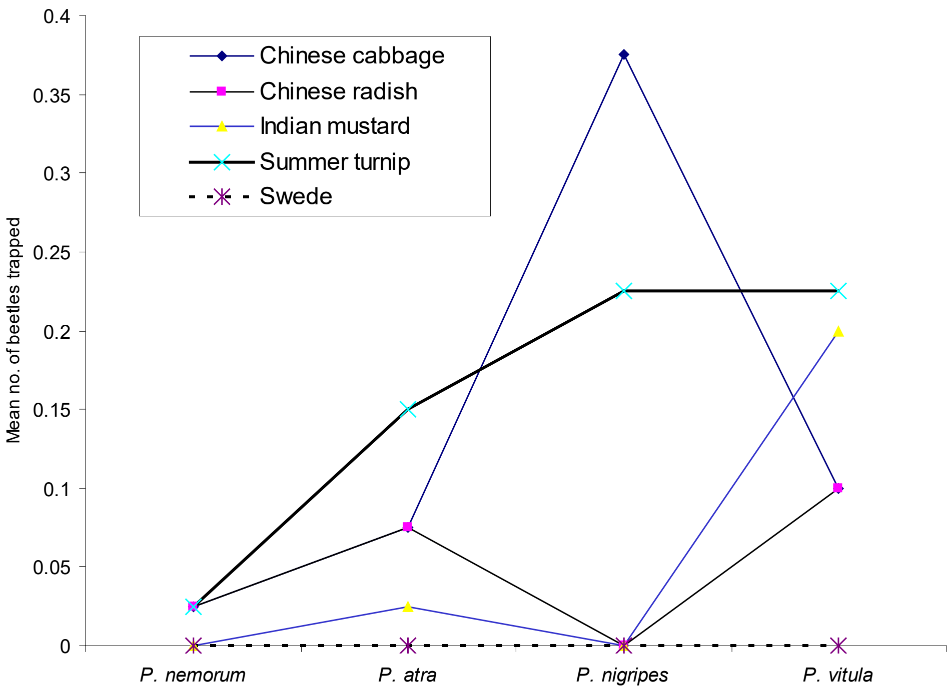


Fig. 15. Overall mean number of flea beetles attracted to trap crops (data for all crops pooled) of different ages at the Devon experimental site.

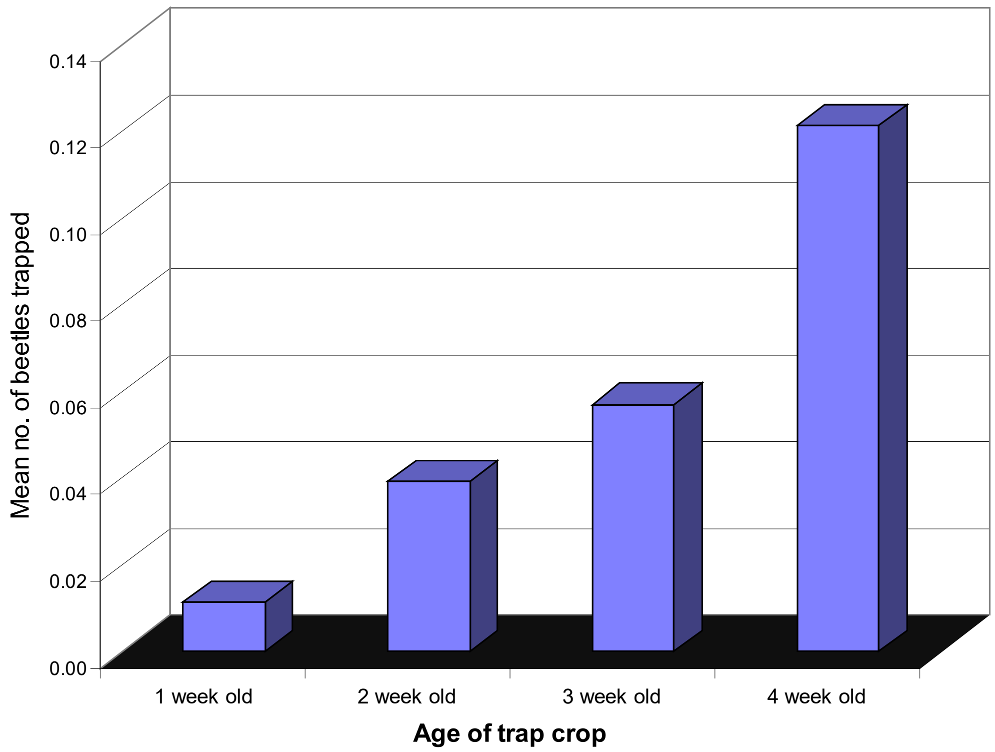


Fig. 16. The interactions between flea beetle species attracted and trap crop age at the Devon experimental site.

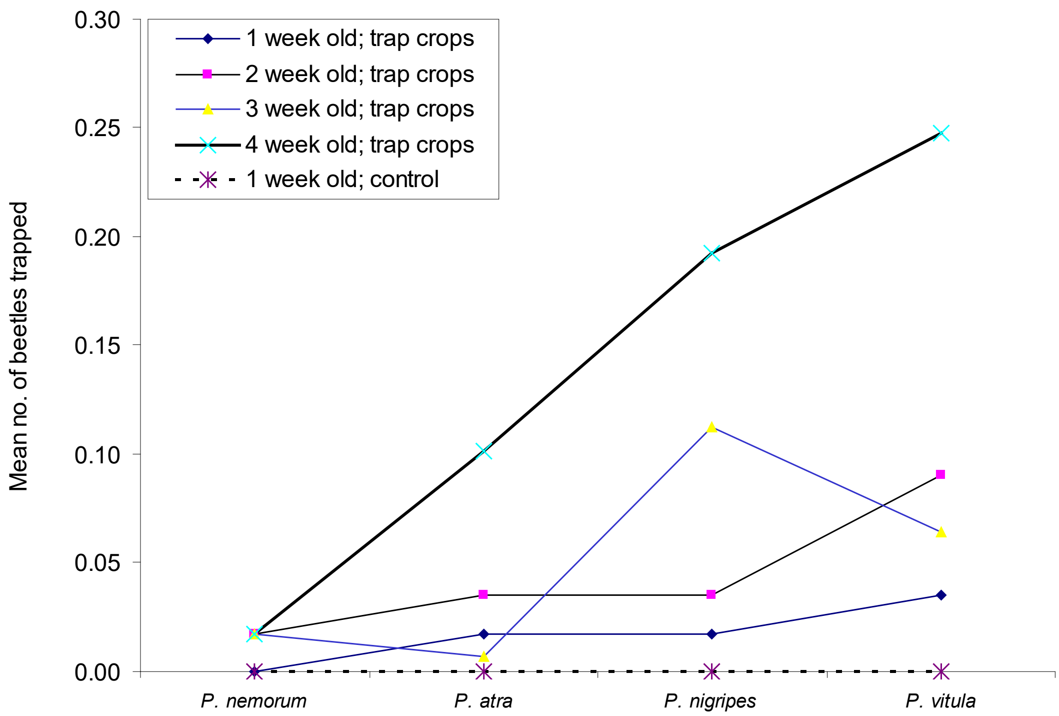


Fig. 17. Mean number of holes per cm^2 of leaf on different crop types 10 days after setting out plant trays at the Herefordshire site.

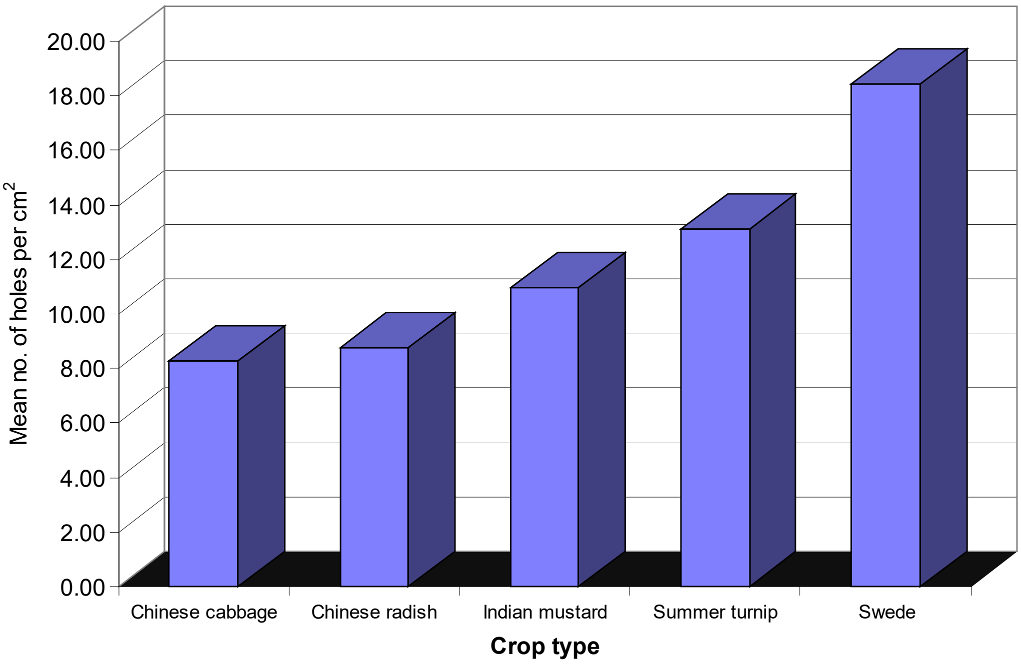


Fig. 18. Mean number of holes per cm^2 of leaf on all plants of different ages (all crop types pooled) 10 days after setting out plant trays at the Herefordshire site.

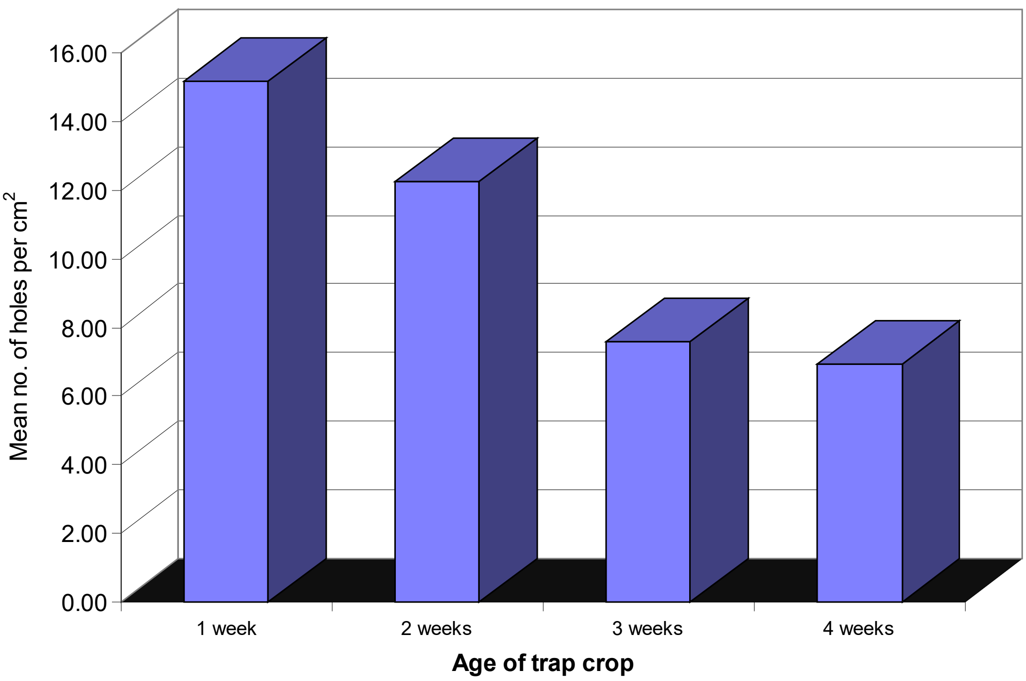


Fig. 19. Mean number of holes per cm^2 of leaf on different crop types 10 days after setting out plant trays at the Devon site.

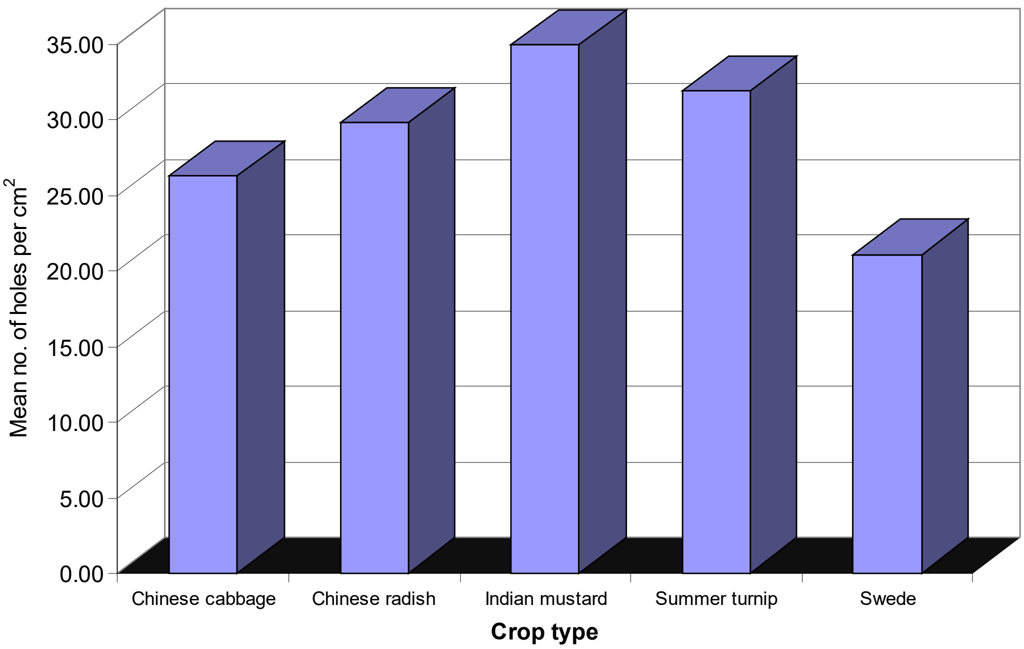
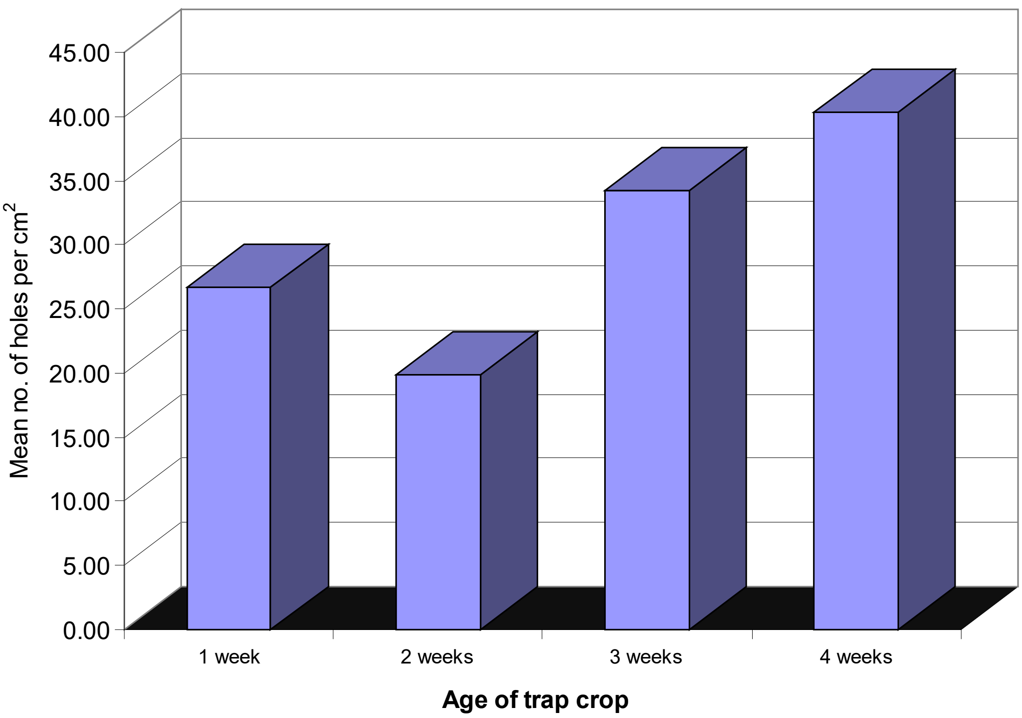


Fig. 20. Mean number of holes per cm^2 of leaf on all plants of different ages (all crop types pooled) 10 days after setting out plant trays at the Devon site.



Assessment of Insecticide Efficacy

Effectiveness of non-OP soil insecticides for the control of flea beetles on brassica seedlings

Materials and methods

Swede seeds were film-coated at HRI, Wellesbourne with tefluthrin (Force 20ST), imidacloprid (Gaucho), fipronil (experimental seed treatment formulation) and carbofuran (Furadan 330ST). Each of the four insecticides were applied at target loadings equivalent to 6.25, 12.5, 25 and 50 g a.i. (active ingredient)/unit (1 unit =100,000 seeds) with a PVA sticker at 0.5 % of product weight. Actual loadings achieved (Table 2) were assessed by high performance liquid chromatography (HPLC) analysis of samples of the treated seed. A further batch of seed was left untreated.

Table 2. Target and actual doses of insecticide applied to swede seed.

Insecticide	Target dose (g a.i./unit)	Actual dose (g a.i./unit)
Carbofuran	6.25	5.8
	12.5	11.8
	25	25.4
	50	47.9
Fipronil	6.25	5.3
	12.5	10.8
	25	20.7
	50	39.4
Imidacloprid	6.25	5.1
	12.5	10.1
	25	16.3
	50	35.6
Tefluthrin	6.25	5.8
	12.5	10.9
	25	21.9
	50	44.5

On 18 May the seed was drilled in four rows in each three m long bed (1.83 m wide) using a precision drill to produce a within row spacing of 7.5 cm. Each block contained one plot drilled with each of the four insecticides plus a plot drilled with the untreated seed. Each block was replicated five times and the whole experiment was laid out as a five by five Latin square. Each insecticide-treated plot contained one row of each of the four test dose levels.

Seedling emergence was assessed on 28 May (10 days after drilling) and seedling survival was measured on 4 June and 9 July. Flea beetle feeding damage was assessed on 4 June by counting the numbers of damaged and undamaged seedlings.

Table 3. Mean numbers of living swede seedlings

Insecticide	Dose (g a.i./unit)	Number of plants (3 m of row)		
		28-May	04-Jun	09-Jul
Untreated	0	48	50	51
Carbofuran	5.8	50	54	51
	11.8	51	55	54
	25.4	50	50	53
	47.9	36	44	45
Fipronil	5.3	51	51	51
	10.8	53	55	53
	20.7	52	52	52
	39.4	51	52	48
Imidacloprid	5.1	49	53	53
	10.1	53	55	53
	16.3	53	54	55
	35.6	44	50	51
Tefluthrin	5.8	53	54	52
	10.9	52	54	51
	21.9	53	55	52
	44.5	52	52	53

Table 4. Mean percentage of swede seedlings damaged by flea beetles

Insecticide	Dose (g a.i./unit)	% seedlings damaged
Untreated	0	76
Carbofuran	5.8	33
	11.8	26
	25.4	22
	47.9	39
Fipronil	5.3	71
	10.8	67
	20.7	72
	39.4	79
Imidacloprid	5.1	63
	10.1	49
	16.3	33
	35.6	36
Tefluthrin	5.8	72
	10.9	72
	21.9	68
	44.5	63

Results

Despite the high levels of flea beetle attack observed on all treatments, there was no evidence of a reduction in plant stand in any treatment (Table 3). The only effect observed was a slight suppression of seedling emergence at the highest doses of both carbofuran (47.9 g a.i./unit) and imidacloprid (35.6 g a.i./unit). However, 17 days after sowing the plant stands were similar in all treatments (Table 3)

Both carbofuran and imidacloprid treatments reduced the percentage of seedlings damaged (Table 4) and the level of control tended to increased with increasing dose (although not at the highest doses). In contrast, damage was not reduced by the fipronil or tefluthrin treatments at any of the doses tested.

Effectiveness of pyrethroid insecticide sprays for the control of flea beetles on turnip seedlings

Materials and methods

Turnip seed was drilled on 18 May at four rows/bed (1.83 m wide) using a precision drill at a within row spacing of 10 cm. On 25 May, lambda-cyhalothrin (Hallmark), deltamethrin (Decis), cypermethrin (Ashlade Cypermethrin), gamma-HCH (Gamma-col) and water only spray treatments were applied in 300 l water/ha at the rates shown in Table 5. The treatments were arranged so that the four insecticide-treated and the untreated plots formed a five by five Latin square of four m long plots

Table 5. Doses of pyrethroid insecticide applied as foliar sprays to turnip seedlings.

Insecticide	Product/ha (ml)	Active ingredient/ha (g)
Lambda-cyhalothrin	300	15
Deltamethrin	600	15
Cypermethrin	250	25
Gamma-HCH	700	560

Seedling emergence was assessed on 28 May (10 days after drilling). Seedling survival and flea beetle damage were assessed on 1 June by counting numbers of damaged and undamaged seedlings in the middle two rows of each plot.

Results

Flea beetle attack was heavy on untreated plots. There was a slight decrease in mean plant stand in all treatments between the assessments made on 28 May and 1 June (Table 6). This was most pronounced in the untreated plots. The slight decrease in the other plots was similar for all four insecticides.

Compared to the control plots all four insecticides reduced the levels of seedling damage (Table 7). All three pyrethroid insecticide treatments were more effective than gamma-HCH, even though the latter was applied at a much higher dose rate.

Table 6. Mean numbers of living swede seedlings

		Number of plants/4 m row		
Insecticide	**Dose (g ai/ha)**	**28-May**	**01-Jun**	**Plant stand (%)**
Untreated	0	44	40	91
lambda-cyhalothrin	15	43	42	97
Deltamethrin	15	44	43	97
Cypermethrin	25	44	43	98
Gamma-HCH	560	38	37	96

Table 7. Mean percentage of swede seedlings damaged by flea beetle.

Insecticide	**Dose (g ai/ha)**	**% seedlings damaged**
Untreated	0	83
Lambda-cyhalothrin	15	46
Deltamethrin	15	56
Cypermethrin	25	53
Gamma-HCH	560	63

General Discussion

Flea beetle monitoring

The monitoring work clearly demonstrated that *Phyllotreta* flea beetles could potentially be active for the whole of the May to July period. The extended monitoring at HRI Wellesbourne also showed that flea beetles continued to be active into the autumn. However, there were clear peaks of activity lasting one to four weeks at all sites, ranging from mid- to late May to the end of June in Devon and at HRI Wellesbourne to late June to mid-July in Herefordshire and East Lothian. There were also clear differences in the species complex between sites. *P. undulata* was the dominant species in East Lothian and Herefordshire, whereas *P. vitula* and *P. nigripes* were more common in Devon. Limited data analyses suggest that *P. nigripes* was a common species at HRI Wellesbourne.

Trap cropping

Clear differences were demonstrated in the attractiveness of the *Brassica* trap crop species tested relative to the swede control at both the Herefordshire and Devon sites. In general, Chinese cabbage, Chinese radish and summer turnip were the most attractive species. This concurs with earlier work which has shown that mustard, turnip and radish were all attractive to, and readily fed upon, by *Phyllotreta* spp. flea beetles (Vargas & Kershaw, 1979). Similarly, unpublished work at the University of Guelph, Ontario, Canada (McKeown, pers. comm.) suggested that of 18 trap crops assessed, Chinese cabbage, white turnip, Japanese and Chinese radish, round black Spanish radish, canola (oilseed rape) and mustard cabbage were very attractive to flea beetles.

The Ontario work suggested that Indian mustard (*Brassica juncea* var. *crispifolia*) was one of the most effective trap crops. Ludwig & Kok (1998) also found Indian mustard to be a potential trap crop for moderate populations of the harlequin bug, *Murgantia histrionica* (Hemiptera: Pentatomidae) on broccoli. However, our work suggested that Indian mustard was probably the least attractive to flea beetles of the trap crops tested. One possible explanation is the interaction between flea beetle species and trap crop type found in both Herefordshire and Devon. In Herefordshire, *P. undulata* was the dominant species, but relatively few were found on Indian mustard (Fig. 10). In Devon, *P. nigripes* was one of the common species, but very few were recorded on either Indian mustard or Chinese radish (Fig. 14). Other work has also shown that 'mustard' *Brassicas* are not necessarily preferred by *Phyllotreta* spp. flea beetles (Ekbom, 1995; Palaniswamy & Lamb, 1992). It should also be noted that much of the previous work has based host preference on damage rather than beetle numbers. Our work suggests that there is not a simple association between plant damage and the number of beetles attracted.

Trap crop age was an important influence on trap crop attractiveness. Our results indicated that older trap crops (four weeks old) were generally preferred to younger crops (one week old) at both sites. Other studies (Palaniswamy & Lamb, 1992) have also shown that the host preferences of *Phyllotreta* flea beetles can change with host age and leaf type (cotyledons versus true leaves). There were also indications that crops of different ages may vary in their attractiveness to individual *Phyllotreta* species (e.g. Figs 12 and 16).

In conclusion, of the trap crops tested, Chinese cabbage and summer turnip were the most consistently attractive crops, though this was not necessarily related to the amount of flea beetle damage on these crops. Other important factors were trap crop age relative to the field crop, and possibly flea beetle species present. The beetles generally preferred trap crops that were up to four weeks older than the field crop. There was also some evidence that individual flea beetle species displayed preferences for particular trap crops, for example *P. nigripes* showed a strong preference for Chinese cabbage in Devon.

It is too early to draw definitive conclusions about the possible role of trap cropping in flea beetle management. Further work on distance of attractiveness and integration with insecticides (scheduled for subsequent work in this project) is still required. However, early indications are promising. Trap crops may also have the added benefit of affecting other pests. For example studies done in Finland showed that Chinese cabbage (and other *Brassica* species) provided cauliflower almost complete protection against pollen beetle, *Meligethes aeneus* (Hokkanen *et al*., 1986).

Insecticide work

The insecticide work suggested that carbofuran and imidacloprid seed treatments were generally more effective than single foliar sprays at reducing the percentage of seedlings damaged by flea beetles. The level of control achieved (60-70% reduction in damage) by the seed treatments was not as high as that reported by Finch & Edmonds (1999) for *Phyllotreta* spp. damage to Brussels sprouts seedlings in semi-open glasshouse. Broadly similar levels of control to our work were reported by Cullis *et al*. (1999) for the use of carbofuran and imidacloprid against flax flea beetles on linseed.

The foliar spray work confirmed that single pyrethroid sprays do not provide a significant level of protection against flea beetle attack. However, the use of repeated treatments may give a more realistic indication of the effectiveness of such treatments in commercial practice.

Acknowledgements

We are grateful for the cooperation of the host farmers at the East Lothian, Herefordshire and Devon field sites.

References

Cullis, A G, Finch, S, Jukes, A A, Hartfield, C M. (1999). Evaluation of insecticidal seed treatments for the control of flax flea beetles in spring sown linseed. *Tests of Agrochemicals and Cultivars* No. 20 (*Annals of Applied Biology* **134** Supplement) 6-7.

Ekbom, B. (1995) Flea beetle (*Phyllotreta undulata*) feeding preferences. *IOBC Bulletin* **18**, 88-94.

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

Hokkanen, M T. (1991) Trap cropping in pest management. *Annual Review of Entomology* **36**, 119-138.

Hokkanen, M T, Granlund, H, Husberg, G B & Markkula, M. (1986) Trap crops used successfully to control *Meligethes aeneus* (Col., Nitidulidae), the rape blossom beetle. *Annales Entomologici Fennici* **52**, 115-120.

Ludwig, S W & Kok, L T. (1998). Evaluation of trap crops to manage harlequin bugs, *Murgantia histrionica* (Hahn) (Hemiptera: Pentatomidae) on broccoli. **Crop Protection 17**, 123-128.

Oakley, J N, Corbett, S J, Parker, W E & Young, J E B. (1996). Assessment of risk and control of flax flea beetles on linseed. *Proceedings of the Brighton Crop Protection Conference - Pests and Diseases* **3** pp 191-196.

Palaniswamy, P & Lamb R J. (1992) Host preferences of the flea beetles *Phyllotreta cruciferae* and *P. striolata* (Coleoptera: Chrysomelidae) for crucifer seedlings. *Journal of Economic Entomology* **85**, 743-752.

Vargas, P & Kershaw, W J S. (1979) Host selection and choice of feeding site by the flea beetle *Phyllotreta undulata* Kutsch. *Anales del Instituto Nacional de Investigaciones Agarias, Proteccion Vegetal* **10**, 81-93.