Project title:	**Protected lettuce: an integrated approach to aphid and caterpillar control**
Report:	**First year**
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Location:	**HRI Wellesbourne, HRI Stockbridge House, Growers nurseries**
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PRACTICAL SECTION FOR GROWERS

The control of aphids and caterpillars in protected lettuce by methods other than the use of insecticides has been identified by the Lettuce Technology to be of high priority.

Growers of protected lettuce crops are dependent on routine, and often intensive, applications of insecticides to control aphids on lettuce foliage. The routine applications remain the same for crops grown throughout the 12 months of the year and take little account of the biology of the pest species. In summer months infestations of caterpillars occur frequently which require further insecticide applications to achieve effective control.

The leading food retailers are urging growers of protected lettuce to reduce their usage of insecticides, but the technologies are as yet unavailable to do so. Knowledge of the insect biology would suggest that the pressure and need for pest control would be very different at different times of year. Control programmes could be modified to take account of this varying pest pressure with the potential of reducing the number of insecticide applications.

Protected lettuce is the host plant for at least three different aphid species. Of those that colonise the foliage, the currant lettuce aphid (*Nasonovia ribisnigri*) is specific to lettuce while the peach potato aphid (*Myzus persicae*) and the potato aphid (*Macrosiphum euphorbiae*) are polyphagous, occurring on a range of different plant species including lettuce. Other species may infest lettuce from time-to-time and this requires clarification. There are many other species of aphid which do not colonise lettuce.

There may be three routes by which lettuce in a production house can become infested with aphids. Firstly, plants become infested during propagation and are then transferred to the production house. Secondly, aphids may fly through the vents of the greenhouse, and thirdly aphids may survive on lettuce debris within the house after harvest and transfer to the new crop as soon as it is planted. This third process of colonisation is overcome by good crop husbandry and the rapid removal of all crop debris from the greenhouse immediately after harvest and before the planting of a new crop, so eliminating a green bridge between crops. This is practised by growers and is not studied in this project.

The larvae of a number of moth species also infest protected lettuce crops. A number of species may occur on lettuce including the silver-Y (*Plusia gamma*), angle shades (*Phlogophora meticulosa*), tomato moth (*Laconobia oleracea*), cabbage moth (*Mamestra brassicae*), yellow underwing (*Noctua pronuba*) and at least two species of tortrix moth. Of these the most serious pests are thought to be the silver-Y, tomato moth and tortrix moths. Crops may become infested with caterpillars by the same routes that they become colonised by aphids. The routes to infestation of lettuce by caterpillars are the same as for aphids, though involve the flight of adult moths.

An effective integrated control strategy could be developed which focuses on the first two of these processes of crop infestation.

The overall objectives of the project are to confirm the identity of the key aphid and caterpillar species infesting protected lettuce and to identify a number of different control options for aphids. These would then be combined within an integrated control programme with the objective of fewer applications of insecticides to crops of protected lettuce.

Summary of Results

1. Water traps placed in crops in Sussex, Hertfordshire, Lancashire and Yorkshire to monitor aphids flying in through glasshouse vents indicated that though very few aphids were recorded, colonisation did take place by this route. The summer months are the key period for this invasion. Trapping will continue in further years to identify the period of risk with more precision.

2. Crops planted sequentially at HRI Stockbridge House were infested with the currant lettuce aphid, the potato aphid, the peach potato aphid and the glasshouse and potato aphid. The main period of infestation was from July to September. Initially the sequential crops overlapped in time in the same glasshouse. This resulted in considerable movement of aphids from one crop to another emphasising the need for rigorous hygene between crops. Subsequently there was no overlapping of crops.

3. Pheromone traps placed outside glasshouses at HRI Stockbridge House recorded the activity of moth species that might colonise lettuce. The silver-Y moth was the most abundant species and was recorded throughout the period from early-June to late-September. The tomato moth was only recorded during a 14 day period from late-June to early-July. The carnation tortrix was recorded from early-July to mid-September. No caterpillars of these or other species were recorded on the crops of lettuce planted sequentially and used also for monitoring aphid infestation.

4. Caterpillars were collected from commercial lettuce crops throughout the country and sent to HRI Stockbridge House for identification. Five different species were identified, the most numerous being the silver -Y. The other species were the white-line dart, the ruby tiger, the angle shades and the large yellow underwing. The latter two species are polyphagous feeding on a number of different plant species.

5. Young plants were sourced from three nurseries at intervals of two weeks from June to November. Two nurseries produce their own lettuce plants and one obtains plants from a commercial propagator. Only one aphid was found on the plants examined during this period. Although this is a very low incidence, it does demonstrate that there is an actual risk of introducing aphids to the production unit with the plants.

6. The screening of glasshouse vents with Enviromesh reduced considerably the numbers of aphids found on lettuce. However, infestation was not eliminated

7. The screening of the glasshouse vents with Enviromesh did not have a measurable effect on temperature, humidity or light measured at crop level. This will be examined in more detail in the second year of the project.

8. The pathogenicity of five isolates of entomopathogenic fungus to the currant lettuce aphid and the peach potato aphid were tested in the laboratory. The most effective strains in terms of the speed of kill and the dose of fungus required to kill were the commercially available strains of *Verticillium lecanii*. These will be tested further in 1999.

9. A review of the literature indicated that no parasitoids had been found on the currant lettuce aphid, though a range of species have been identified from the peach potato aphid and the potato aphid. Of the parasitoid species identified from these aphids, *Aphidius colemani, A. matricariae* and *A. ervi* are available commercially. The potential of these latter biological control agents to parasitise different aphid species within the lettuce environment will be studied during the second year of the project.

Action points for growers

This report provides results from the first year of the project and must therefore be considered as preliminary. However, the following points should be noted:

- Aphids may colonise lettuce crops during propagation and then be introduced to the cropping house. They may also enter through the glasshouse vents. Preliminary results suggest that colonisation can be reduced by screening glasshouse vents.

- The silver-Y moth seems to be the main caterpillar species found on lettuce crops.

- There are biological control agents that are effective against at least some of the aphid pests of lettuce which may provide the opportunity for reducing insecticide usage.

Practical and financial anticipated benefits

A reliable integrated control programme for aphids on protected lettuce and the identification of key caterpillar species will:

1. Provide a sustainable pest control programme that is based on a combination of control options rather than a limited number of insecticides.

2. Retain and improve the competitiveness of the UK protected lettuce industry by producing a product which will satisfy standards sought by the major UK food retailers.

3. Satisfy consumer requirements for reduced use of insecticides.

4. Minimise reliance on a single control strategy.

INTRODUCTION

Growers of protected lettuce crops are dependent on routine, and often intensive, applications of insecticides to control aphids on lettuce foliage. The routine applications remain the same for crops grown throughout the 12 months of the year and take little account of the biology of the pest species. In summer months infestations of caterpillars occur frequently which require further insecticide applications to achieve effective control. Alternative methods of aphid and caterpillar control are a high priority for growers of protected lettuce.

The leading food retailers are urging growers of protected lettuce to reduce their usage of insecticides, but the technologies are as yet unavailable to do so. Knowledge of the insect biology would suggest that the pressure and need for pest control would be very different at different times of year. Control programmes could be modified to take account of this varying pest pressure with the potential of reducing the number of insecticide applications.

Protected lettuce is the host plant for at least three different aphid species. Of those that colonise the foliage, the currant lettuce aphid (*Nasonovia ribisnigri*) is specific to lettuce while the peach potato aphid (*Myzus persicae*) and the potato aphid (*Macrosiphum euphorbiae*) are polyphagous, occurring on a range of different plant species including lettuce. Other species may infest lettuce from time-to-time and this requires clarification. There are many other species of aphid which do not colonise lettuce. There may be three routes by which lettuce in a production house can become infested with aphids. Firstly by plants becoming infested during propagation and then being transferred to the production house, secondly by aphids flying in through the vents of the greenhouse, and thirdly by aphids surviving on lettuce debris within the house after harvest and transferring to the new crop as soon as it is planted. This third process of colonisation is overcome by good crop husbandry and the rapid removal of all crop debris from the greenhouse immediately after harvest and before the planting of a new crop, so eliminating a green bridge between crops. This is practised by growers and will not be discussed further.

The larvae of a number of moth species also infest protected lettuce crops. A number of species may occur on lettuce including the silver Y (*Plusia gamma*), the angle shades (*Phlogophora meticulosa*), the tomato moth (*Laconobia oleracea*), the cabbage moth (*Mamestra brassicae*), the yellow underwing (*Noctua pronuba*) and at least two species of tortrix moth. Of these the most serious pests are thought to be the silver Y, tomato moth and tortrix moths. Crops may become infested with caterpillars by the same routes that they become colonised by aphids.

An effective integrated control strategy could be developed which focuses on the first two of these processes of crop infestation.

1.1 Commercial objective

The overall objective of the project is to identify a number of different control options for aphids on protected lettuce that could be combined within an integrated control programme with the end result that less insecticides are applied to crops, and to identify the species of caterpillars that damage lettuce.

2. MONITORING APHID INVASION AND DEVELOPMENT IN LETTUCE CROPS

2.1 Objective

To identify the periods of the year when protected lettuce crops are at risk from the different aphid species and identify the species involved for each risk period.

2.2 Use of traps

2.2.1 Methods

Two yellow water traps were placed in a lettuce crop at each of four sites, except at HRI Stockbridge House where a single trap was operated. The traps were emptied at three to four day intervals between April and September, and weekly between October and March. The contents of the traps were sent to HRI Wellesbourne where the insects were sorted and the aphids identified and counted.

The sites were:

1. Darnicle Hill Nursery, Hertfordshire
2. Lovania Salads, Lancashire
3. Madestein UK Ltd, Sussex
4. HRI, Stockbridge House, North Yorkshire

2.2.2 Results and discussion

At the three commercial sites very few aphids were recorded from water trap samples (Table 1a-c); individuals of *M. persicae, M. euphorbiae* and *P. bursarius* were found in July or October in 1997, and in May in 1998. At HRI Stockbridge House large numbers of *N. ribisnigri* and *M. euphorbiae* were recorded from water traps in August (Table 1d). This was a consequence of populations developing within the glasshouse as numbers increased unrestrained on overlapping crops (see section 2.3.2). This was overcome by ensuring intervals between crops to avoid the carry over of aphids from old to new plants.

The data indicate that small numbers of winged aphids are found in glasshouses. The presence of species that do not colonise lettuce (data not presented) indicates that at least some of these aphids enter the glasshouse either through the vents of through open doors.

2.3 Use of sequentially sown crops

2.3.1 Methods

Lettuce crops were planted sequentially, in half the glasshouse (Glasshouse FF 3 at HRI Stockbridge House, area 150 m^2), throughout the year as follows:

Weeks 26, 30, 34 1997	- cv Flandria
Weeks 41 1997, 3 1998	- cv Rachel
Weeks 15, 21 1998	- cv Flandria

The first three crops were each planted before the previous one had matured, so they overlapped by approximately two weeks. Thereafter, crops were planted immediately after the previous one was harvested to minimise the transfer of aphids between crops.

The crop was divided into sixteen plots arranged in four beds. Each plot contained 78 (13 rows of six) lettuce plants. On each sampling date, one row of six plants was selected at random in each of four plots, i.e. one plot per bed. The roots were checked for the presence of *Pemphigus bursarius* (lettuce root aphid) and the heads were dismantled and leaves were examined and all aphids recorded. Assessments were done weekly between May and September, and at two week intervals between October and April.

2.3.2 Results and discussion

The mean numbers of *Nasonovia ribisnigri* (currant-lettuce aphid), *Macrosiphum euphorbiae* (potato aphid), *Myzus persicae* (peach-potato aphid) and *Aulacorthum solani* (glasshouse and potato aphid) per lettuce head on each assessment date are shown in Figure 1. Note that the data presented represent the period from early-June 1997 to the end of April 1998.

The aphid species found most commonly was *N. ribisnigri*. All crops grown between June and September 1997 were infested with this species; the largest numbers being found in August and September. However, none were found on plants between the beginning of October 1997 and end of May 1998.

Macrosiphum euphorbiae and *M. persicae* were recorded in all crops between July and September 1997 but then not until mid-March 1998; the first infestations of both being detected on the 18 March. *Aulocorthum solani* were only found in late August and September 1997.

The relatively large numbers of *N. ribisnigri* and *M. euphorbiae* were recorded in mid-August 1997 were due in part to the transfer of winged aphids from the older crop to the new plants. Until then, crops had been overlapped in time to ensure that there was always a "green target" for invading aphids but subsequently this practice was stopped.

No *P. bursarius* were found on the lettuce roots in any of the crops.

3. MONITORING MOTH INVASION AND CATERPILLAR DEVELOPMENT

3.1 Objective

To identify the periods of the year when protected lettuce crops are at risk from the different caterpillar species and identify the species involved for each risk period.

3.2 Use of traps

3.2.1 Introduction

There is little available information regarding the use of pheromone traps in or around glasshouse structures, so the studies in the first year of this project concentrated on developing methodologies at HRI Stockbridge House that could be used more widely later in the project. In the first instance, the work was restricted to three species of moths, *Plusia gamma* (silver-Y moth), *Laconobia oleracea* (tomato moth) and *Cacoecimorpha pronubana* (carnation tortrix moth), for which pheromone traps were available commercially.

3.2.2 Methods

The following pheromone traps were placed on 5 June 1997 and examined weekly until 3 October 1997. Trapping was not continued through the winter months as low temperatures out doors usually prevent the flight of adults of these species even if they are present.

P. gamma One Oecos Funnel Trap mounted on a pole approximately 0.8m above ground 5m from the glasshouse.

L. oleracea Two Oecos Delta Traps; one mounted on a pole approximately 0.8m above the ground and one positioned on a glasshouse roof approximately 4m above the ground.

C. pronubana Two Oecos Delta Traps mounted on poles approximately 0.8m above the ground. They were orientated at right angles and positioned approximately 40m apart.

Lures were changed at intervals of six weeks.

3.2.3 Results and discussion

The numbers of moths caught in the pheromone traps is summarised in Table 2. The species recorded most frequently from pheromone traps was *P. gamma*.

The first *P. gamma* were detected on 5 June 1998 and an average of 0.24 were caught per day between then and 25 September 1998. *Cacoecimorpha pronubana* were recorded between 8 July 1998 and 14 September 1998 with an average of 0.13/trap/day. *Laconobia oleracea* were active during a 14 day period in late June/early July when there was an average of 0.14/trap/day.

3.3 Use of sequentially sown crops

3.3.1 Methods

This work was done in greenhouse FF 3, HRI Stockbridge House, in the same crops used to monitor aphid invasion (Section 2.3).

Assessments were concurrent with aphid assessments. All caterpillars found on the roots or foliage of the lettuce plants were identified and recorded.

3.3.2 Results and discussion

No caterpillars were found.

3.4 Samples from commercial crops

3.4.1 Methods

Caterpillars collected from lettuce by David Stokes during the course of consultancy visits to lettuce growers were sent to HRI Stockbridge House for identification. Where necessary, specimens were reared to adults to confirm the identifications.

3.4.2 Results and discussion

The results are summarised in Table 3.

Twenty caterpillars were received at Stockbridge House and 12 survived to become adults. Five different species were identified, the most numerous being silver -Y (*P. gamma*). The other species were white-line dart (*Euxua tritici*), ruby tiger (*Phragmatobia fuliginosa*), angle shades (*Phlogophora meticulosa*) and large yellow underwing (*Noctua pronuba*). The latter two species are polyphagous feeding on a number of different plant species.

4. PROPAGATION AS A SOURCE OF INFESTATION

4.1 Objective

To determine whether lettuce propagation is a source of aphid infestation for the main production crop.

4.2 Methods

Batches of 50 lettuce plants from each site were examined prior to planting and the number and species of aphids recorded. Plants were examined at intervals of two weeks from 1 June to 21 November1997, then at four weekly intervals until 4 May 1998, and then again at two weekly intervals.

The sites were:

1. HRI, Stockbridge House, North Yorkshire
2. Mr J Sykes, Snaith, North Yorkshire
3. Mr D Parkinson, Snaith, North Yorkshire

Stockbridge House and Mr. Sykes both produce their own lettuce plants, while Mr Parkinson obtains plants from a commercial propagator.

At Stockbridge House, the lettuce plants were examined before routine application of insecticides to determine the potential risk of aphid infestation.

At all three sites, the lettuce plants were examined between spraying and before planting, to determine the actual risk of infestation.

4.3 Results and discussion

Plants examined in the propagation unit at Stockbridge House before routine application of insecticide revealed the presence of two aphid species, *N. ribisnigri* and *M.euphorbiae*, on one occasion. This demonstrated the potential risk of introducing aphids to the production unit with the plants.

Only one aphid (an alate *M. euphorbiae*) was found on the lettuce plants between the routine application of insecticide and planting. Although this is a very low incidence, it does demonstrate that there is an actual risk of introducing aphids to the production unit with the plants.

5. EXCLUSION OF MOTHS AND APHIDS

5.1 Objective

To determine the potential for screening production houses to limit insect infestation of crops.

5.2 Methods

Two glasshouses (FF 3 and FF 5, HRI, Stockbridge House) each of similar structure, size ($150m^2$) and orientation were used. The roof vents and the doorway of glasshouse FF5 were screened with Agralan Enviromesh Type S48. Glasshouse FF3 was the unscreened control.

Lettuce crops were planted sequentially, in half of each glasshouse, throughout the year as follows:

Weeks 26, 30, 34 1997	- cv Flandria
Weeks 41 1997, 3 1998	- cv Rachel
Weeks 15, 21 1998	- cv Flandria

Each of the first three crops was planted before the previous one had matured, so that they overlapped by approximately two weeks. Thereafter, crops were planted immediately after the previous one was harvested to minimise the transfer of aphids from one crop to another. Insect infestation was assessed by two methods:

Traps: One yellow water trap was placed within the lettuce crop in each glasshouse. The traps were emptied at three to four day intervals between April and September, and weekly between October and March. The contents of the traps were sent to HRI Wellesbourne where the insects were sorted and the aphids identified and counted.

Plants: Each crop was divided into sixteen plots, arranged in four beds, and each plot contained 78 (13 rows of six) lettuce plants. In the first and final week of each crop, one row of six plants was selected at random in each of four plots, i.e. one plot per bed. The roots were checked for the presence of *Pemphigus bursarius* (lettuce root aphid) and caterpillars. The heads were dismantled, leaves examined and all aphids and caterpillars recorded.

The effect of screening on the environment within the glasshouses was also monitored. Temperature and humidity in both the screened and unscreened houses were recorded throughout the experiment. Solar radiation was measured over a five week period in February and March 1998 to determine whether screening affected light levels at crop level.

5.3 Results

1. Traps

No aphids were recorded from the water trap in the screened house as compared to larger numbers in the unscreened house (Table 1d) (see also section 2.2).

2. Plants

The mean numbers of *N. ribisnigri, M. euphorbiae, M. persicae* and *A.solani* per lettuce head in the unscreened house on each assessment date are shown in Figure 1. Aphids were found in every crop and all were rendered unmarketable. No caterpillars were found.

The mean numbers of *N. ribisnigri, M. euphorbiae,* and *M. persicae* per lettuce head in the screened house on each assessment date are shown in Figure 2. No *A. solani* were found in this house. Very small numbers of aphids were found in three of the seven crops grown during the year. On one occasion, in July, it is known that the aphids were introduced on plants from propagation. The other infestations occurred in the winter and early spring, at times when the pests were not migrating, and it is most probable that these aphids were also taken into the production house on plants from propagation. No caterpillars were found.

Screening the production house clearly reduced the pressure of pest invasion but the presence of aphids demonstrated the need to both improve the pest control procedures in the propagation unit and to have a second line of defence within the production house.

3. Environment

The temperature in the screened and unscreened houses during periods in both the summer and winter are shown in Figure 3. The differences between the houses were minimal and within the variability of the measuring equipment.

The relative humidities in the screened and unscreened houses between late October and early February are shown in Figure 4. Relative humidity in the screened house was consistently lower than in the unscreened house although the differences were small were within the variability expected of the measuring equipment. This is unlikely to have had any significant effect on plant growth.

Solar radiation measurements accumulated per day in the screened and unscreened houses during a period from mid-February to mid-March1998 are given in Figure 5. There was little difference between the two houses except at the end of the observation period when more light energy was recorded in the screened than the unscreened house. This is a suprisng result and suggests that the sensors may be at fault.

In the second year of the project measurements will be taken that take account of any possible differences between sensors.

6. BIOASSAY OF FIVE FUNGAL ISOLATES AGAINST *MYZUS PERSICAE* AND *NASONOVIA RIBISNIGRI*

6.1 Objective

To identify the potential of entomopathogenic fungi that control pest aphid species.

6.2 Methods

Insect rearing

Myzus persicae and *Nasonovia ribisnigri* were reared separately on lettuce (cv. Webs Wonderful) at 20°C± 2 with a photoperiod of 16 hours. Large numbers of adult aphids were reared for bioassays. Apterous (wingless) *M. persicae* were used for bioassays, but due to the propensity of *N. ribisnigri* to produce alatae (winged), these were used for bioassays with this species.

Culture of fungal isolates

Five isolates with known activity against aphids were tested; *Verticillium lecanii* 1.72 (Vertalec), *V. lecanii* 19.79 (Mycotal), *Metarhizium anisopliae* 245, *Paecilomyces fumosoroseus* PFR and *Beauveria bassiana* 414. The first two strains are available commercially in the UK while the remaining three strains are either unavailable commercially or under commercial development elsewhere in the world.

Samples of conidia were taken from working slopes (stored at 4°C), spread onto Saboraud Dextrose Agar (SDA) and allowed to grow for seven days at 23°C. Conidia were then harvested in 0.01% Triton X100 and suspensions of 10^5, 10^6, $3x10^6$, 10^7, $3x10^7$ and 10^8 spores ml^{-1} were prepared for each isolate using an improved Neubauer haemocytometer.

Bioassay procedure

A computer controlled spraying apparatus was used to deliver a precise dose of each spore suspension to groups of twenty aphids on damp filter paper in a 9cm diameter Petri plate. Aphids were left for an hour to recover, then were placed into the bioassay chambers. Bioassays were done using the whole, attached leaves of 4 week old lettuce plants. A plastic box (120x75x17mm) with a push-fit lid was fitted around a single leaf; a groove, cut into one side of the box allowed it to fit around the petiole. The bioassay chamber was supported by plant identification labels taped to the back, then pushed into the soil. Cotton wool was wrapped around the petiole at the point of entry into the chamber to block any gaps through which aphids could escape, and the lid of the box was secured with two elastic bands. The back and the base of the chamber were lined with damp filter paper throughout the bioassay; this absorbed any water droplets formed and ensured humidity was maintained above 95% (necessary for fungal infection). Bioassays were carried out at 20°C±1, photoperiod 16 hours and mortality was monitored daily for seven days. Any cadavers were removed, placed on damp filter paper in sealed Petri plates and examined seven days after the end of the bioassay to determine whether sporulation had occurred.

All fungal isolates were bioassayed three times, and the order in which treatments were

carried out was fully randomised. The two aphid species were bioassayed separately.

6.3 Results

Handling mortality

Deaths up to 48 hours after inoculation were attributed to handling damage. The mean percentage of aphids dying was 20.2 (sd 6.25), 22.7 (sd 9.34) and 8.3 (sd 1.88) for bioassays 1, 2 and 3 respectively. These data were excluded from cumulative mortality counts.

Survival time

Data from each dose were not independent as the same insect population was monitored over time, thus neither logit, nor probit analysis could be used to estimate lethal time (LT) values. However, average survival time was calculated for defined spore concentration where fungal-induced mortality reached 100% (Table 4).

A single factor ANOVA indicated a significant difference in survival time for *M. persicae*, with aphids treated with either of the two isolates of *V. lecanii* dying significantly faster than when treated with the other isolates. In contrast there was no significant difference in average survival time of *N. ribisnigri* treated with the different strains of fungus.

LC_{50} at day 4

Mean fungal-induced mortality four days after infection was transformed using logits and plotted against log dose. Linear regression was used to estimate LC_{50}s; these values were backtransformed to concentrations (Table 5).

A single factor ANOVA on the data from individual replicates indicated no differences in *M. persicae* between the strains. However, it must be noted that the variability was large. There was a significant difference between estimated LC_{50}s of the five fungal strains against *N. ribisnigri* with *V. lecanii* 19.79 being most pathogenic.

6.4 Discussion

The strains of *V. lecanii* already available commercially show considerable potential for the control of *M. persicae* and *N. ribisnigri*. However, experimentation is required to determine the efficacy of these fungi under conditions found in glasshouses.

7. POTENTIAL OF PARASITOIDS TO CONTROL APHIDS

7.1 Objective

To identify the potential of parasitoids for the control of pest aphid in lettuce.

7.2 Methods

The scientific literature was searched to identify the parasitoids of the different aphid species that are known to occur on lettuce. This search was extended to include all species of aphid from lettuce even if they occur only rarely.

7.3 Results and discussion

A number of parasitoid species have been identified from two of the main aphid pests, *M. persicae* and *M. euphorbiae*, but none have been recorded from the third key aphid pest *N. ribisnigri* (Table 6). Some of the records are from crops that have not been identified clearly. However, *M. persicae* and *M. euphorbiae* are aphids that feed on many species of plant and this should not affect the interpretation of the information.

Two species of parasitoid , *Aphidius colemani* and *A. ervi*, were both identified from *M. persicae* and *M. euphorbiae* and are also available as commercial biological control products. It is now necessary to determine whether either of these two species will parasitise *N. ribisnigri* and to determine which parasitoid is likely to be most effective in lettuce crops to control the three main aphid pests.

8. ACKNOWLEDGEMENTS

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Table 2. Number of moths caught per day in the pheromone traps near glasshouses at HRI Stockbridge House, May to October 1997 (- represents a zero catch).

	Plusia gamma[a]	*Cacoecimorpha pronubana*[a]		*Laconobia oleracea*[a]	
Date	Trap1	Trap 1	Trap 2	Trap 1	Trap 2
28/5/97	-	-	-	-	-
5/6/97	0.125	-	-	-	-
9/6/97	0.5	-	-	-	-
19/6/97	0.1	-	-	-	-
24/6/97	0.6	-	-	0.2	0.2
4/7/97	0.5	-	-	0.1	-
8/7/97	0.5	-	0.25	0.25	-
17/7/97	0.2	-	-	-	-
24/7/97	0.14	-	0.14	-	-
31/7/97	0.29	-	-	-	-
8/8/97	0.125	0.25	0.25	-	-
14/8/97	0.67	0.33	-	-	-
20/8/97	0.17	-	0.17	-	-
28/8/97	0.25	-	0.25	-	-
14/9/97	0.06	0.12	0.18	-	-
19/9/97	-	-	-	-	-
25/9/97	0.17	-	-	-	-
3/10/97	-	-	-	-	-
Total	**29**	**6**	**10**	**3**	**1**

[a] Specific and common names of moth species

Plusia gamma	Silver-Y
Cacoecimorpha pronubana	Carnation tortrix moth
Laconobia oleracea	Tomato moth

Table 3. Numbers of caterpillars collected from crops of protected lettuce, 1997-1998.

Year	Site	Date received	Identification [a]
1997	Great Abington 1, Cambs.	15 July	1 *Euxoa tritici*
	Great Abington 2, Cambs.	15 July	1 Dead at pupa
		16 September	1 *Phragmatobia fuliginosa*
	Great Abington 3, Cambs.	29 July	*2 Plusia gamma*
			1 *Euxoa tritici*
		28 October	1 Dead
	Great Abington 4, Cambs.	29 July	1 Parasitised
	Doddington, Cambs.	9 September	4 *Plusia gamma*
			1 Dead after Dipel spray
	Fen Drayton, Cambs.	16 September	2 Dead
		14 October	2 Dead
1998	Goffs Oak, Hertfordshire.	10 February	1 *Phlogophora meticulosa*
	Cambridgeshire	4 March	1 *Phragmatobia fuliginosa*
	Great Abington 5,Cambs.	10 March	1 *Noctua pronuba*

[a] Specific and common names of moths in Table 3:

Euxoa tritici	White-line dart
Noctua pronuba	Large yellow underwing
Phlogophora meticulosa	Angle shades
Phragmatobia fuliginosa	Ruby Tiger
Plusia gamma	Silver-Y

Table 4. Average survival time in days (and standard deviation) of *Myzus persiace* treated with five strains of entomopathogenic fungi at a spore concentration of 10^8 ml^{-1} and *Nasnovia ribisnigri* when treated with a spore concentration of 10^7 ml^{-1}

Strain	*M. persicae*	*N. ribisnigri*
B. bassiana	4.42 (1.072)	3.97 (0.671)
M. anisopliae	3.85 (0.530)	3.91 (0.500)
P. fumosoroseus	4.65 (0.426)	3.61 (0.431)
V. lecanii 1.72	2.23 (0.112)	3.54 (0.638)
V. lecanii 19.79	3.24 (0.420)	3.50 (0.000)
S.E.D.	0.49	-
F value	7.97	1.62
P	0.004	0.24

Table 5. Estimated LC_{50}s (and standard deviation) of five fungal strains required to kill *Myzus persicae* and *Nasonovia ribisnigri* after four days.

Strain	*M. persicae*	*N. ribisnigri*
B. bassiana	3.60×10^7 (2.10×10^7)	6.80×10^6 (9.53×10^6)
M. anisopliae	1.62×10^{10} (2.74×10^{10})	7.26×10^6 (2.65×10^6)
P. fumosoroseus	5.10×10^{14} (8.70×10^{14})	4.21×10^5 (8.20×10^5)
V. lecanii 1.72	3.73×10^5 (1.32×10^5)	1.09×10^6 (3.72×10^5)
V. lecanii 19.79	1.30×10^7 (1.10×10^7)	2.21×10^5 (1.67×10^5)
S.E.D.*	-	3.6×10^6
F value	1.00	3.86
P	n.s.	<0.05

* S.E.D. values refer to the logit transformed data and cannot be applied directly to the backtransformed data.

Table 6. Potential parasitoids of aphid pests of lettuce identified from a review of the literature.

Aphid species	Parasitoid Species	Crop	Effectiveness	Reference.
Nasonovia ribisnigri	None recorded			
Myzus persicae	*Aphidius colemani*	Glasshouse crops	Good	van Steenis (1992)
	Aphidius matricariae	Glasshouse crops	Good	Halima Kamel *et al.* (1993), Kornilov *et al.* (1991), van Steenis (1992)
	Aphidius ervi	Glasshouse crops		Halima Kamel *et al.* (1993)
	Aphelinus asychis	Glasshouse crops		Halima Kamel *et al.* (1993)
	Praon volucre	Glasshouse crops		Halima Kamel *et al.* (1993)
	Trioxys angelica	Glasshouse crops		Halima Kamel *et al.* (1993)
	Lysiphlebus testaceipes	Glasshouse crops	Poor	van Steenis (1992)
Macrosiphum euphorbiae	*A. colemani*	Glashouse crops, eggplant	Incomplete development	Messing *et al.* (1995), van Steenis (1992)
	A. ervi	Wheat, barley and maize	Good	Feng *et al.* (1992), Halima Kamel *et al.* (1993)
	A. matricariae	Glasshouse crops	Bad	Halima Kamel *et al.* (1993), van Steenis (1992)
	Aphidius sonchi		Bad	Liu *et al.* (1985)
	Aphius nigripes	Potato	Good	Brodeur (1994)
	L. testaceipes	Glasshouse crops	Bad	van Steenis (1992)
	A. asychis	Glasshouse crops		Halima Kamel *et al.* (1993)
	P. volucre	Glasshouse crops		Halima Kamel *et al.* (1993)
	Praon Sp.	Wheat, barley and maize	Poor	Feng *et al.* (1992)
Aulocorthum solani	*Lysiphlebus fabarum*	Pepper	Good	Lyashova (1992)

Aphis gossypii	*A. colemani*	Glasshouse crops	Very good	van Steenis (1992, 1995)
	A. matricariae	Glasshouse crops	Poor	Halima Kamel *et al.* (1993), van Steenis (1992, 1995)
	L. testaceipes	Glasshouse crops	Not good	van Steenis (1992, 1995)
	Lysiphlebus confusus	Glasshouse crops		Halima Kamel *et al.* (1993)
	Ephedrus cerasicola	Cucumber	Not good	van Steenis (1995)
	T. angelica	Glasshouse crops		Halima Kamel *et al.* (1993)
Uroleucon sonchi	*Endaphis aphiimyza (Cecidomyidae)*	Safflower		Narangalkar *et al.* (1992)
Hyperomyzus lactucae	*P. volucre*	*Sonchus* sp., Lettuce	Good, Poor	Aeschlimann *et al.* (1985), Carver (1986)
	A. sonchi	*Sonchus* sp. Lettuce	Good Good	Aeschlimann *et al.* (1985), Carver (1986)
Pemphigus bursarius	*Protaphelinus mackauer*	*Populus nigra*		Rishi (1984)

Figure 1. The mean number of aphids per plant on crops of lettuce planted sequentially in an unscreened glasshouse at HRI Stockbridge House, June 1997 to April 1998.

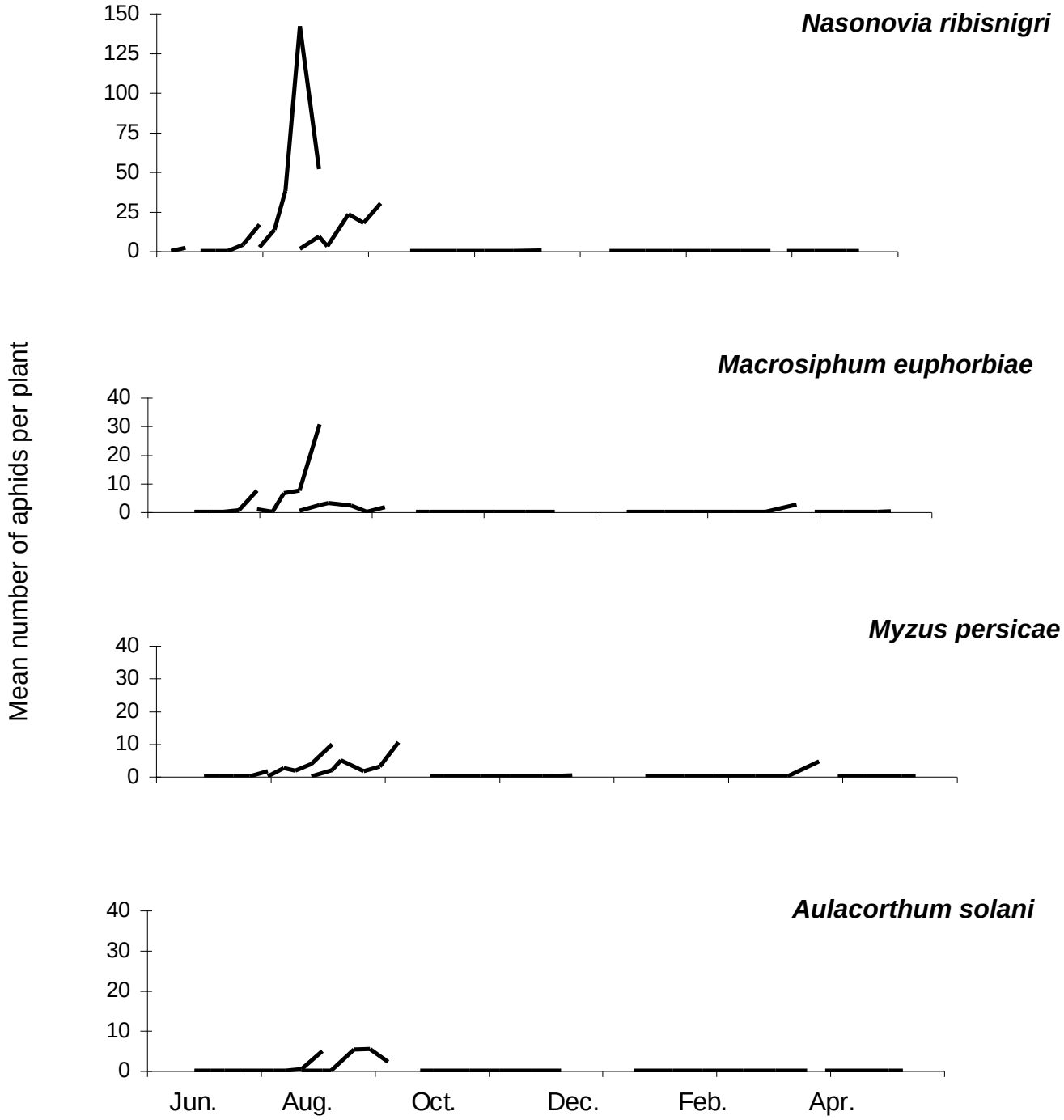

Figure 2. Mean number of aphids per plant on crops of lettuce planted sequentially in a screened greenhouse at HRI Stockbridge House, June 1997 to April 1998.

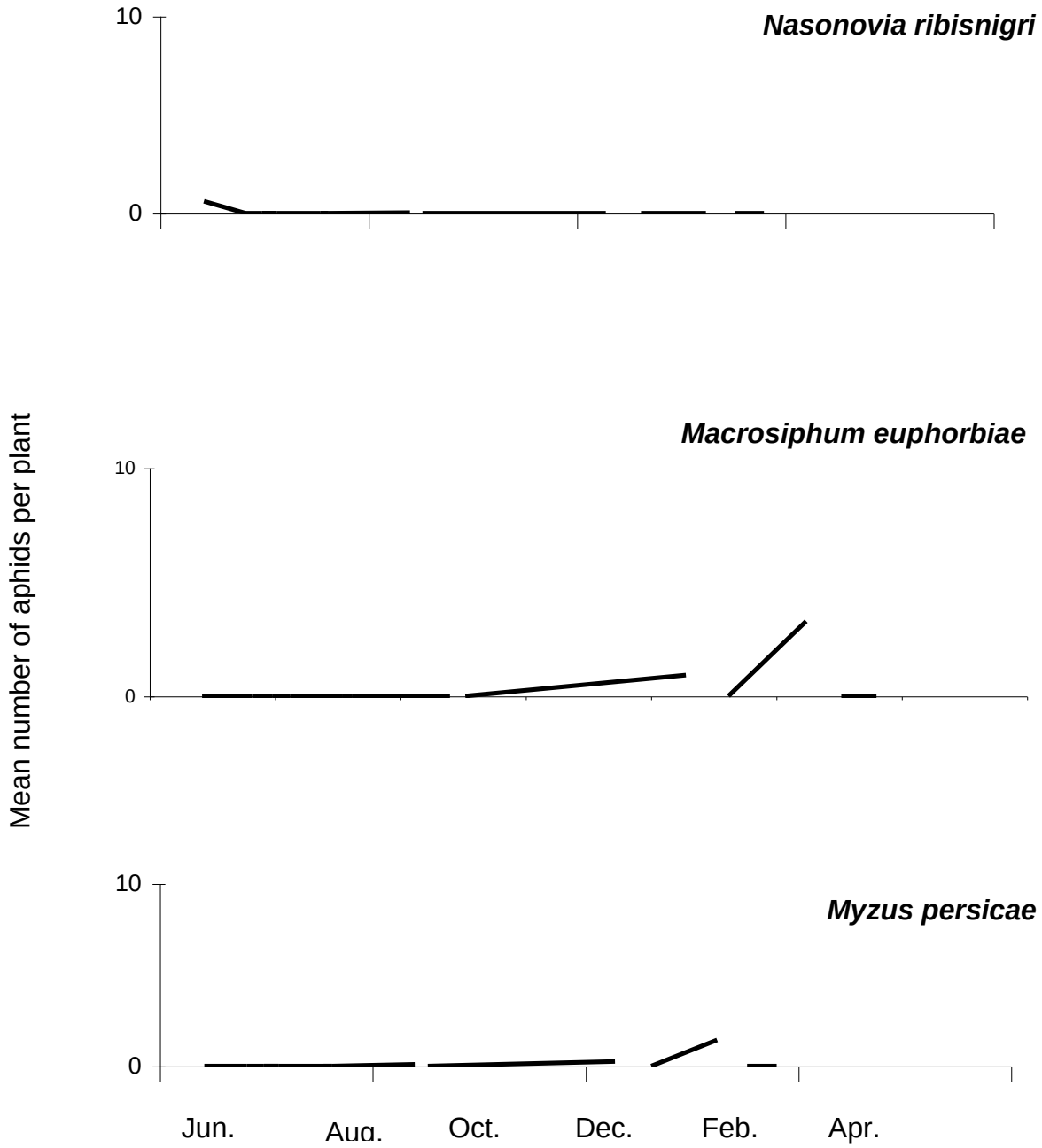

Figure 3. The temperature in a greenhouse with unscreened and screened vents at

HRI Stockbridge House in a) summer and b) winter.

Figure 4. The relative humidity in a greenhouse with screened and unscreened vets at HRI Stockbridge House during two periods in the winter of 1997 to 1998.

Figure 5. The light energy recorded in a screened and unscreened greenhouse at HRI Stockbridge House during February and March 1998.