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The results and conclusions in this report are based on an investigation conducted over a three year period. 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.

Use of pesticides

Only officially approved pesticides may be used in the UK. Approvals are normally granted only in relation to individual products and for specified uses. It is an offence to use non-approved products or to use approved products in a manner that does not comply with the statutory conditions of use except where the crop or situation is the subject of an off-label extension of use.

Before using all pesticides and herbicides check the approval status and conditions of use.

Read the label before use: Use pesticides safely.

CONTENTS

Headline

On peppers, predatory lacewings *Chrysoperla carnea* provided consistent control of MACE and non-MACE peach-potato aphids (*Myzus persicae*). The parasitoid *Aphidius colemani* was more effective against non-MACE than MACE peach-potato aphids.

Background and expected deliverables

The peach potato aphid, *Myzus persicae*, is a polyphagous species that attacks a wide range of protected and outdoor crops. For some time there have been forms in the UK, which produce high levels of esterase, which are resistant to pyrethroid, organophosphate and carbamate, but susceptible to pirimicarb insecticides. This is known as esterase resistance. To manage this resistance, growers of protected crops have been encouraged to base their aphid control strategies on biological control using mainly *Aphidius colemani* and *Aphidoletes aphidimyza,* supplemented by 'open' rearing units. Biological control strategies have worked well in protected crops for most of the season, but some growers have to resort to occasional treatments of pirimicarb to bring any imbalance back under control or to control sudden aphid invasions.

In recent years, a strain of *Myzus persicae* with a new form of resistance, having a modified acetylcholinesterase ('MACE') that confers complete resistance to dimethyl carbamates such as pirimicarb, has been found. This strain is typically, though not always, red. The occurrence of MACE aphids in UK protected crops has resulted in crop losses. Pirimicarb is completely ineffective against these aphids and where populations also have high levels of esterase resistance, there are very few effective approved chemicals that can be used to reduce aphid populations in conjunction with the natural enemies. One recent additional chemical that can be used in conjunction with biological control agents is pymetrozine (approved in the UK as the product 'Chess').

Since it was first detected in the UK in 1995, MACE resistance has fluctuated but generally remained at low levels in field populations of *Myzus persicae*. However, the incidence of MACE resistance in glasshouse populations has been greater. This suggests that glasshouses may be acting as the main reservoir of MACE-resistant *Myzus persicae* in the UK, and that these aphids are likely to be a more frequent problem in glasshouse crop production than in field crops. The persistence of MACE resistance within the UK, coupled with the relatively limited range of effective compounds that are compatible with biological control agents, has increased the need for a biologically based control strategy that is effective against all forms of *Myzus persicae*.

The commercial objective of this project is to develop sustainable control of both MACE and non-MACE *Myzus persicae* in protected crops, based on a robust biological control programme supported by compatible remedial treatments.

Summary of the project and main conclusions

Effects of MACE resistance on the biology of *M. persicae* (peach potato aphid)

The effect of MACE resistance on the rate of population increase of *M. persicae* was found to be dependent on the level of esterase resistance in the aphid. MACE and non-MACE aphids with high levels of esterase resistance had similar rates of population increase.

MACE aphids were more aggregated around the growing points of pepper plants than non-MACE aphids. In small scale experiments, more than 70% of MACE aphids, compared with only 40% of non-MACE aphids, were present in the growing tips of pepper plants. This was also seen in crop scale experiments and suggests that MACE resistance has an impact on the behaviour and distribution of *M. persicae* on pepper crops. This information could be used to modify control strategies where MACE aphids are being controlled biologically.

Effectiveness of different parasitoid species in controlling *M. persicae* (peach potato aphid)

Of the parasitoid species tested, *Aphidius colemani* and *Aphidius matricariae* provided high levels of control of both MACE and non-MACE aphids when compared with *Praon myziphagum*.

Aphidius matricariae attacks only *M. persicae* whereas *A. colemani* will parasitise other important pest aphid species in glasshouses, most notably *Aphis gossypii*. Due to this capacity to control other important pests, and its wider availability, *A. colemani* was chosen as the most suitable parasitoid species for further investigation.

In large scale experiments, the introduction of *Aphidius colemani* at a rate of 2 per m^2 per week significantly reduced the numbers of MACE and non-MACE *Myzus persicae* on the pepper plants. *Aphidius colemani* was more effective in controlling non-MACE *Myzus persicae* than it was in controlling MACE *Myzus persicae*.

Effectiveness of different predator species in controlling *M. persicae* (peach potato aphid)

Control of MACE and non-MACE aphids by first or second instars of the predator species *Chrysoperla carnea*, *Aphidoletes aphidimyza* and *Adalia bipunctata* was similar. However, the presence of *C. carnea* reduced the proportion of MACE and non-MACE aphids on the growing points of pepper plants, whereas the other species did not.

C. carnea (lacewings) was chosen for further evaluation in large-scale experiments because it reduced the density of MACE aphids in the growing tips of plants, possibly reducing the damage that may be done during fruit set and early fruit development. The lacewing *C. carnea* introduced at a rate of ~20 larvae per m^2 per week, were equally effective against MACE and non-MACE aphids, reducing aphid numbers on different plant parts to a greater extent than the parasitoid *A. colemani*. These experiments were done in large insect-proof cages.

Conclusions

- The results of this project suggest that the increased use of predatory lacewings in conjunction with the continued use of the parasitoid *Aphidius colemani* would improve the efficiency of control when MACE *M. persicae* are present in the crop.

- Additional work is needed to produce a comprehensive strategy for the year-round control of insecticide-resistant aphids on pepper crops using biological control agents. This would focus on the best ways to integrate the predatory and parasitoid species used in this project and on how temperature variation at different times of year changes the effectiveness of *A. colemani* against MACE and non-MACE *M. persicae*.

Financial benefits

The control of MACE-resistant *Myzus persicae* represents a particularly difficult challenge for glasshouse crops, due to the limited number of approved products for control of aphids with this form of resistance, coupled with an increasing desire for food without pesticide residues.

The results of this study have shown that MACE *Myzus persicae* colonise pepper plants differently to non-MACE forms, in particular moving to the growing points of the crop. In experimental trials, increasing the release rate of *Aphidius colemani* to 2 per m^2 per week improved control of MACE aphids as did the release of lacewing larvae at a rate of 20 per m^2 per week under high aphid pressure. Further development work is required with input from biological control companies to adapt these control strategies to commercial pepper crops.

Potential benefits include:
(a) Reduced direct economic crop loss resulting from honeydew and rejected produce.
(b) Improved knowledge of biological control programmes for aphid control.
(c) Reduced reliance on chemical insecticides.

Action points for growers

The following action points are prepared with the recommendation that additional or back-up advice is sought from a crop advisor or technical advisor from a biocontrol company.

- Growers of pepper crops should routinely use *Aphidius colemani* and *Aphidoletes aphidimyza* at the normal rates recommended by the biocontrol companies for the control of aphids in pepper crops. Close crop monitoring is essential to assess the level of control achieved and to get any advance warnings of increases in aphid numbers.

- If the number of aphids suddenly increases so that a 'hot spot' results, increase the release rate of *Aphidius colemani* to 2 per m^2 per week. *Chrysoperla carnea* (lacewing) larvae are also good for aphid 'hot spots' and can be used at rates of up to 20 per m^2 per week, applied near to where the aphids are located.

- Growers should be on the look out for MACE *Myzus persicae*, the peach potato aphid, which are usually red in colour, and tend to congregate at the top of pepper plants. Sprays of pirimicarb will not work against these aphids as they are resistant. Where MACE aphids are found, introducing lacewing larvae at a rate of 20 per m^2 per week for several weeks, and applying them near to the growing points, is likely to achieve better control of resistant aphids than increasing the numbers of *A. colemani* alone.

- Some populations of aphids may be resistant to several insecticides and hence if the efficacy of an insecticide appears to be declining, or if a new infestation is difficult to control, it is advisable to send samples of aphids to IACR-Rothamsted for insecticide resistance testing (Dr. Steve Foster, Tel:01582 763133; e-mail stephen.foster@bbsrc.ac.uk).

- Eradicoat (BCP Ltd) is a starch based product and can act as an IPM compatible remedial treatment to provide aphid control in pepper crops. Experience to date has shown that it is most effective against the melon cotton aphid (*Aphis gossypii*) than either the peach potato aphid (*Myzus persicae*) or the glasshouse potato aphid; the reason being that Eradicoat works best against aphids that form dense colonies.

- Other IPM compatible remedial treatments for aphid control in pepper crops include 'Chess' (pymetrozine), nicotine, fatty acids, and where there are no MACE *Myzus persicae*, Aphox (pirimicarb).

Science Section

INTRODUCTION

The development of insecticide-resistant forms of the aphid *Myzus persicae* means that, for a number of protected crops, sustainable long-term management of this aphid species will require the use of biological control agents. Biological control strategies work well in protected crops for much of the growing season, but most growers resort to occasional treatments of pirimicarb to support biological control or to control sudden invasions of aphids.

In recent years, a strain of *M. persicae* with a new form of resistance called modified acetylcholinesterase resistance ('MACE') has occurred. This confers effective immunity to dimethyl carbamates, such as pirimicarb. After the initial discovery of these aphids in the UK in 1995, they spread rapidly, so that in 1997 and 1998, the frequency of MACE *M. persicae* was far higher in glasshouses than in field crops. MACE insecticide resistance renders pirimicarb ineffective and where aphid populations also have high levels of esterase resistance, there are few IPM compatible chemicals available that can be used with biocontrol agents to suppress aphid populations. Pymetrozine is one such recently approved chemical that has been shown to be effective against *M. persicae* with different levels of insecticide resistance (Foster et al, 2002) but is also harmless to a range of beneficial insect species (Sescher et al, 2002). As a result of this limited range of compounds UK growers are seeking a biologically-based control strategy that is as effective against MACE forms of *M. persicae* as non-MACE forms. The competitiveness of the UK industry is further compromised by the greater range of aphicides available for use on salad crops in mainland Europe.

A number of parasitoid and predator species are available for the control of *M. persicae*. Although the parasitoid *Aphidius matricariae* is considered to be most effective against *M. persicae*, *Aphidius colemani* is more commonly produced by suppliers, as it also controls *Aphis gossypii* and has been used with reasonable success for several years. Although parasitoids are likely to remain the main control agent, aphid predators (*Aphidoletes aphidimyza*, *Chrysoperla carnea* and *Adalia bipunctata*) are also available commercially. Predators may play an important role in controlling aphids, but recommendations for their use are still poorly developed. Detailed work during the third year of this project has been aimed at providing information on the effectiveness of the preferred predator species *C. carnea*.

Laboratory experiments were done to determine how this species changes the distribution of MACE and non-MACE *M. persicae* on peppers. The results of these experiments then led to a crop scale experiment using *C. carnea* as the sole control agent for MACE and non-MACE *M. persicae*. The results of this work, when considered together with the results from Years 1 & 2 of the project, may provide tools that can be combined to give maximal protection of pepper crops against *M. persicae*, regardless of the incidence of different forms of insecticide resistance.

Commercial Objective

To achieve sustainable control of both MACE and non-MACE *M. persicae* in protected crops, based on a robust biological control programme.

SUMMARY OF RESULTS FOR YEAR 1 (1999)

Effect of MACE resistance on the intrinsic rate of increase (r_m) of M. persicae

There was a significant reduction in the intrinsic rate of increase ($r_{m)}$ of *M. persicae* with R3 compared to R1 esterase resistance. However, this difference was not seen between clones of *M. persicae* with R3 and R1 esterase resistance that also had MACE resistance. This suggested that MACE resistance reduced the r_m of *M. persicae* expressing low levels of esterase resistance, but had no impact on *M. persicae* expressing high levels of esterase resistance. These results suggest that MACE resistance can interact with esterase resistance to reduce the intrinsic rate of increase of *M. persicae*.

Effect of MACE resistance on the feeding position and response to alarm pheromone of M. persicae

When undisturbed by any biological control agents a greater proportion of MACE than non-MACE *M. persicae* was found feeding on the growing points of pepper plants. The impact of different insecticide-resistance mechanisms on the response to aphid alarm pheromone was complex. As levels of esterase resistance increased the response to alarm pheromone increased in MACE and decreased in non-MACE *M. persicae*. This changing response to alarm pheromone was further modified by the presence of kdr resistance. Homozygous kdr resistance (RR) significantly reduced the response to alarm pheromone of MACE and non-MACE *M. persicae* with high levels of esterase resistance. However, the presence of heterozygous kdr resistance in MACE *M. persicae* resulted in an increased response to alarm pheromone, compared to non-MACE *M. persicae*.

The performance of different parasitoid species against MACE and non-MACE M. persicae

Aphidius colemani and *Aphidius matricariae* had comparable levels of performance against both MACE and non-MACE *M. persicae*. Levels of parasitism by these species was significantly higher than by *Praon myziphagum*. Due to the availability of *A. colemani* and its capacity to parasitise *A. gossypii*, this species was chosen to determine the effectiveness of hymenopterous parasitoids in crop scale experiments against MACE and non-MACE *M. persicae* on peppers.

SUMMARY OF RESULTS FOR YEAR 2 (2000/2001)

Effectiveness of three predator species against MACE and non-MACE M. persicae in laboratory experiments.

Early instar larvae of the three species tested (*Adalia bipunctata, Aphidoletes aphidimyza* and *Chrysoperla carnea*) produced similar, but small, effects on the number of MACE and non-MACE *M. persicae* on pepper plants. It was noted that infestation of plants with *Chrysoperla carnea* resulted in a lower number of aphids on the growing points of plants. On the basis of these data it was decided that a further laboratory experiment with *C. carnea* should be done in Year 3 to determine the

extent of any change in aphid distribution on peppers caused by the presence of *C. carnea*.

Determine the efficacy on a crop scale of Aphidius colemani against MACE and non-MACE M. persicae.

In this experiment, a statistically significant block effect made formal analysis of the numbers of MACE and non-MACE *M. persicae* impossible. Despite this, there was evidence to suggest that, following repeated inoculations with *A. colemani*, there were more MACE than non-MACE *M. persicae* per plant (Table 1).

Table 1
Mean aphid score (A) and mean Log number of aphid mummies (B) per plant and per plant part for peppers infested with MACE or non-MACE *Myzus persicae*. All values that differ by more than the LSD value are significantly different at the 5% level. Values in bold or italics are compared using the LSD value in bold or italics respectively.

	Plant part				
A) Aphid score Clone of *M. persicae*	Bottom	Mid branch A	Mid branch B	Growing tips	Whole plant
High esterase/kdr/MACE	**0.622**	**1.355**	**1.014**	**2.067**	
(- *A. colemani*)	1.02	2.11	1.58	2.43	*1.87*
(+ *A. colemani*)	0.23	0.61	0.45	1.7	*0.7*
High esterase/kdr	**0.807**	**0.927**	**0.922**	**1.269**	
(- *A. colemani*)	1.36	1.53	1.47	2.08	*1.73*
(+ *A. colemani*)	0.25	0.32	0.38	0.46	*0.33*
LSD		**0.51**			*0.71*

This was due to the reduced effectiveness of *A. colemani* against MACE compared to non-MACE *M. persicae* which was demonstrated by the greater numbers of non-MACE compared to MACE aphid mummies per plant. Differing levels of control were seen between experimental runs, which suggested that changes in temperature after *A. colemani* introduction may have altered the effectiveness of *A. colemani* against MACE and non-MACE *M. persicae*.

EXPERIEMENTAL WORK IN YEAR 3 (2002)

1. Effect of *Chrysoperla carnea* on the control and Distribution of MACE and non-MACE *M. persicae*.

Objective
To determine the effect of *Chrysoperla carnea* on the numbers and distribution of MACE and non-MACE *M. persicae* on individual small pepper plants.

Materials and Methods
An experiment was done with two clones with different resistant status (R_3/kdr/ MACE red clone 2050A and an R_3/kdr/non-MACE green clone 2169G).

Sixty small pepper plants (*Capiscum annuam* L.) were used, each with six leaves on the main stem. Each pepper plant was enclosed in a plastic bag and infested with 25 second/third instar MACE and 25 second/third instar non-MACE *M. persicae*, so that 50 aphids were present on each plant. Thirty of these plants were then each inoculated with a single second instar *C. carnea* larva (nine days old at 20°C), whilst the other 30 were kept as uninoculated control plants.

The plants were kept in a controlled environment room (21 ± 2°C; 16/8 h light/dark photoperiod) and the total number of aphids on each plant part (cotyledons, leaves, growing point) was recorded two and seven days after inoculation. Aphids from the MACE and non-MACE clones were distinguished by their red and green colouration respectively.

The numbers of aphids of each clone on each plant part were summed, to give the total number of aphids of each clone per plant. The proportions of each clone on each plant part were then calculated. Prior to analysis of variance, the total numbers of aphids per plant were logarithmically transformed (ln (x)), whereas the proportions of aphids of each clone on each plant part were arcsine-transformed (arcsin $\sqrt{p}$).

Results
There were fewer aphids on plants inoculated with a single *C. carnea* larva than on uninoculated plants (Table 2). The difference between inoculated and control plants increased substantially between two and seven days after inoculation (Table 2). However, there was no difference between the number of MACE and non-MACE *M. persicae* on untreated or treated plants, after either two or seven days from inoculation (Table 2).

Table 2. The mean number of MACE and non-MACE *M. persicae* per plant two and seven days after inoculation with a single second instar *C. carnea* larva, compared to uninoculated control plants.

Two days after inoculation	**Mean number of aphids per plant**	
	with	without
Aphid clone	*C. carnea*	*C. carnea*
R3/kdr/MACE	16.3	22.4
R3/kdr/non-MACE	15.7	20.5

Seven days after inoculation	**Mean number of aphids per plant**	
	with	without
Aphid clone	*C. carnea*	*C. carnea*
R3/kdr/MACE	10.9	316.5
R3/kdr/non-MACE	15.7	295.5

There were proportionally more MACE than non-MACE *M. persicae* on the growing points of pepper plants two ($F = 6.07$, $p < 0.001$, 8 df) and seven ($F = 5.83$, $p < 0.001$, 8df) days after inoculation (Table 3).

Table 3.
The mean percentage of MACE and non-MACE *M. persicae* on each plant part of all small pepper plants (i.e. regardless of predator inoculation) two and seven days after inoculation. Leaf 1 is at the bottom of the plant and leaf 6 is at the top.

	Mean percentage of aphids per plant part			
	Two days after inoculation		**Seven days after inoculation**	
Plant part	MACE	non-MACE	MACE	non-MACE
On soil	0.5	0.4	0.2	0.2
Cotyledons	0.3	0.7	0.1	0.1
leaf 1	6.3	12.1	2.1	9.4
leaf 2	7.5	11.3	2	6.4
leaf 3	2.5	8.1	6.9	7.1
leaf 4	4.4	8.6	1.7	6.9
leaf 5	2.3	4.9	3.2	4.4
leaf 6	1.2	3	1.9	5.9
Growing points	55.9	33.6	54.7	28.8

Chrysoperla carnea reduced the proportion of aphids on the growing points of pepper plants and this effect was consistent for both MACE and non-MACE *M. persicae* both two (F = 0.66, p = 0.725, 8df) and seven days after inoculation (F = 1.12, p = 0.347, 8df) (Table 4).

Table 4
The mean proportion of MACE and non-MACE *M. persicae* on different parts of small pepper plants either with a single *C. carnea* larva or without a *C. carnea* larva (control plants) two and seven days after inoculation.

Two days after inoculation	**Mean proportion of aphids**			
	MACE		non-MACE	
Plant part	*C. carnea*	control	*C. carnea*	control
On soil	1.5	0.0	0.6	0.2
Cotyledons	0.7	0.0	1.4	0.2
leaf 1	8.9	4.1	13.5	10.8
leaf 2	7.6	7.5	9.5	13.3
leaf 3	2.1	2.8	10.1	6.3
leaf 4	4.8	4.1	10.5	6.8
leaf 5	2.7	2.0	4.4	5.5
leaf 6	2.2	0.5	2.3	3.7
Growing points	46.3	65.4	26.7	40.9

Seven days after inoculation	**Mean proportion of aphids**			
	MACE		non-MACE	
Plant part	*C. carnea*	control	*C. carnea*	control
On soil	0.0	0.5	0.0	0.4
Cotyledons	0.0	0.0	0.0	0.1
leaf 1	0.4	5.2	5.9	13.7
leaf 2	1.4	2.8	3.3	10.4
leaf 3	12.0	3.1	5.9	8.4
leaf 4	1.2	2.3	4.6	9.6
leaf 5	3.4	3.0	3.4	5.7
leaf 6	3.4	0.8	9.2	3.2
Growing points	33.6	74.9	18.7	40.0

Discussion

These results bear out the indications from previous experiments that *C. carnea* reduces the proportion of both MACE and non-MACE *M. persicae* on the growing points of pepper plants. The response of *C. carnea* is the same to both MACE and non-MACE *M. persicae*, which suggests that the predator makes no distinction between the two clones. Seven days after inoculation the presence of a single *C. carnea* larva on a plant reduced the proportion of aphids on the growing points to approximately half of that on a plant without a predator (Table 4, seven days after inoculation). In addition, the high level of control of both MACE and non-MACE *M. persicae* after seven days suggests that *C. carnea* could be highly effective against these pests on pepper crops.

2. Determine optimum release strategies for *Chrysoperla carnea*

Objective
Compare the efficacy of *Chrysoperla carnea* against red MACE-resistant *M. persicae* and green non-MACE *M. persicae* in protected pepper crops.

Materials and Methods
Pepper plants (cv. Mazurka) were grown in rockwool plugs. After germination the larger plants were placed in individual rockwool squares which were then put into larger rockwool slabs (90cm) at two plants per slab. Experimental plots of 24 slabs (48 plants) were arranged as for previous experiments (Kift et al, 2002). During each experimental run two plots were grown per compartment in each of two compartments, with each compartment being a block in the experimental design. Each plot was caged individually with insect proof netting.

The plants were treated as a commercial crop prior to inoculation with aphids (glasshouse temperature 16-26°C). They were grown with two flowering stems and side shoots were removed weekly until inoculation of aphids. No side shoots were removed after inoculation of aphids. This was to reduce the chance of cross contamination of predators between treated and untreated plots within blocks.

Two plots in each block were inoculated with a single aphid clone (either MACE or non-MACE) during the first experimental run, and with the other aphid clone on the second run. Each plant was inoculated with five third or fourth instar aphids on the upper leaves. Plants were inoculated on 22 May 2002 for the first experimental run, and on 10 September 2002 for the second. The aphids were allowed to settle on the plants for two days before the first of three, weekly, predator introductions was made.

One plot in each block was inoculated with *C. carnea*, whilst *C. carnea* was not introduced into the other plot. This design meant that, for analysis, the effect of aphid clone was nested within the block structure, to ensure that any effect of experimental block on aphid numbers was accounted for. To introduce the predators, 25g of substrate containing *C. carnea* was placed into each cage 2, 9 and 16 days after aphid inoculation, in both experimental runs. The predators were introduced as

recommended by suppliers and the substrate was sprinkled liberally on the top of all the plants to be treated. Estimates were made of the numbers of larvae found in the substrate (average of 164 individuals in 10g substrate). This meant that each inoculation consisted of approximately 400 individuals. Since each cage covered 20 m^2, this gave an inoculation rate of approximately 20 larvae per m^2 per week. This is at the upper limit of the recommended range of 5-20 larvae per m^2 per week, however, the level of initial aphid inoculation within each plot was also much higher than would be expected in a normal cropping situation.

Assessment and statistical analysis

Twenty eight days after inoculation 15 plants were taken at random from the central double row of plants in each plot (18 June for the first run, and 8 October for the second run). Each plant sample comprised of three leaves at the bottom of the plant (called 'bottom'), three leaves from the middle of the plant for each flowering stem (called 'mid branch A' and 'mid branch B') and up to 10 growing points at the top of the plant (called 'growing points'). The high number of growing points on sample plants was due to the lack of side shoot removal during the four week experiment. The number of aphids was counted using a scoring system if the number of individuals on a single leaf or growing point was greater than 80. The scale used was as follows:-

Score	No. aphids
0	0-80
1	81-160
2	161-320
3	321-700
4	>700

The scale was validated for each experimental run by counting all the aphids on ten leaves or growing points that had previously been assigned a score.
Statistical analysis of aphid numbers used the mean aphid score. This was calculated as a mean value for each plant part (from the samples taken), and these mean values were then used to produce a mean value for each plant. These data were subjected to analysis of variance using the mean values for each plant part.

Results

Very high levels of control of both MACE and non-MACE *M. persicae* were achieved in this experiment. The mean numbers of aphids per plant were very low (less than 60 aphids per plant) where *C. carnea* had been introduced compared to an estimate of over 2500 non-MACE and 4500 MACE *M. persicae* per plant on uninoculated control plants.

It is clear that there were relatively high numbers of MACE compared with non-MACE *M. persicae* on the growing points of the uninoculated pepper plants (Table 5). However, statistical analysis of all the data showed that similar numbers of MACE and non-MACE *M. persicae* were present on each plant part ($F = 0.42$, $p = 0.742$, 3df). This is because half of all the values in the analysis including both MACE and non-MACE *M. persicae* were zero.

Table 5
Mean aphid score per plant part for plants infested with MACE or non-MACE *Myzus persicae.* All values that differ by more than the LSD value are significantly different at the 5% level. Values in italics are compared using the LSD value in italics. There was no difference in the number of MACE and non-MACE *M. periscae* on different plant parts in this experiment.

	Mean aphid score				
Clone of *M. persicae*	Bottom	Mid branch A	Mid branch B	Growing points	whole plant
R3/kdr/MACE	**0.44**	**0.54**	**0.52**	**1.02**	
(- *C. carnea*)	0.88	1.07	1.03	2.04	*1.54*
(+ *C. carnea*)	0	0	0	0	*0*
R3/kdr	**0.65**	**0.39**	**0.38**	**0.37**	
(- *C. carnea*)	1.29	0.79	0.77	0.75	*0.84*
(+ *C. carnea*)	0	0	0	0	*0*
LSD					*0.38*

Discussion

Chrysoperla carnea performs equally well against MACE and non-MACE *M. persicae* on pepper plants. A very high level of control was achieved by *C. carnea* in these experiments and this predator appeared to be more effective than the parasitoid species *A. colemani*, that was used in previous experiments. This difference in performance was probably due to differences between 1) the time needed for the parasitoids to develop within their hosts and 2) the more immediate action of the predators.

CONCLUSIONS

- This project has identified parasitoid (*Aphidius colemani*) and predator (*Chrysoperla carnea*) species that were able to reduce the numbers of MACE and non-MACE *M. persicae* on pepper crops in large-scale experiments.
- *Aphidius colemani* was relatively more effective against non-MACE *M. persicae* than MACE *M. persicae*. However, it still caused large reductions in the numbers of MACE *M. persicae* during a four-week experiment.
- *Chrysoperla carnea* had a similar impact on the numbers of both MACE and non-MACE *M. persicae*, which was to reduce infestations by these aphids to very low levels.
- This project has shown the importance of continued introductions of both parasitoid and predator species and also the benefits of using introduction rates that are towards the higher end of the recommended range.
- Although the predator and parasitoid species have not been considered together, further work in this area is likely to provide a robust and reliable method of aphid control in pepper crops, regardless of the incidence of insecticide resistance.
- These experiments have used either MACE or non-MACE clones of *M. persicae* in isolation, and it may be that when presented with choices of different strains of *M. persicae*, the effectiveness of *A. colemani* or *C. carnea* could change. Such a situation is more likely to occur in commercial crops, and would need to be addressed by further work.
- Within this project, the aim has been to undertake crop-scale experiments using crops that are infested with aphids in a uniform way. This is unlikely to occur in a commercial cropping environment and may affect the searching behaviour and therefore the effectiveness of either of these biocontrol agents. Again, this would have to be addressed by further work.

TECHNOLOGY TRANSFER

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