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

AUTHENTICATION

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

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Grower Summary

Headline

- Meshes alone do not completely prevent insect damage. Their impact can be improved by additional sprays and have the added advantage of increasing crop growth.
- Surrounding production beds with a low-barrier or fence can intercept the low-flying diamondback moth and leaf-miner adults. In combination with the standard farm mesh this should achieve a high level of pest control.
- Some insecticides/mesh combinations provided excellent control with spinosad now registered for use on leafy Brassicas. A coded product that showed promise has now been released.

Background and expected deliverables

Growers identified the Brassica flea beetle complex as a research priority (HDC research strategy & Pesticide Gap Analysis, 2005), because adult flea beetle feeding causes 'shot-holes' in the leaves of the crop. This significantly reduces quality and thus marketability of Brassicas grown for salads. In addition to flea beetles, speciality salad and leafy vegetables are also attacked by a range of other insect pests such as diamondback moth caterpillars and weevils.

Brassica flea beetle control is a challenge, partly because some insecticides that were used in the past have been withdrawn and are no longer available to growers. An increase in rape acreage (source of immigrant pests) and the reduced use of insecticides on rape has made the situation worse. Several potentially useful insecticides such as spinosad (registered for Brassicas since the start of the project) and neonicotinoids, which could offer growers some additional choices to manage flea beetles, were evaluated in this project. Experiments were designed with the long-term goal to produce an acceptable crop without the application of insecticides.

In addition to the use of insecticidal sprays, there are some other potentially useful pest-management technologies. One possibility is the use of seed coated with a film of pesticide. Such seed treatments are already available for several fodder Brassica crops. Previous research on cabbage and cauliflower has shown that flea beetle damage can be reduced by imidacloprid. Our own previous trials have shown that thiamethoxam has the best effect as a seed treatment and so thiamethoxam was selected for an additional trial in 2009.

Another potential non-chemical control tactic is the use of trap crops. This was investigated recently in the UK, but few practical recommendations came out of this research (Parker et al., 2002). The main problem with using trap crops is that high-value leafy Brassicas are extremely attractive in their own right to Brassica-feeding flea beetles and so differences in attractiveness are difficult to exploit.

A well proven control technique is the use of physical barriers, particularly meshes such as Wondermesh and Enviromesh. Some growers use fleece, plastic sheets or glass to protect this high value crop. Meshes protect crops against many insect pests, but are expensive and labour intensive to use. They are however considered cost-effective in situations where even low numbers of insects can quickly destroy the quality and value of the crop. Although highly effective, meshes alone are not sufficient to completely prevent insect damage. Some pests can either feed through the mesh or their larvae may be small enough to pass through the mesh. Pests may also enter the crop underneath the mesh at the edges. Additional insecticidal sprays are the normal practice to reduce this problem.

After assessing the results of the previous two years' research, it was evident that no spray regime or any of the (low-rate) seed treatments had achieved an adequate level of pest/damage control. The use of protective meshes, however, had consistently given the best protection with their protection being improved by additional sprays.

Given the current pesticide regulatory environment, it would be highly desirable to replace sprays in the current farm practice with a lure-and-kill technology. This year's field trials made use of information we have gained previously and were designed to study a lure and kill strategy (used with meshes) in place of the spray regime. An integral component of the trial was to examine spatial patterns of damage within a trial crop. In order to test this technology, a large trial was needed that approached the commercial scale.

A second separate field trial was also carried out this year on a smaller scale, similar to that used in the previous two years. It involved the use of thiamethoxam as seed treatments at three different rates. If successful in controlling the spectrum of pests, treated seed might be useful in growing the sacrificial 'lure' crop.

Summary of the project and main conclusions

The trials were carried out on a farm near Deal in Kent during June/July 2009. The first trial involved testing a potential 'lure-and-kill' technology on a commercial scale. The second trial was aimed at assessing different concentrations of thiamethoxam-treated seed with a view to its use as a sacrificial crop. The main conclusions that can be drawn from the data collected this year were:

- Flea beetle populations were low again in this final year and much of the crop damage was attributable to other pests including leaf miners and diamondback moth (DBM) larvae. However the project found that the dominant insect-pest species changed each year from flea beetles, to weevils, to diamondback moth and two different leaf miner species in years one, two and three, respectively.

- The standard insect mesh treatments were highly effective at preventing access to the crop for most immigrant pest species and they therefore prevented the majority of damage to this short duration crop.

- An important secondary benefit of the mesh was that it increased the crop growth rate.

- Some of the trial insecticides provided excellent control in combination with the mesh and one of these, Spinosad, has now been registered for use on leafy Brassicas. In addition, the coded product that showed considerable promise has now been released.

- Meshes alone are not sufficient in preventing insect damage and providing sufficient protection to meet the high quality standards demanded by the crop buyers. Some pests can enter the crop by going under the edges of the mesh or laying eggs on or through the mesh, resulting in larvae presence within the crop.

- Seed-treatments do not provide adequate protection (figure below); and sacrificial-crop beds are not efficient enough at killing adult DBM. Surrounding production beds with a low-barrier or fence could intercept the low-flying DBM and leaf-miner adults as they approach the meshed crop. If these are used in combination with the standard farm mesh, they should achieve a high level of insect-pest control.

A tatsoi leaf from the seed-treatment trial with the leaf-miner holes and smaller mines present.

- High numbers of living adult DBM (figure below) were counted in the sacrificial crop beds in the days following spray application. The sacrificial crop beds, therefore, acted as expected by attracting insect pests including adult DBM. However, the twice weekly insecticide sprays were insufficient to control the mobile adults.

DBM adult resting on a tatsoi leaf - there were high populations of diamondback moth during the trial period.

- In the ‘lure and kill’ trial, there were clear edge effects on both the left and right sides of the trial, irrespective of the presence of the sacrificial (sprayed) plots. The lowest damage occurred in the middle of the trial.
- The greatest pest pressure of immigrant DBM adults occurred on the Left Hand Side of the trial, which suggests that these were low-flying individuals that stopped to lay eggs (oviposit) soon after the border of the trial was encountered.
- The differences in the damage patterns caused by DBM and leaf-miner, suggest that the source directions of immigrant adults are different.
- The seed-treatment trial gave several interesting results:
    - Insect pest species and their behaviour were affected differently.
    - Very high numbers of small wounds were caused by leaf miner adults on all plots (which were not covered by the standard mesh).
    - Damage caused by leaf-miner adults in some of the seed-treated plots was greater than in the control.
    - The two treatments with the highest doses of thiamethoxam had the least DBM damage, but adult DBM were still observed in all plots.
    - In terms of total damage from all pests, there was a decreasing amount of damage with increasing seed-treatment dose, i.e. the control and Treatment 4 plots suffered the greatest and least damage, respectively.

Financial benefits

A cost-benefit analysis of the different treatments looked at in this project has not been carried out, but some are clearly highly effective at protecting the crop. One of the aims of the project was to try to identify control technologies that could be used in combination with the use of the farm’s mesh covers that are currently used to protect crops. The composition of the insect-pest complex that attacked the trials in each of the previous three years changed markedly, but in each year mesh covers provided an extremely important element of protection for the tatsoi crop. Due to the high pest pressure present each year, it is unlikely that the crops could have been grown successfully (i.e. to the quality demanded by the retailers) without mesh covers.

The information obtained during the three years of this project indicates that there may be ways in which the meshed crop can be grown without the need for insecticides to be applied to it, which could have significant financial benefits, but an additional field trial will be needed to test these ideas.

Action points for growers

- The presence of adjacent, sprayed, sacrificial-crop beds does not provide adequate protection to the crop, because the insecticide sprays were not sufficiently effective at killing the DBM adults. Most of the damage in 2009 was caused by DBM adults that oviposited either on the mesh or through it onto the crop, soon after they encountered the edge of the crop.

- Seed treatments provide very limited and insufficient protection against the insect-pest complex. The presence of large numbers of DBM adults in all of the seed-treated plots made it apparent that seed-treatments do not work as a substitute for spraying insecticide onto the sacrificial crop beds.

- The coded product that showed considerable promise in the previous year's trial has now been released.

- DBM adults fly at very low levels. Surrounding the mesh-covered crop with a low, insecticide-impregnated fence, of a material similar to the type used in year one, would have a good chance of success and may overcome the need to apply any sprays to the meshed crop.

Science Section

Introduction

The Brassica flea beetle complex was identified as a priority researchable topic (HDC research strategy & Pesticide Gap Analysis, 2005). The increasing importance of these pests on Brassicas and, in particular speciality salad and leafy vegetables, may be related to reduced insecticide use on oil seed rape crops, which allows high populations to build up and subsequently emigrate from them. P*hyllotreta undulate*, *P. atra* and *P. diademata* are the main species in the flea beetle pest complex. Adult feeding causes 'shot holes' in the crop, which significantly reduce quality and thus marketability. In addition to flea beetles, speciality salad and leafy vegetables are also attacked by a range of other insect pests including caterpillars such as the Diamondback moth (DBM), the cabbage stem weevil, *Ceutorhynchus pallidactylus*, Brassica weevil, *Ceutorhynchus assimilis* and the cabbage stem flea beetle, *Psylliodes chrysocephala*, which has become the most important establishment pest in autumn grown crops in the UK (Winfield, 1992; Walters *et al*., 2001). Control of these pests, particularly flea beetles, is an increasing challenge because some insecticides that were used in the past are no longer available to growers. However, it was considered that several potentially useful insecticides, such as alternative pyrethroids and neonicotinoids might offer growers some additional choices to manage these highly damaging pests.

Some previous work with the insecticides showed that spinosad (now registered for leafy Brassicas) and imidacloprid had given equivocal results. A report on field experiments with cabbage and cauliflower crops indicated that flea beetle damage could be reduced with imidacloprid, but that it was ineffective at controlling cabbage root fly and caterpillars. Use of seed treatments using plant-systemic insecticides, commonly used for forage Brassicas was an interesting research line to clarify the potential usefulness of this technology for crops destined for human consumption.

Another potential non-chemical control tactic was the use of trap crops, and this was recently investigated in the UK, but few practical recommendations came out of this research. One serious problem with using trap crops is that high-value leafy Brassicas are extremely attractive in their own right to Brassica-feeding flea beetles and it is unlikely that there are plant species that are more attractive than the crops themselves.

One widely used control technique with proven success is use of physical barriers that prevent the pest from having access to the crop. Growers use various types of barriers such as fleece, plastic sheets, glass or meshes. Of these, Wondermesh and Enviromesh are the most common ones deployed to protect high value crops. For the leafy vegetable (salad) crops, meshes protect against several insect pests and despite their significant capital cost (*c*. £400 for a 13 m width x 50 m length) and the high labour requirement to manipulate them during the season, they are currently considered necessary and cost-effective. The key reason for this is that they efficiently exclude a big percentage of potential pests and in these high value crops even a very low numbers of insects can quickly destroy the quality of the crop.

Physical barriers alone are not always enough to protect from insect damage, because some pests can get under the barrier, so additional use of insecticide may be needed. Currently insecticide is sprayed (but there may be more targeted ways to kill flying adults approaching the crop).

Summary of the work and conclusions of 2007-2008 (years 1 and 2)

The work in 2007 demonstrated that flea beetles were not emerging from within the crop beds, but were migrating into crops from nearby areas, many of which contained crops of oilseed rape. The flea beetle life cycles took six to eight weeks in the NRI insectary, with the majority of this time being spent as root feeding larvae in the soil. This is longer than the period over which most leafy Brassica crops are in the ground and because the ground is tilled between crops, carry over of pests from one crop to the next on the farm is highly improbable. The problem faced by leafy-Brassica growers, therefore, is clearly one that is generated by an immigrant flea beetle population.

The year 1 trial proved that meshes protect the crops from most damage caused by insect pests to a highly significant extent and also increased crop growth – beds protected by mesh (insecticide-impregnated or normal) produced higher yields, independent of pest damage. Minor insect damage did occur under meshes, either because early instar DBM larvae migrated through the mesh or because of immigration underneath the edges. Meshes also protected crops from damage caused by birds and small mammals and, in years 2 and 3, trials including control plots were covered in a coarse hail and pigeon-proof netting from the time of emergence.

An encouraging finding was that several insecticides provided significant (but insufficient) protection even when the crop was not covered by mesh. The two most promising were bifenthrin and spinosad and the latter has since been registered for use on these crops.

In 2008, flea beetle populations were lower than in the previous year and much of the damage was attributed to other insect pests, such as weevils. Meshes again proved highly effective at preventing damage and the coded product, applied twice (eight days between treatments) was effective against the insect-pest complex and weevils in particular. This product has since been released.

In year two, seed treatments gave disappointing results, probably because the rate of product applied was restricted to comply with the maximum area rate determined by PSD. The Tatsoi crop requires a very high seed rate and so each seed received a relatively low level of treatment, possibly too low to exert the required systemic insecticidal effect.

The work this final year (2009) was designed to make use of the information generated previously, in a new approach to managing the pest complex. If successful, it would remove the need to spray the crop with insecticides.

The approach taken in this final year was therefore:

i) prioritisation of experimental treatments and trial design in consultation with AHDB and industry stakeholders,
ii) liaise with a specialist company to have batches of seeds treated with two additional doses of systemic insecticide,
iii) conduct two separate field trials to assess pest control technologies,
iv) identify the causes of damage types in the crop,
v) data analysis and interpretation,
vi) prepare the final report, including discussion of possible future work.

Materials and Methods (2009)

Field trial 1 (sacrificial crop, lure-and-kill trial)

Four ideas were considered as possible ‘lure-and-kill sacrificial crop’ techniques for the 2009 trial. After discussion with Mr Thane Goodrich and Mr Jonathan Powell, the design selected involved a comparison between treatments adjacent to an unmeshed sacrificial crop and those adjacent to bare soil. The main crop area was covered in the standard mesh (square holes with side lengths of 0.77mm) (Figure 1). The sacrificial crop plots were covered in coarse bird-mesh (green netting with holes 42 mm long x 14 mm wide) to prevent non-insect damage (Figures 1 and 2). They were sprayed every four days with a pyrethroid insecticide (deltamethrin or bifenthrin). The idea was that the farm’s standard mesh would provide the main protection, but additional protection against DBM might be provided by the adjacent ‘sacrificial-crops’, by their attraction and removal. These main experimental ‘commercial crop’ beds were not be sprayed with insecticide. The hypothesis being tested, therefore, was to discover whether or not the experimental crop beds adjacent to the sacrificial crops incurred less insect damage than those adjacent to bare soil.

Figure 1. The sacrificial-crop bed is central and is covered in green mesh, supported by wire hoops. Adjacent to it on the LHS are the trial beds and the commercial beds (RHS) both covered in insect-proof mesh.

Figure 2. The sacrificial-crop beds (LHS) and trial beds with the insect-proof mesh removed at the end of the trial, when damage assessment took place.

This trial was carried out on a commercial ‘field’ scale and so the experimental plots were covered with a single sheet of 200 m length standard mesh that covered a width of six crop beds. Along the length of each crop bed, tatsoi was sown in 20 m plots, separated from one another by a 10 m gap of bare soil. This design produced six ‘columns’ of crop, separated by bare earth, which stretched perpendicularly across adjacent areas of the six beds (Figure 3). In the beds on either side of the farm mesh, three areas per bed of ‘sacrificial crop’ and three of bare soil were allocated randomly to be positioned adjacent to the columns of covered crop. The trial design, therefore, involved three columns of mesh-covered crop protected by sacrificial crop beds and three left unprotected, i.e. with only bare soil adjacent to the crop beds.

Trial plots were laid out and seeded on the 8th June 2009 and all treatment labels put in place. The soil was dry when sowing took place, but it rained the same evening. Propachlor herbicide was applied one or two days after sowing, as per the standard farm practice (propachlor is a herbicide that controls germinating weeds in Brassica crops). Bird-proof meshes were put in place on all experimental crop areas that were not covered with insect-proof mesh when the seed began to germinate.

First spray treatment of deltamethrin (bifenthrin for subsequent sprays) was applied to all six of the sacrificial beds on 17th June, with brushing by rakes carried out one or two days later. This cycle was repeated every four days (Table 1).

DBM adults present in the sacrificial crop beds

On the 26th June and the 3rd July, the sacrificial crop beds were brushed with rakes to cause slight damage and increase the emission of plant volatiles to make them more attractive to pests. As this was done, the numbers of adult DBM moths that flew up from the beds were counted.

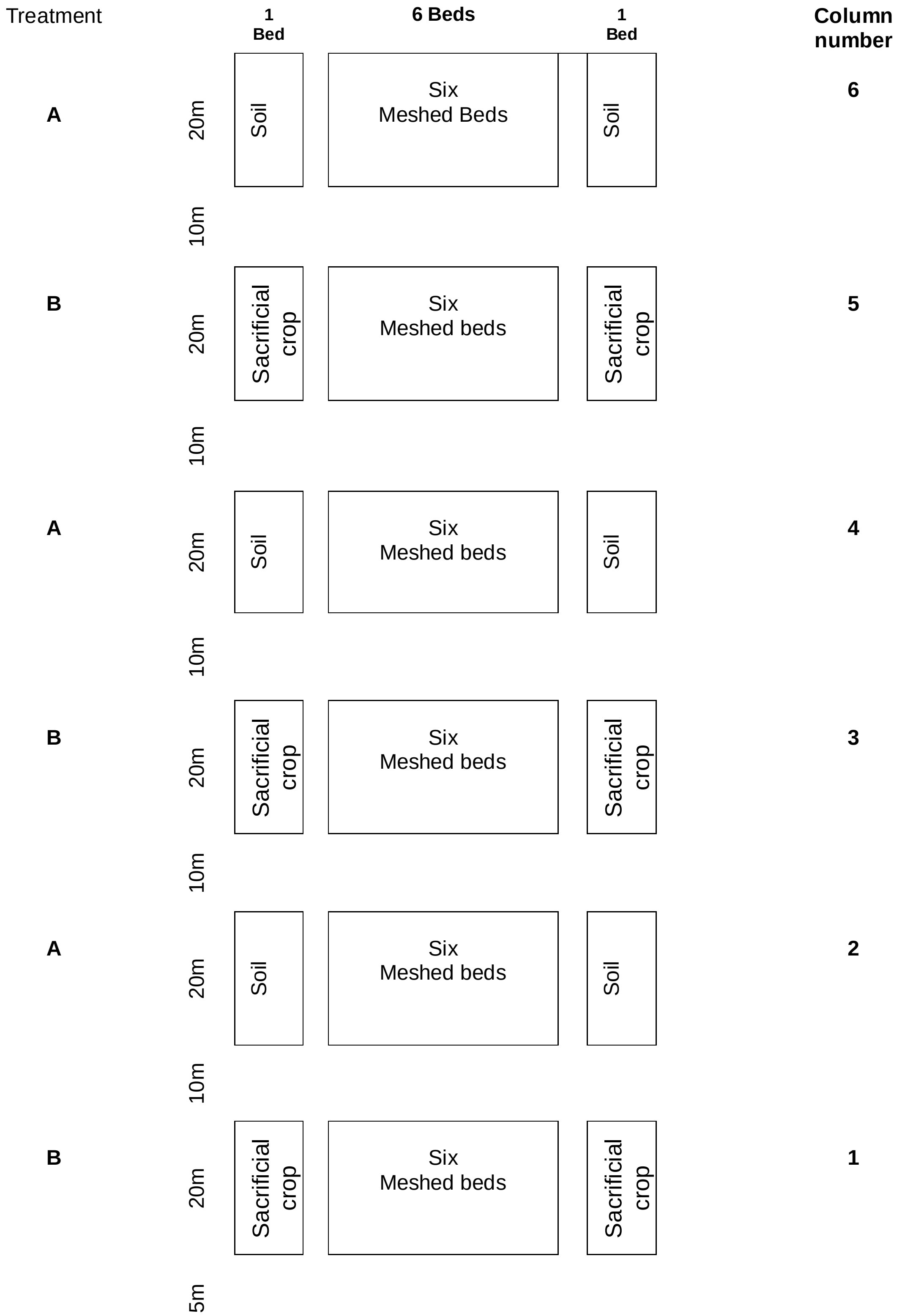

Figure 3. The six middle beds were covered with standard farm mesh and the sacrificial plots were covered with bird-mesh.

Table 1. The timing of events in the first trial using sacrificial crops beds.

Day	**Date**	
0	8 June 2009	All trial plots sown
	12th June	Wondermesh applied to cover main six beds
	13th June	Pigeon mesh put on sacrificial beds
	17th June	Deltamethrin applied to sacrificial beds
	19th June	Bruising treatment applied to sacrificial beds
	22nd June	Bifenthrin applied to sacrificial beds
	23rd June	Bruising treatment applied to sacrificial beds
	25th June	Bifenthrin applied to sacrificial beds
	26th June	Bruising treatment applied to sacrificial beds
	30th June	Bifenthrin applied to sacrificial beds
	2nd July	Damage assessment made to trial plots
	3rd July	Damage assessment in adjacent commercial beds

Damage assessment (lure-and-kill trial)

The 36 plots of crop (six beds x two treatments x three replicates) were sampled for damage assessment separately and in the following manner. Each plot was covered in a notional grid of 160 squares, 40 along the length and four across the width. Before starting the assessment, each sampling point was allocated by the computer generation of a random set of 20 co-ordinates. The co-ordinates were then identified in each plot and a square quadrat was placed at that point, which enclosed an area of 0.1 square metres. Total damage within the quadrat was then assessed and recorded, which generated a data set of 720 values.

Field trial 2 (thiamethoxam seed treatments)

For the second trial, three rates of seed treatment were compared to an untreated control, with all plots covered with bird-proof mesh covers. The dosage rates were (i) low (3.76 g of thiamethoxam a.i. per 700 g of tatsoi seed, which was the same batch of seeds as that used in 2008), (ii) 10 times (37.6 g) and, (iii) 50 times (187.9 g) the lowest rate. The trial involved a randomised block design with four replicates, i.e. 16 plots. Each plot was 6m long with 2m gaps between plots and 5 m of untreated ground at each end. The trial plan and timing of events are given in Figure 4 and Table 2.

Bridleway

Bed 1	Bed 2	Bed 3	Bed 4
D T X 10	C T X 5	A Control	C T X 5
B T x 1	A Control	D T x 10	A Control
C T X 5	D T x 10	C T X 5	B T x 1
A Control	B T x 1	B T x 1	D T x 10
Bed 1	Bed 2	Bed 3	Bed 4

Grassy access road

Figure 4. Layout of the seed treatment trial. Treatment A = untreated control, Treatment B = 3.76 g of thiamethoxam a.i. per 700 g of tatsoi seed, which was the same batch of seeds as that used in 2008, Treatment C = 10 times (37.6 g) and Treatment D = 50 times (187.9 g) the lowest rate.

Table 2. The timing of events for the Seed Treatment trials in June 2009.

Day	**Date**	
0	8 June	Trial plots sown
	14th June	Temporary covering with mesh applied
	16th June	Mesh cover replaced with hail mesh
	19th-30th	Visual inspections made through mesh

	1st July	Damage assessment made

Damage assessment

Damage was assessed in two ways in order to make the data comparable both with previous year's data collection and the current sacrificial crop trial data. For the method used in previous years, twenty plants in each plot had been selected randomly and the damage caused by different pests was counted. This consisted of pin-holes (Figures 5 and 6), leaf-miner mines (Figures 7 and 8), flea beetle holes and DBM windowing and holing. Plots were also divided into a grid and random co-ordinates selected as for trial 1. The damage due to DBM in 10 quadrats per plot was recorded.

Figure 5. There were very high numbers of leaf-miner (Liriomyza spp.) adults present on the unmeshed seed-treatment trial crop. The adult fly is on the top leaf surface but typical damage caused by female Liriomyza spp on the lower surface can be seen on the RHS of the picture.

Figure 6. A tatsoi leaf from a plant that was exposed artificially to large numbers of leaf-miner adults. This type of severe damage caused withering, early shedding of the leaves and must provide multiple entry points for plant disease.

Figure 7. A tatsoi leaf from the seed-treatment trial with the leaf-miner holes and smaller mines present.

Figure 8. A kale leaf, which was exposed to leaf-miner adults collected from the experimental field site, with the wider mines present.

Compliance with statutory regulations

An Administrative Experimental Approval for Research and Development Work was obtained from PSD in 2008. The personnel that carried out the trial had obtained certification (PA1 and PA6) in application of pesticides in accordance with the regulations on use of experimental pesticides.

Experimental crop and timing

Tatsoi, variety ‘Tozer’, was used as the crop in both trials, because it is highly attractive to flea beetles and they can cause damage that reduces the value significantly, even at low levels of infestation. For consistency, the field trials were carried out in the same months as in previous years.

The trial land

The trial was carried out on the Intercrop farm in fields at Bramble Hill (Grid ref. from GPS: N 51^{o} 14’ 21.8’’ E 001^{o} 18’ 47.1’’) on land and with considerable logistical and advisory support kindly provided by Intercrop Farm staff.

Results and Discussion

Causes of crop damage in 2009

As was the case in 2008, in the early period of the trial, very few flea beetles were observed. In terms of leaf damage, four distinct types were observed.

1. The typical holing resulting from flea beetle bites, which was only observed in the seed-treatment trial.
2. Windowing, i.e. a single epidermis removed by early instar diamond back moth larvae that makes the leaf translucent - followed later by holes in the leaf. This type of damage was observed in both trials and was the predominant kind found under the mesh in the sacrificial-crop trial. Numerous adult DBM were present in the sacrificial crop plots (Figure 9).
3. Clusters of very small leaf wound marks, which we later established were caused by leaf-miner (Liriomyza spp.) adults (Figure 6). This damage was only seen in the seed-treatment trial and was caused by the barbed ovipositors of female leafminer adults. Females pierce holes in the upper surface of the leaf to extract plant sap (feeding spots) and the holes are also used to deposit eggs.
4. Two sizes of leaf mines (Figures 7 and 8) were seen in both trials, differentiated by the width of the mine tunnels, i.e. narrow or wide.

Figure 9. There were high populations of diamondback moth during the trial period. The image is of a DBM adult resting on a tatsoi leaf.

Results of field trials

The Lure and Kill (sacrificial crop) trial

A surface view of the mean log transformed damage by DBM is given in Figure 10. There were clear edge effects on both the left and right sides of the trial, with lower damage occurring in the middle of the trial. The highest DBM damage was recorded along the LHS border of the trial and this reached a maximum in the plot adjacent to the sacrificial crop bed on the LHS of column four. These data show that the greatest pest pressure of immigrant DBM adults occurred on the LHS of the trial and suggests that these were low-flying individuals that stopped to oviposit when the border of the trial was encountered. The sacrificial crop beds did apparently act to concentrate the adults (see also Table 3 below), but did not function as anticipated, because they were not efficient at killing the adult DBM, i.e. the sacrificial crops did not act as DBM adult ‘sinks’. This may have occurred because, (i) adults have a greater resistance to the insecticidal sprays, (ii) they were better able to avoid them, or (iii) more adults immigrated into the beds after spaying and were able to survive there.

Table 3. Diamondback moth adult counts in the sacrificial beds on two different dates.

	26th June		3rd July	
	LHS	RHS	LHS	RHS
Road and hedgerow end	33	7	15	7
Middle bed	19	8	30	14
Bridleway end	10	7	27	13

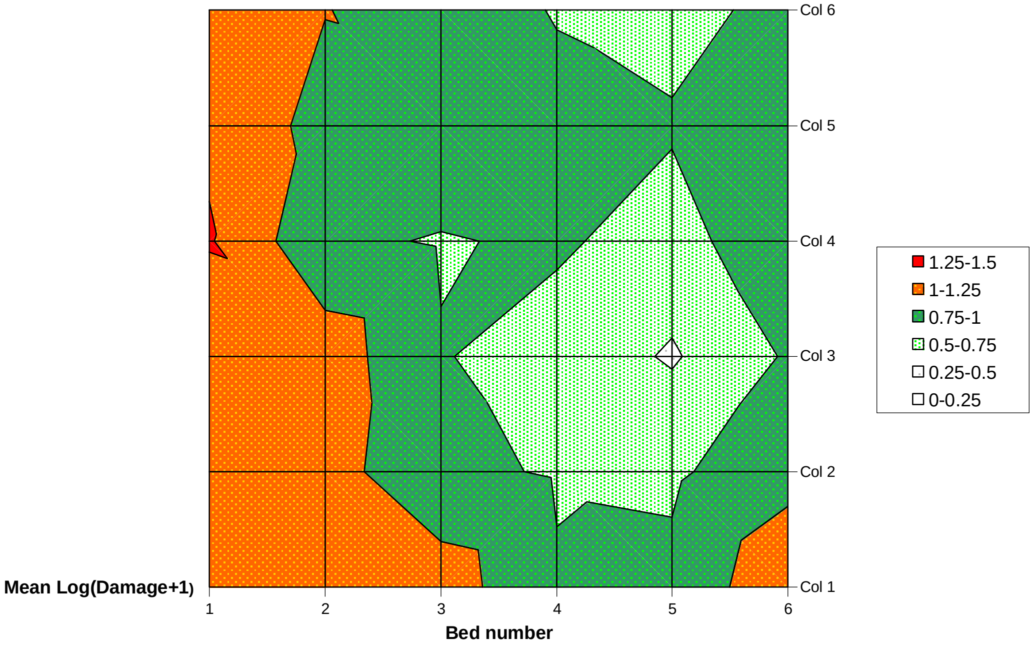

Figure 10. The surface view of the damage caused by DBM holes and windowing on the leaves in the first trial.

Figure 11 shows that the damage differences observed in the different beds were significantly different (ANOVA, *P* < 0.05) and that the highest and lowest mean damage scores were recorded, respectively, on bed numbers one and five.

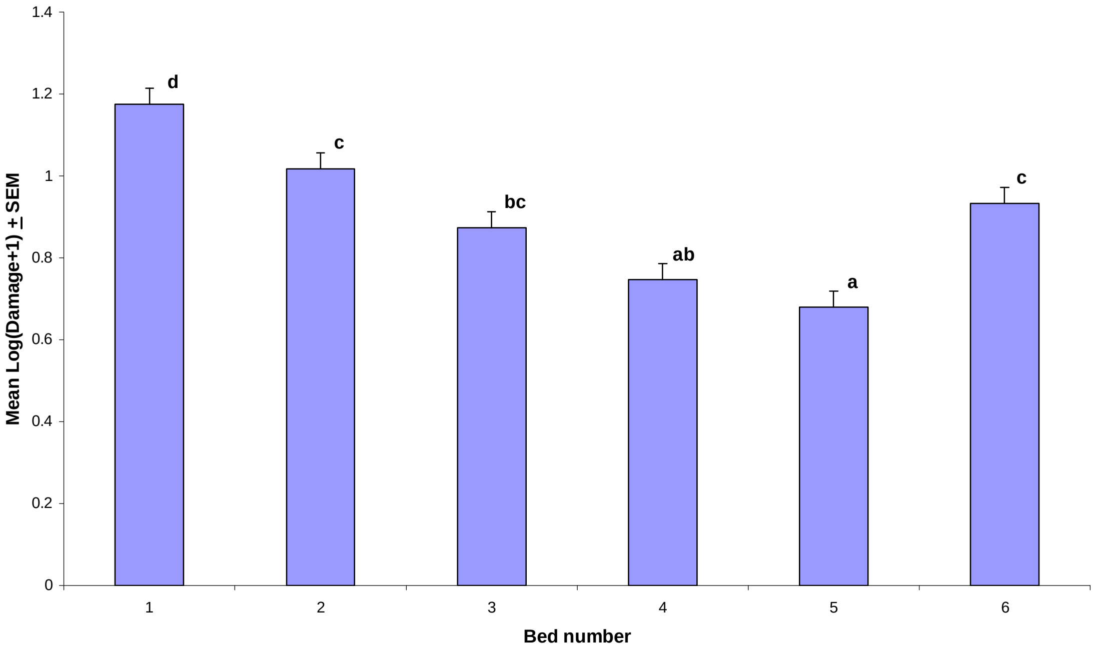

Figure 11. Damage caused by DBM holes and windowing on the leaves, i.e. a single epidermis removed by early instar DBM larvae that makes the leaf translucent - followed later by holes in the leaf . Data were Log$_{10}$(x+1) transformed and a mean calculated per plot. ANOVA was carried out on plot means followed by Tukey's pairwise comparisons at the $P <$ 0.05 significance level. Means with the same adjacent letters are not significantly different. Error bars are standard errors of means.

High numbers of adult diamondback moths were counted in the sacrificial plots throughout the trial period (Table 3). The highest numbers occurred on the LHS of the trial, which is consistent with the greater damage on that side.

A surface view of the mean log transformed damage by leaf-miner is given in Figure 12. Damage by this pest also occurred at the edge of the trial. The greatest damage in this case, however, was recorded at the bottom RHS of the trial. These data also suggest that these were low-flying individuals that stopped to feed and oviposit when the border of the trial was encountered. These data, particularly in comparison to the leaf-miner damage that occurred in the seed-treatment trial, suggest strongly that the farm's standard mesh provides good protection against this particular pest.

The differences in the damage patterns caused by DBM and leaf-miner, suggest that the sources of these immigrant adults are different.

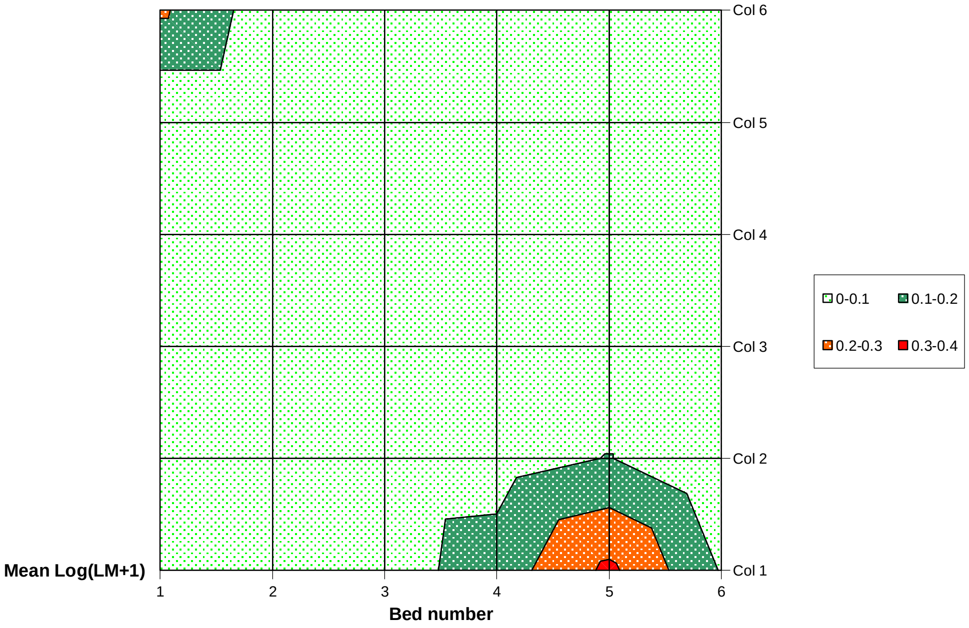

Figure 12. Damage caused by leaf-miner mines visible on the tatsoi leaves.

Seed treatment trial

All of the seed treatments plants suffered serious attack by adult leaf miners. An interesting result was that damage in the seed-treated plots was greater than in the control (Figure 13). This was perhaps due to the leaf-miner adults being able to detect insecticide, or being unable to feed on the insecticide treated plants, which would lead them to try again elsewhere. If their leaf-piercing behaviour was increased in this way, it would have lead to the greater number of pin-holes recorded in the seed treatment plots.

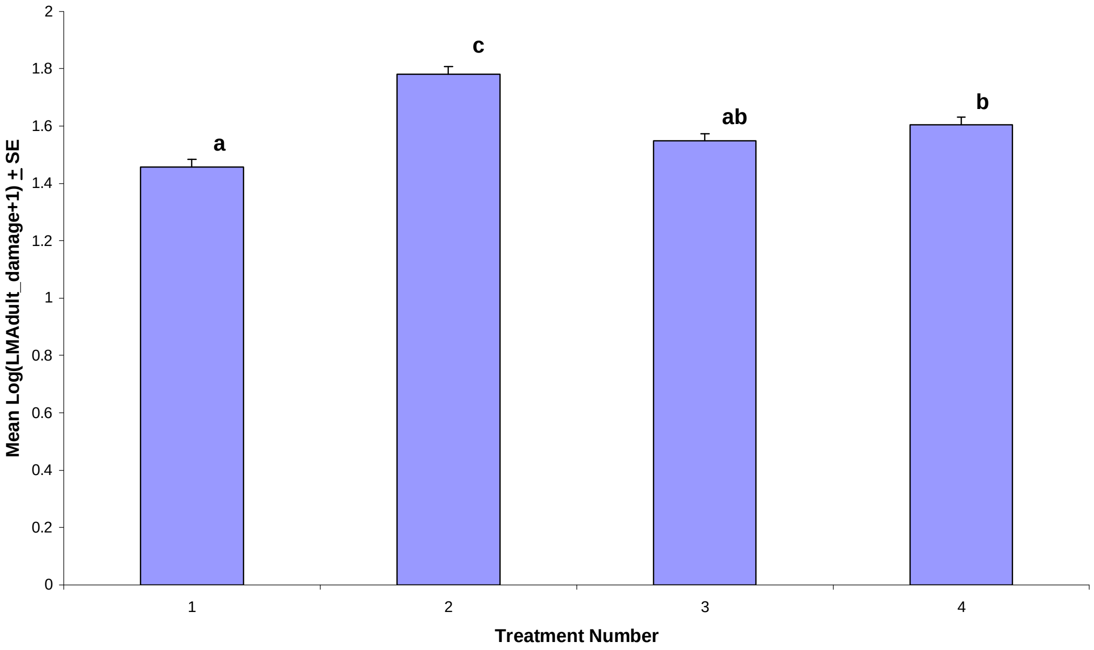

Figure 13. Pin-hole damage caused by adult leaf-miner. Treatment 1 = untreated control, Treatment 2 = 3.76 g of thiamethoxam a.i. per 700 g of tatsoi seed, which was the same batch of seeds as that used in 2008, Treatment 3 = 10 times (37.6 g) and Treatment 4 = 50 times (187.9 g) the lowest rate. Data were $\text{Log}_{10}(x+1)$ transformed and a mean calculated per plot. ANOVA was carried out on plot means followed by Tukey's pairwise comparisons at the $P < 0.05$ significance level. Means with the same adjacent letters are not significantly different. Error bars are standard errors of means.

The numbers of leaf mines present in the different treatments were significantly different and highest in treatment 2 (Figure 14). This pattern of results might be explained by the increased piercing and oviposition by leaf-miner adults on the seed-treated plants, but the subsequent reduced survival of the larvae at the higher insecticide doses (treatments 3 and 4). Even in the highest dose treatment, some larvae were able to make mines, suggesting that this pest may already be becoming resistant to thiamethoxam.

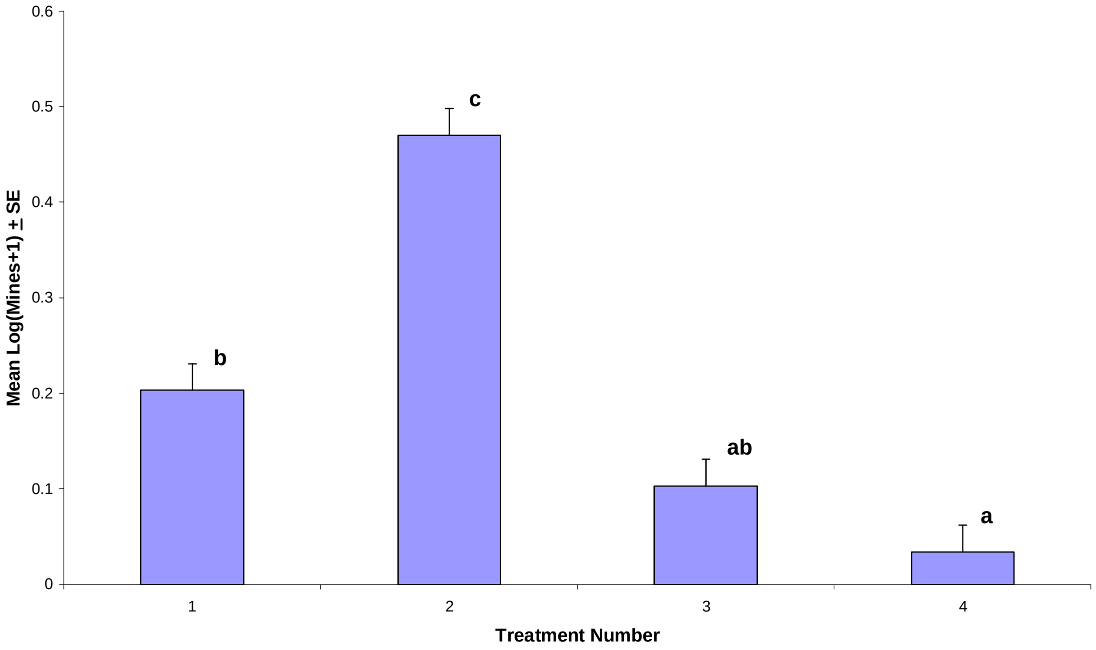

Figure 14. Damage caused by leaf miner mines visible on the leaves . Treatment 1 = untreated control, Treatment 2 = 3.76 g of thiamethoxam a.i. per 700 g of tatsoi seed, which was the same batch of seeds as that used in 2008, Treatment 3 = 10 times (37.6 g) and Treatment 4 = 50 times (187.9 g) the lowest rate. Data were $\text{Log}_{10}(x+1)$ transformed and a mean calculated per plot. ANOVA was carried out on plot means followed by Tukey's pairwise comparisons at the $P < 0.05$ significance level. Means with the same adjacent letters are not significantly different. Error bars are standard errors of means.

The seed treatments proved much more effective against flea beetles and prevented damage from this pest at the two higher doses (treatments 3 and 4) (Figure 15).

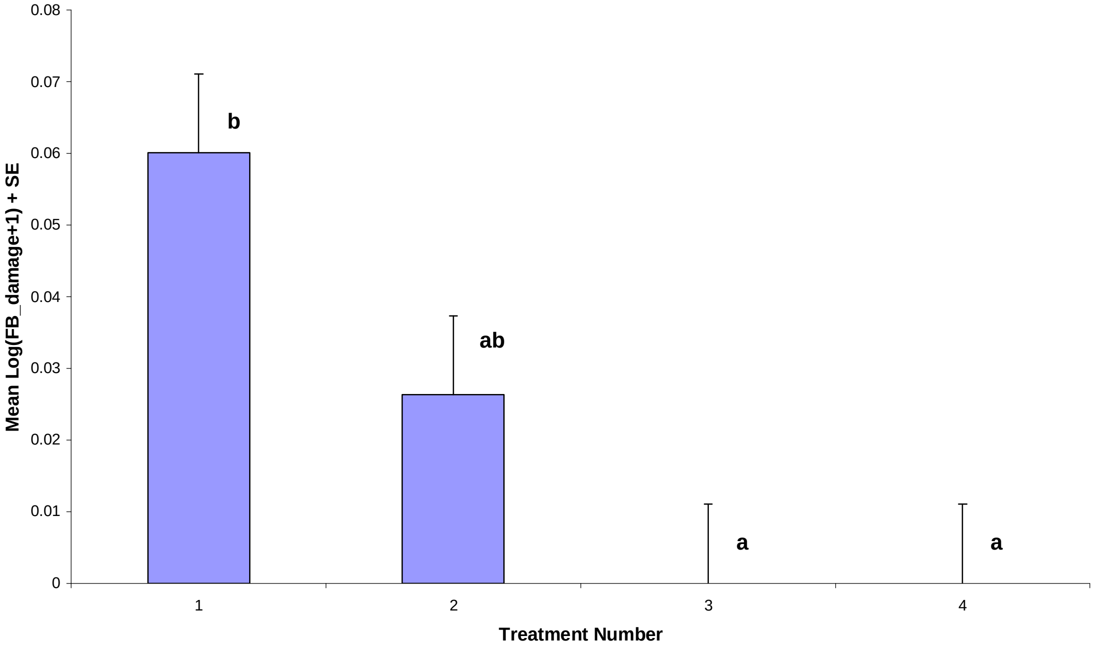

Figure 15. Damage caused by flea beetles. Treatment 1 = untreated control, Treatment 2 = 3.76 g of thiamethoxam a.i. per 700 g of tatsoi seed, which was the same batch of seeds as that used in 2008, Treatment 3 = 10 times (37.6 g) and Treatment 4 = 50 times (187.9 g) the lowest rate. Data were $Log_{10}(x+1)$ transformed and a mean calculated per plot. ANOVA was carried out on plot means followed by Tukey's pairwise comparisons at the $P < 0.05$ significance level. Means with the same adjacent letters are not significantly different. Error bars are standard errors of means.

Diamondback larvae damage was greatest in the control plots and lower in the seed-treatment plots. Even at the highest seed-treatment dose, however, some damage was apparent (Figure 16).

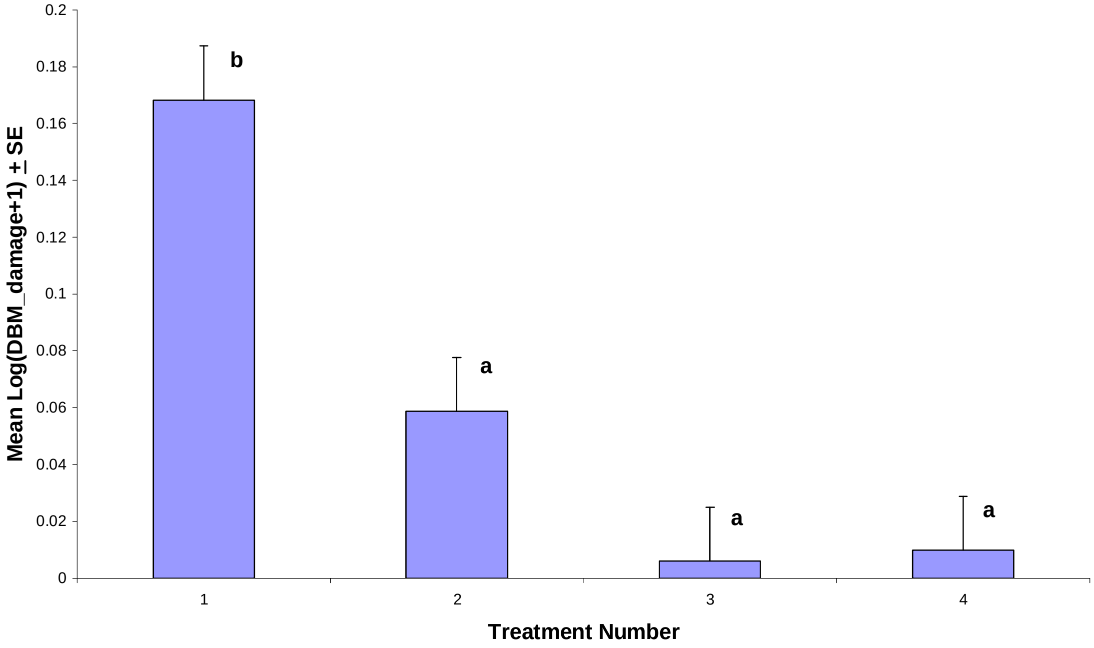

Figure 16. DBM damage. Treatment 1 = untreated control, Treatment 2 = 3.76 g of thiamethoxam a.i. per 700 g of tatsoi seed, which was the same batch of seeds as that used in 2008, Treatment 3 = 10 times (37.6 g) and Treatment 4 = 50 times (187.9 g) the lowest rate. Data were $Log_{10}(x+1)$ transformed and a mean calculated per plot. ANOVA was carried out on plot means followed by Tukey's pairwise comparisons at the *P* < 0.05 significance level. Means with the same adjacent letters are not significantly different. Error bars are standard errors of means.

When all of the different damage types were counted together, in order to get an indication of total damage, there was a decreasing amount of damage with increasing seed-treatment dose, i.e. the control and Treatment 4 plots suffered the greatest damage and least damage, respectively (Figure 17).

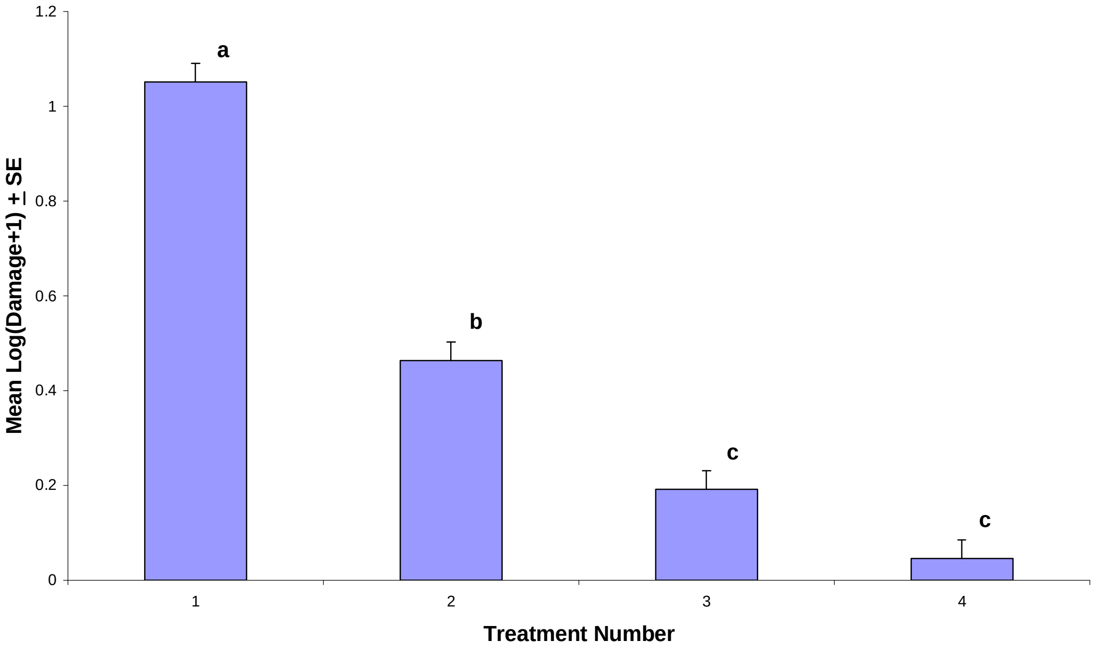

Figure 17. The assessment of total damage in the different treatments, recorded using the same quadrats and randomisation method as used as in main trial. Data were $Log_{10}(x+1)$ transformed and a mean calculated per plot. ANOVA was carried out on plot means followed by Tukey's pairwise comparisons at the $P < 0.05$ significance level. Means with the same adjacent letters are not significantly different. Error bars are standard errors of means.

Conclusions

The conclusions from the third year of work and the project as a whole are:

- Flea beetle populations were low again in June – July 2009 and much of the damage was attributable to other pests including leaf miners and diamondback moth.
- The standard farm mesh was effective at preventing damage from a range of insect pests, including flea beetle spp., weevils, leaf-miner adults and, to a lesser extent, leaf miner larvae.
- The standard farm mesh is much less effective at preventing damage from Lepidoptera larvae, such as DBM.
- In the sacrificial crop trial, high numbers of adult DBM were counted in the sacrificial crop beds in the days following spray application. The sacrificial crop beds, therefore, acted as expected to attract insect pests including adult DBM, but the insecticide sprays were inefficient at controlling numbers, possibly due to the rate of new immigrant arrivals.

- In the sacrificial crop trial, there were clear damage gradients and edge effects on both the left and right sides of the trial, with the lowest damage occurring in the middle of the trial.
- The greatest pest pressure of immigrant DBM adults occurred on the LHS of the trial, which suggests that these were low-flying females that stopped to oviposit when the border of the trial was encountered.
- The differences in the damage patterns caused by DBM and leaf-miner, suggest that the sources of these immigrant adults were different.
- The seed-treatment trial gave an interesting result in that the pin-hole damage caused by leaf-miner adults in the seed-treated plots was greater than in the control.
- The two treatments with the highest doses of thiamethoxam had the least DBM damage, but adult DBM were still observed in all plots.
- In terms of total damage, there was a decreasing amount of damage with increasing seed-treatment dose, i.e. the control and Treatment 4 plots suffered the greatest and least damage, respectively.
- If the sacrificial crop technology is to be improved, a lure-and-kill method needs to be developed that is efficient at removing DBM adult females. The thiamethoxam seed treatments did not act in this way and so, unfortunately, would not be suitable.
- A potential improvement to the lure-and-kill method would be to use the insecticide-impregnated mesh as a low fence, in combination with the farm's standard mesh. This should prevent low-flying Lepidoptera and Diptera pests from flying on to and over the meshed crops and thus enable it to be grown without insecticidal sprays being applied to it.

Technology transfer

The performance of the meshes in controlling pest access to the crop is highly significant and no other single technology is as effective against the Brassica-pest complex. Insect damage is reduced still further by the application of insecticidal sprays or by impregnating the mesh with insecticide.

Seed treatments gave variable results and were able to control the damage caused by the majority of insect pests. For leaf-miner adults, however, they actually increased significantly the amount of damage caused by this pest in two out of three seed treatments.

At the start of year three, it was apparent that meshes could not be dispensed with, because no insecticidal spray product on its own could cope with the diversity of pests. The emphasis of the research, therefore, changed to developing a pest-management system that would allow the crop to be grown without insecticide being applied to it.

The results obtained this year were highly informative and suggest a way that this might be possible. The yellow, insecticide-impregnated mesh tested in year 1 could be used as a fence (rather than a covering mesh) to prevent immigration of low-flying insect pests over the meshed beds. This combination of physical barriers would potentially allow production of a crop without any application of insecticide onto it. We have sufficient insecticide-impregnated yellow mesh to enable a year 4 trial to be carried out to test this idea, subject to the agreement of Intercrop and availability of financial support from the AHDB.

We are preparing a draft article for HDC news (due at the end of September) as part of the knowledge transfer activities of the project and hope to publish these data in a peer-reviewed scientific journal in due course.

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