ANNUAL REPORT

Project title:	Control of capsid bugs within IPM programmes in protected crops.
Report:	Annual Report, April 2000
Previous reports:	Annual Reports, April 1997, April 1998 and April 1999
Project number:	PC123
Project leaders:	R. J. Jacobson, HRI Stockbridge House Dr G. Port, Newcastle University
Key workers:	J. Hadlow, HRI Stockbridge House K. M. Russell, HRI Stockbridge House F. Hunter, Newcastle University
Location:	Horticulture Research International Stockbridge House Cawood North Yorkshire. YO8 3TZ Tel: 01757 268275 Fax: 01757 268996 Department of Agricultural and Environmental Science Ridley Building University of Newcastle Newcastle upon Tyne. NE1 7RU Tel: 0191 222 6894 Fax: 0191 222 5229
Project Co-ordinator:	D. Hargreaves
Date commenced:	April 1996
Date completed:	October 2001
Keywords:	Capsids, IPM, Cucumbers, Peppers, Aubergines, Protected Edible Crops, *Beauveria bassiana*, Chess, pymetrozine, Naturalis, Applaud, buprofezin, habitat.

HDC.

The results and conclusions in this report are based on a series of experiments and surveys. The conditions under which the work was carried out and the results 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.

CONTENTS

PRACTICAL SECTION FOR GROWERS

Background and objectives

Capsids belong to the Miridae, a large family of small to medium sized soft-bodied insects that exploit a wide range of habitats. For many years, a plant feeding species, *Lygus rugulipennis* (European tarnished plant bug), has been a sporadic pest in U.K. glasshouses but until recently it has been uncommon for specific action to be taken against it in edible crops. When pest control was based entirely on chemicals, invading *L. rugulipennis* did not establish breeding populations on plants because they were killed by insecticides applied against other pests, such as *Trialeurodes vaporariorum* (glasshouse whitefly). With the advent of IPM in protected salad crops in the 1970s and 80s, capsids were able to survive and colonise plants. However, reports of serious damage remained rare until the early-1990s, when the number of requests for advice relating to control of capsids began to increase markedly. In 1996, the HDC commissioned a project aimed at improving the knowledge of the behaviour of plant feeding capsids in protected salads as a first step in formulating a sustainable control strategy within the existing IPM programmes.

Work completed in previous years (1996-1999)

<u>Identifying the problem</u>

The work in the first year of the project concentrated on determining the importance of capsid infestations in protected edible crops. Detailed crop monitoring at several sites in Yorkshire showed that two species were causing damage: *Lygus rugulipennis* in cucumber crops and *Liocoris tripustulatus* in pepper and aubergine crops. The following symptoms were seen in cucumbers, peppers and aubergines: i) feeding in growing points resulted in distorted growth and holes in leaves as they expanded; ii) probing in stems just below growing points resulted in death of the growing point; iii) feeding and egg laying in very young fruit resulted in distortion as the fruit swelled; iv) feeding on maturing fruit resulted in surface scars which rendered the fruit unmarketable. No damage was seen in tomato crops even where they were grown adjacent to heavily infested cucumber and pepper crops.

Based on the detailed monitoring information, an illustrated fact sheet was produced to aid growers recognise capsids and symptoms of their damage (HDC Fact Sheet 37/96) and this was circulated with a questionnaire to all cucumber, pepper and aubergine growers registered with the HDC. A total of 120 cucumber, pepper and aubergine growers responded to the survey and 48 confirmed that they had seen capsid activity in their crops. Approximately one third of those who had seen damage, reported that it occurred over large areas of their crops. The most seriously affected were cucumbers where the estimated financial loss ranged from £0.3 to £2 per m^2. Many of the growers who reported less serious damage had restricted the development of the problem by applying broad spectrum insecticides but indicated that this had affected biological control of other pests and had resulted in secondary problems. The survey confirmed that this was a nationwide problem that had become much more serious during the last four years.

Monitoring capsid invasion

A reliable method of monitoring the migration of capsid bugs into greenhouses would enable control measures to be more accurately timed. Flat and cylindrical white and yellow traps have been evaluated in cucumber and pepper crops that were infested with *L. rugulipennis* and *L. tripustulatus* respectively. The numbers of *L. rugulipennis* and *L. tripustulatus* caught were quite small, indicating that the insects were not specifically attracted to any of them. However, the numbers of male *L. rugulipennis* caught were greatly increased when the traps were baited with live females. Volatile chemicals, assumed to be sex pheromones, have now been isolated from female *L. rugulipennis* and will be evaluated as attractants in monitoring traps.

Control using entomopathogenic fungi (*Verticillium lecanii* and *Beauveria bassiana*)

Three commercially available entomopathogenic fungi (*i.e*. two strains of *Verticillium lecanii* [Mycotal and Vertalec] and one *Beauveria bassiana* [Naturalis]) were evaluated against both *L. rugulipennis* and *L. tripustulatus* in laboratory bioassays in 1998. Naturalis showed greatest effect and was subsequently evaluated against *L. rugilipennis* in experimental glasshouses. Two methods of application (*i.e.* high volume spray and ultra low volume mist) provided similar results with numbers of adult *L. rugulipennis* being reduced by 60% compared to untreated controls.

Beauveria bassiana is active against a wide range of invertebrates and it is important to know the impact that it will have on the biological control agents used to control other pests in IPM programmes. The effects of *B. bassiana* on the predatory mite, *Amblyseius cucumeris*, and the parasitic wasp, *Encarsia formosa*, were determined in laboratory-based bioassays during 1998/99. There was no evidence to suggest that *B. bassiana* was harmful to *A. cucumeris*. However, *B. bassiana* was harmful to *E.formosa.* The results of two experiments demonstrated that *B.bassiana* sprayed on parasitised *Trialeurodes vaporariorum* (glasshouse whitefly) scales, before and after they turned black, reduced survival of the parasitoid by 36% and 62% respectively. *Beauveria bassiana* also infects *T. vaporariorum* directly and can provide effective control of this pest, so the overall effect on this component of the IPM programme may not be detrimental.

Control using insecticides

The potential of two selective insecticides, buprofezin (as Applaud) and pymetrozine (as Chess), against *L. rugulipennis* was determined in small-scale experiments in 1998. There was no evidence to suggest that the insect growth regulator, Applaud, prevented *L. rugulipennis* nymphs moulting or that it reduced oviposition by adult female *L. rugulipennis*. Although the antifeedant chemical, Chess, did not kill adult *L. rugulipennis*, there was some evidence that damage to the growing points of treated plants was reduced compared to untreated controls.

Ecology of capsids

The ecology of *L. rugulipennis* and *L. tripustulatus* is not well known. In particular, there is little information about where the adult capsids spend the winter months prior to invading the glasshouses. A survey of potential overwintering sites began in 1998. Litter samples (leaves, grass etc.) from HRI Stockbrige House and Close House (University of Newcastle field station) were collected and examined for the presence of capsids using hand sorting and heat extraction methods. Very low numbers of capsids were retrieved from the litter samples. These studies are continuing.

Specific targets for 1999/2000

Following the Project Review Meeting in March 1999, the following work plan was agreed for year 4 of the project:

1. To evaluate traps baited with sex pheromones for monitoring the migration of *L. rugulipennis* into protected edible crops. (HRI and University of Newcastle).
2. To evaluate the efficacy of the entomopathogenic fungus, *B. bassiana*, against *L. rugulipennis* on whole plants. (HRI).
3. To determine the compatability of *B. bassiana* with important parasitoids and predators used in the cucumber IPM programme. (HRI).
4. To determine the efficacy of the selective insecticide, pymetrozine (as Chess), against *L. rugulipennis*. (HRI).
5. To improve the knowledge of the natural habitats and activity patterns of *L. rugulipennis* and *L. tripustulatus*. (University of Newcastle).

Summary of Results in 1999/2000

A preliminary evaluation of prototype pheromone traps in capsid infested cucumber crops did not provide conclusive results. This may have been because the dose and/or ratio of the chemical components were incorrect. Modified lures were not available in 1999 due to technical problems with their production at NRI. However, the ability to monitor capsid invasion remains an important component of this project and pheromone baited traps will be evaluated in commercial cucumber crops as soon as the lures become available.

The efficacy of two methods of applying two formulations of *B. bassiana* was evaluated against established populations of *L. rugulipennis* on cucumber plants. The overall mean number of adult *L. rugulipennis* in the *B. bassiana* treatments was approximately 78% lower than the untreated control, compared to approximately 60% lower in the previous experiment. The additional control can be attributed to the programme of three sprays compared to the previous single spray. The mean relative humidity during this experimental period was approximately 70% in the crop canopy compared to 90% in the previous experiment, which suggests that infection of *L. rugulipennis* by *B. bassiana* is not dependant on high RH. *Beauveria bassiana* clearly has potential for the control of *L. rugulipennis* both as a HV spray and a LV mist. The latter is relatively inexpensive because it requires minimal labour. It would allow the cost-effective application of a series of treatments throughout the main *L. rugulipennis* invasion period and is therefore an attractive option. However, further studies are required to determine the optimum frequency and rate of application on a larger scale in commercial crops.

The effects of the entomopathogen on the predatory mite, *Phytoseiulus persimilis*, and the parasitic wasp, *Aphidius colemani*, were determined in laboratory-based bioassays. Although it was demonstrated that *B. bassiana* could infect adult *P. persimilis*, this did not have a significant effect on the populations tested. There was no evidence to suggest that *B. bassiana* infects adult *A. colemani* or has an adverse effect on the population.

A small scale glasshouse experiment demonstrated that pymetrozine reduced *L. rugulipennis* feeding damage when the bugs had a choice of sprayed and unsprayed plants. This is an important development because pymetrozine as the product Chess is now approved in the UK for use on cucumber crops.

Ms Fiona Hunter has completed the first year of her PhD, which is aimed at improving the knowledge of natural habitats and activity patterns of *L. rugulipennis* and *L. tripustulatus*. The studies are focusing on the insects' overwintering sites, spring migration, population dynamics and host plant choice. Much of the first season's work has been devoted to developing and testing experimental methods. These will be used to investigate the subjects more thoroughly during the coming year.

Action points for growers

- Capsid damage to cucumber, pepper and aubergine crops can occur from May to September.

- Growers should be aware of the types of damage caused by capsids. Please refer to HDC Factsheet 37/96 'Capsid bugs in protected crops'.

- Most of the insecticides that are effective in controlling capsids are not compatible with Integrated Pest Management (IPM) Programmes.

- Preliminary results from the 1999/2000 trials indicate that the newly approved antifeedant product, Chess (pymetrozine) may be effective in providing control of capsid bugs while also being compatible within IPM programmes. However the results are not conclusive and growers should await the results of the year 2000 trials for further guidance. Do check with the product manufacturers Novartis Crop Protection UK Ltd to seek further information on Chess.

- **Note that Chess (pymetrozine) is only approved for use on cucumber crops in the UK. Chess is not currently approved for use on peppers or aubergines.**

Note on the approval status of the pesticides and entomopathogenic fungi used in the trials

- **Mycotal (*Verticillium lecanii*)**

Use permitted for the control of whitefly in protected cucumber, pepper and aubergine crops.

- **Vertalec (*Verticillium lecanii*)**

Use permitted for the control of aphids in protected cucumber, pepper and aubergine crops.

- **Applaud (buprofezin)**

Use permitted for the control of glasshouse whitefly and tobacco whitefly in protected cucumber, pepper and aubergine crops.

- **Chess (pymetrozine)**

Chess has recently been approved for use in the UK on protected cucumber crops. Use is not permitted currently on pepper or aubergine crops and off-label applications are being sought.

- **Naturalis (*Beauveria bassiana* JW-1)**

Use is not permitted currently on protected cucumber, pepper or aubergine crops in the UK. Product undergoing registration via the PSD for use on protected crops.

Recommendations for further work

The project was reviewed in March 2000 and the following work programme planned:

1. Monitoring capsid invasion
   Pheromone baited traps will be evaluated in commercial crops once the chemical lures become available.

2. *Beauveria bassiana*
   All work on *B. bassiana* is on hold until a commercial product is approved for use on the relevant crops in the UK. Approval is expected in 2001. Once approval occurs, high volume (HV) and Low volume (LV) applications of *Beauveria bassiana* will be evaluated for the control of capsids in commercial cucumber crops.

   Bioassays will be developed in 2000/2001 to determine the persistence of fungicides shown to be harmful to *B. bassiana* (see HDC Project report for PC 129).

3. Chess (pymetrozine)
   The efficacy of Chess (pymetrozine) for the control of capsids will be evaluated further in 2000 on cucumber and pepper plants.

4. Natural habitats for capsids
   Work on improving the knowledge of natural habitats and activity patterns of capsids will continue at Newcastle University as part of a PhD study.

Practical and financial benefits from the study

The provision of robust, sustainable and manageable strategies for the control of capsids in cucumbers, peppers and aubergines will:

- Avoid direct damage and financial losses caused by these pests.
- Avoid secondary problems associated with the breakdown of IPM in these crops.
- Help to satisfy demands of UK's leading food retailers for produce grown under minimal pesticide regimes.

It is anticipated that ornamental crops will also suffer damage from capsids as growers move towards full IPM strategies. Therefore, the acquisition of knowledge and the development of new control measures against these pests will ultimately provide greater benefits within the whole UK horticultural industry.

SCIENCE SECTION

INTRODUCTION

Background

Capsids belong to the Miridae, a large family of small to medium sized soft-bodied insects that exploit a wide range of habitats. For many years, a plant feeding species, *Lygus rugulipennis* (European tarnished plant bug), has been a sporadic pest in UK glasshouses (Wardlow, 1985) but until recently it has been uncommon for specific action to be taken against it in edible crops. When pest control was based entirely on chemicals, invading *L. rugulipennis* did not establish breeding populations on plants because they were killed by insecticides applied against other pests, such as *Trialeurodes vaporariorum* (glasshouse whitefly). With the advent of IPM in protected salad crops in the 1970s and 80s, capsids were able to survive and colonise plants. However, reports of serious damage remained rare until the early-1990s, when the number of requests for advice relating to control of capsids began to increase markedly. In 1996, the Horticultural Development Council (HDC) commissioned a project aimed at improving the knowledge of the behaviour of plant feeding capsids in protected salads as a first step in formulating a sustainable control strategy within the existing IPM programmes.

Scientific/technical targets of the project

Years 1 and 2

1. A literature search to ensure that the research team has all available information.
2. The pest's activity will be monitored at selected sites to improve the knowledge of the species involved, their natural habitats and the timing of crop invasion.
3. A fact sheet will be prepared aimed at improving grower awareness of the damage caused by capsids.
4. An industry survey will be completed to determine the full extent of the problem in protected edible crops.

Years 3 to 5

In 1998, the project was extended to encompass the following additional targets:

5. To improve the knowledge of the biology and behaviour of *L. rugulipennis* and *L. tripustulatus*, with particular reference to their activity in protected edible crops.
6. To develop methods of monitoring the invasion of protected edible crops by capsids.
7. To develop methods of controlling *L. rugulipennis* and *L. tripustulatus* within IPM programmes in protected edible crops.
8. To study the natural habitats of *L. rugulipennis* and *L. tripustulatus* and identify factors that have changed their status as pests.
9. To identify possible measures that may reduce the invasion of *L. rugulipennis* and *L. tripustulatus* into glasshouses.
10. To identify natural enemies of *L. rugulipennis* and *L. tripustulatus* that may be exploited in IPM programmes in glasshouses.

Summary of work completed in Years 1, 2 and 3 (Jacobson, 1997; Jacobson, 1998; Jacobson, 1999)

During 1996 and 1997, cucumber, tomato, pepper and aubergine crops were monitored at sites that had suffered intermittent damage by capsids in recent seasons. Two species of capsids were found to be causing damage; *Lygus rugulipennis* in cucumbers and *Liocoris tripustulatus* in peppers and aubergines. No damage was seen in tomato crops even where they were grown adjacent to heavily infested cucumber and pepper crops. The following symptoms were seen in cucumbers, peppers and aubergines:

i) capsid feeding in growing points resulting in distorted growth and holes in leaves as they expanded
ii) capsid probing in the stem just below the growing point resulting in death of the growing point
iii) capsid feeding and egg laying in very young fruit resulting in distortion as the fruit swelled
iv) capsid feeding on maturing fruit resulting in surface scars which rendered the fruit unmarketable.

Based on the detailed monitoring information, an illustrated fact sheet was produced to aid growers recognise capsids and symptoms of their damage (Jacobson & Hargreaves, 1996). In March 1997, this fact sheet was circulated with a questionnaire to all cucumber, pepper and aubergine growers registered with the HDC. Of 120 growers who responded to the survey, 48 confirmed that they had seen capsid activity and approximately one third of those reported that it occurred over large areas of their crops. The most seriously affected were cucumbers where the estimated financial loss ranged from £0.3 to £2 per m^2. Many growers who reported less serious damage had restricted the development of capsid infestations by applying insecticides but indicated that this disrupted IPM programmes and resulted in secondary problems with other pests. The reported occurrences of *L. rugulipennis* in cucumber crops indicated that there was a small invasion in late-spring followed by a much larger invasion in July. This is consistent with the described bivoltine life cycle (Southwood, 1956; Easterbrook, 1997). The activity of *L. tripustulatus* was more evenly spread between May and September. Approximately 90% of growers who reported damage by capsids, had first seen it during the last five years; thus confirming that infestations were becoming more common in protected salad crops. There were no distinct differences between geographical regions showing this to be a national problem. Detailed examination of vegetation in the immediate vicinity of infested glasshouses failed to identify important breeding sites, so it must be assumed that both species migrate to the glasshouses from other locations. It is unclear why capsids should have become more troublesome in cucumbers, peppers and aubergines in recent years. It is unlikely that the behaviour of the two species has simultaneously changed, so it is probably due to differences in the availability of plant food or natural habitats. As there has been no widespread change in crop husbandry or insecticide usage that could have allowed capsids a new opportunity to colonise these crops, the most probable explanation is a change in their natural habitats outside the glasshouses leading to larger invasions.

A reliable method of monitoring the migration of capsid bugs into greenhouses would enable control measures to be timed more accurately. In 1996, flat and cylindrical white and yellow traps were evaluated in cucumber and pepper crops that were infested with *L. rugulipennis* and *L. tripustulatus* respectively. The numbers of *L. rugulipennis* and *L. tripustulatus* caught were quite small, indicating that the insects were not specifically attracted to any of them. However, the numbers of male *L. rugulipennis* caught were greatly increased when the traps were baited with live conspecific females. Volatile chemicals, assumed to be sex pheromones, have now been isolated from female *L. rugulipennis* and are being evaluated as attractants in monitoring traps (Innocenzi *et al*., 1998).

Three commercially available entomopathogenic fungi (*i.e*. two strains of *Verticillium lecanii* [Mycotal and Vertalec] and one *Beauveria bassiana* [Naturalis]) were evaluated against both *L. rugulipennis* and *L. tripustulatus* in laboratory bioassays in 1998. Naturalis showed greatest effect and was subsequently evaluated against *L. rugilipennis* in experimental glasshouses. Two methods of application (*i.e.* high volume spray and ultra low volume mist) provided similar results with numbers of adult *L. rugulipennis* being reduced by 60% compared to untreated controls.

Beauveria bassiana is active against a wide range of invertebrates and it is important to know the impact that it will have on the biological control agents used to control other pests in IPM programmes. The effects of the entomopathogen on the predatory mite, *Amblyseius cucumeris*, and the parasitic wasp, *Encarsia formosa*, were determined in laboratory-based bioassays during 1998/99. There was no evidence to suggest that *B. bassiana* was harmful to *A. cucumeris*, which was consistent with results from another project (HDC Project PC 129) in which populations of *A. cucumeris* on cucumber plants and in culture packs were unaffected by high volume sprays of the entomopathogenic fungus. However, *B.bassiana* was harmful to *E.formosa.* The results of two experiments demonstrated that *B.bassiana* sprayed on parasitised *Trialeurodes vaporariorum* (glasshouse whitefly) scales, before and after they turned black, reduced survival of the parasitoid by 36% and 62% respectively. *Beauveria bassiana* also infects *T. vaporariorum* directly and can provide effective control of this pest, so the overall effect on this component of the IPM programme may not be detrimental.

The efficacy of two selective insecticides, buprofezin (as Applaud) and pymetrozine (as Chess), against *L. rugulipennis* was determined in small-scale experiments in 1998. There was no evidence to suggest that the insect growth regulator, buprofezin, prevented *L. rugulipennis* nymphs moulting or that it reduced oviposition by adult female *L. rugulipennis*. Although the antifeedant chemical, pymetrozine, did not kill adult *L. rugulipennis*, the damage to growing points of treated plants was much reduced compared to untreated controls.

The ecology of *L. rugulipennis* and *L. tripustulatus* is not well known. In particular there is little information about where the adult capsids spend the winter months prior to invading the glasshouses. A survey of potential overwintering sites began in 1998. Litter samples (leaves, grass etc.) from HRI Stockbrige House and Close House, the University of Newcastle field station, were collected and examined for the presence of capsids using hand sorting and heat extraction methods. Very low numbers of capsids were retrieved from the litter samples. The studies are continuing.

Year 4 (2000/2001) – Work plan

Following the Project Review Meeting in March 1999, the following work plan was agreed for year 4 of the project:

1. To evaluate traps baited with sex pheromones for monitoring the migration of *L. rugulipennis* into protected edible crops. (HRI and University of Newcastle).
2. To evaluate the efficacy of the entomopathogenic fungus, *B. bassiana*, against *L. rugulipennis* on whole plants. (HRI).
3. To determine the compatability of *B. bassiana* with important parasitoids and predators used in the cucumber IPM programme. (HRI).
4. To determine the potential of the selective insecticide, pymetrozine, against *L. rugulipennis*. (HRI).
5. To improve the knowledge of the natural habitats and activity patterns of *L. rugulipennis* and *L. tripustulatus*. (University of Newcastle).

PART 1 – DEVELOPMENT OF METHODS OF MONITORING CAPSID INVASION

Progress to date:

Capsid bugs may invade protected crops as early as April but the main migration occurs when populations increase in their natural habitats during the summer. Despite their relatively large size, capsids can be difficult to find in glasshouses and the appearance of damaged growing points and fruit is often the first indication of their presence. Improved monitoring procedures are required to detect capsid invasion and indicate when control measures should be applied.

Although standard white and yellow sticky traps were not very attractive to *L. rugulipennis*, the numbers of males caught were greatly increased when the traps were baited with live conspecific females. Volatile chemicals, assumed to be sex pheromones, were isolated from female *L. rugulipennis* and incorporated in lures for use in monitoring traps (Innocenzi *et al*., 1998). A preliminary evaluation of prototype pheromone traps in capsid infested cucumber crops did not provide conclusive results. This may have been because the dose and/or ratio of the chemical components were incorrect.

Modified lures were not available in 1999 due to technical problems with their production at NRI. However, the ability to monitor capsid invasion remains an important component of this project and pheromone baited traps will be evaluated in commercial cucumber crops as soon as the lures become available.

PART 2 – CONTROL OF CAPSIDS WITH *BEAUVERIA BASSIANA*

Experiment title:

To compare the efficacy of two methods of applying two formulations of *Beauveria bassiana* against established populations of *Lygus rugulipennis* on cucumber plants.

Introduction:

Laboratory-based bioassays completed in 1998, demonstrated that *B. bassiana* (Naturalis) had the potential to control *L. rugulipennis* but this required confirmation in glasshouse experiments. Two methods of applying the entomopathogen (*i.e.* high volume spray and low volume mist) were subsequently evaluated in cucumber crops. The low volume mist was applied through a Turbair Scamp 240, which was chosen because the machine's output was suitable for the relatively small experimental glasshouses. Preliminary studies, using water sensitive paper pinned in various positions throughout the glasshouse, determined the most appropriate volume of liquid to apply through the Turbair. Additional tests compared the number of viable spores in the *B. bassiana* suspension in the spray tank with the number in the spray as it emerged from the spray nozzle. The action of the Turbair did not affect the number or viability of the spores. Following one application, the overall mean number of adult *L. rugulipennis* in the *B. bassiana* treatments was approximately 60% lower than the untreated control. This level of control was broadly consistent with that recorded when *B. bassiana* was applied against *Lygus lineolaris* on cotton in the USA and against *Lygus hesperus* in laboratory studies at the University of Idaho (Brown, pers. com.). However, the relative humidity in the glasshouse was relatively high (approximately 90%) during the 1998 experiment, which favoured the development of the fungal entomopathogen, and it was recommended that the experiment be repeated under more challenging conditions of lower relative humidity. The present experiment, which was completed in 1999, incorporated an additional *B. bassiana* product (BotaniGard WP) that was reported to contain larger numbers of viable spores than Naturalis.

Materials and methods:

Site: HRI, Stockbridge House

Glasshouse: Headley Hall Glasshouse Unit

Treatments:
1. Untreated control.
2. *B. bassiana* (Naturalis) HV spray.
3. *B. bassiana* (BotaniGard WP) HV spray.
4. *B. bassiana* (Naturalis) LV mist.
5. *B. bassiana* (BotaniGard WP) LV mist.

Rates of Application:

2. 400m1 Naturalis/l00l water applied HV spray.
3. 125g BotaniGard per 100l water applied HV spray.
4. 14.4ml Naturalis per 280ml water per 109m^3 applied LV mist.
5. 4.5g BotaniGard WP per 280ml water per 109m^3 applied LV mist.

Application: Treatments 2-5 were all applied three times; *i.e.* on 8, 9 and 10 September 1999 when the plants were about 1.8m tall. The high volume sprays were applied to maximum leaf retention using a fully calibrated Oxford Precision Sprayer. The rate of application was equivalent to 2025 litres per hectare. The low volume mist treatments were applied using a fully calibrated Turbair Scamp 240. The rate of application was approximately equivalent to 70 litres per hectare.

Crop: Cucumber, cv Enigma

Planting date: 5 August 1998

Growing medium: The plants were grown hydroponically in peat bags with excess feed solution running to waste and were trained by the cordon-V system.

Expt design: The experiment was designed with Mr John Fenlon (Biometrician, HRI, Wellesbourne). Due to the pest's mobility, each treatment was confined to a separate glasshouse section. Whole treatments were not replicated but each section contained twenty four plants arranged in four plots.

Pest infestation: Adult *L. rugulipennis* were collected from natural habitats between 26 August and 6 September 1999 and released in equal numbers in each of the glasshouse sections.

Assessments:

1. Samples were taken from each spray mixture and the number of viable *B. bassiana* spores determined by culturing on growth media.

2. The numbers of *L. rugulipennis* per plant were determined in each glasshouse unit immediately before application of treatments and 7 days after application of treatments. The assessments were done in the early morning when the insects were least active. On each occasion, alternate plants were examined carefully, working from bottom to top, with particular attention given to growing points, side shoots and flowers.

3. Dead *L. rugulipennis* were collected and placed on damp filter paper in Petri dishes and incubated without light at 23^0C. Fungal growth on dead insects was subsequently sub-cultured on growth media, incubated until sporulation occurred and identified.

4. The temperature and humidity in the glasshouses were recorded throughout the experiment.

Analysis of data: Data from each assessment date were analysed by analysis of variance and differences compared using LSD. Some caution is required when interpreting the results from experiments such as this, where it is impractical to fully replicate treatments. There is no true replication and within treatment variation is used as a measure for experimental variation.

Results

The approximate numbers of viable *B. bassiana* spores per ml of each spray mixture are shown in Table 1.

The mean numbers of adult *L. rugulipennis* per plant in each treatment, on each assessment date, are shown in Table 2. There was no significant difference in the numbers of *L. rugulipennis* on the plants in the five treatments before *B. bassiana* was applied. The data from the post-application assessment showed that there was no significant difference between the numbers of *L. rugulipennis* on plants in the four *B. bassiana* treatments but all had significantly fewer *L. rugulipennis* than the untreated control ($P<0.05$). The presence of *B. bassiana* was confirmed on dead *L. rugulipennis* that were collected on 17 September 1999.

The mean temperature during the experimental period was 19^{O}C. The relative humidity recorded in the crop canopy between 7 and 17 September 1999 is shown in Figure 1. The mean RH for this period was 70%.

Discussion and Conclusion

The overall mean number of adult *L. rugulipennis* in the *B. bassiana* treatments was approximately 78% lower than the untreated control, compared to approximately 60% lower than the untreated control in the previous experiment in 1998. The additional control can be attributed to the programme of three sprays compared to the previous application of a single spray.

The mean relative humidity during this experimental period was approximately 70% in the crop canopy compared to 90% in the previous experiment. This suggests that infection of *L. rugulipennis* by *B. bassiana* is not dependant on high RH in the aerial environment.

Beauveria bassiana clearly has potential for the control of *L. rugulipennis* both as a HV spray and a LV mist. The latter is relatively inexpensive because it requires minimal labour. It would allow the cost-effective application of a series of treatments throughout the main *L. rugulipennis* invasion period and is therefore an attractive option. However, further studies are required to determine the optimum frequency and rate of application on a larger scale in commercial crops.

Table 1. Approximate numbers of viable *B. bassiana* spores in each spray mixture.

Product	Application method	Approximate number of viable spores per ml of spray mixture on:		
		8 Sept	9 Sept	10 Sept
Naturalis	HV	0.9×10^5	1.0×10^5	1.3×10^5
	LV	1.3×10^6	1.6×10^6	1.2×10^6
BotaniGard WP	HV	0.6×10^7	0.9×10^7	0.7×10^7
	LV	0.7×10^8	0.9×10^8	0.6×10^8

Table 2. Mean numbers of adult *L. rugulipennis* per plant in each treatment, on 7 September 1999 and 17 September 1999.

Treatments	Mean number of *L. rugulipennis* adults per plant:	
	Before application of *B. bassiana* (7 Sept)	Seven days post-application of *B. bassiana* (17 Sept)
1. Untreated control	1.75	1.5
2. Naturalis - HV	1.92	0.58
3. BotaniGard WP - HV	1.75	0.33
4. Naturalis - LV	1.92	0.25
5. BotaniGard WP - LV	2.08	0.17
LSD (df = 15)	0.97	0.48

PART 3 – COMPATABILITY OF *BEAUVERIA BASSIANA* WITH *PHYTOSEIULUS PERSIMILIS* AND *APHIDIUS COLEMANI*

Introduction:

If *B. bassiana* is to be incorporated in the cucumber IPM programme, it is important to know the impact that it will have on the biological control agents used to control other pests.

The effects of the entomopathogen on the predatory mite, *Amblyseius cucumeris*, and the parasitic wasp, *Encarsia formosa*, were determined in laboratory-based bioassays during 1998/99. There was no evidence to suggest that *B. bassiana* was harmful to *A. cucumeris*, which is consistent with results from another project (HDC Project PC 129). However, *B. bassiana* was harmful to *E. formosa.* The results of two experiments demonstrated that *B. bassiana* sprayed on parasitised *Trialeurodes vaporariorum* (glasshouse whitefly) scales, before and after they turned black, reduced survival of the parasitoid by 36% and 62% respectively. *Beauveria bassiana* also infects *T. vaporariorum* directly and can provide effective control of this pest, so the overall effect on this component of the IPM programme may not be detrimental.

The compatibility experiments were continued in 1999/2000. In preliminary studies, bioassays were developed to determine the effects of *B. bassiana* on the spider mite predator, *Phytoseiulus persimilis* and the aphid parasitoid, *Aphidius colemani*.

3.1. EXPERIMENT 1 - COMPATABILITY WITH *PHYTOSEIULUS PERSIMILIS*

Title:

Effect of *Beauveria bassiana* on mature *Phytoseiulus persimilis*.

Materials and Methods:

Site: HRI, Stockbridge House

Treatments:
1. Untreated control - water only
2. *B. bassiana* at the rate of 4ml product (Naturalis) per litre of water.

Plants: French bean

Insects: *Phytoseiulus persimilis* adults were sourced from the BCP Ltd production unit.

Application: Treatments were applied on 24 February 2000. For each replicate, five adult *P. persimilis* were placed on a microscope slide cover slip, which was mounted on a flooded filter paper in a 90mm Petri dish. The dish was then placed in a Potters Precision Laboratory Spray Tower (Potter, 1952) and 2ml of the relevant spray applied at 0.75 bar.

Incubation: When the spay was dry, the predators were transferred to a bean leaf set in tap water agar in a 90 mm Petri dish. Fifteen adult *Tetranychus urticae* (two-spotted spider mites) were released on the leaf and the dish was sealed with parafilm to prevent the mites escaping. The replicate dishes were incubated at 21°C and 16L:8D for the duration of the experiment. Each dish was examined daily and additional prey mites added if required.

Experimental Design: Each Petri dish formed a replicate and there were twenty replicates per treatment.

Asssessment:

1. Samples were taken from each spray mixture and the number of viable *B. bassiana* spores determined by culturing on growth media.

2. Seven days after application of treatments, the number of live and dead adult *P. persimilis* were recorded in each replicate. The number of dead *P. persimilis* with obvious fungal growth was also recorded.

Analysis of Data: The percentage of *P. persimilis* that survived in each replicate were calculated. The data were then analysed by analysis of variance (following angular transformation) and differences compared using LSD.

Results and Discussion:

The spray mixture contained 3.2 x 10^5 viable *B. bassiana* spores per ml.

The effect of *B. bassiana* on survival of adult *P. persimilis* is sumarised in Table 3. There was approximately 40% mortality of *P. persimilis* overall but no significant difference between the treatments. Fungal growth was found on 32% and 0% of the dead bodies collected from the *B. bassiana* and control treatments respectively.

Although it was demonstrated that *B. bassiana* can infect *P. persimilis*, this did not have a significant effect on the populations tested.

Table 3. The effect of *B. bassiana* on survival of adult *P. persimilis*

Mean (angular transformed) percentage of *P. persimilis* that survived following treatment with:		LSD
water	*B. bassiana*	
65 (54.6)	56 (49.3)	(11.1)

3.2. EXPERIMENT 2 - COMPATABILITY WITH *APHIDIUS COLEMANI*

Title:

Effect of *Beauveria bassiana* on mature *Aphidius colemani*.

Materials and Methods:

Site: HRI, Stockbridge House

Treatments:
1. Untreated control - water only
2. *B. bassiana* at the rate of 4ml product (Naturalis) per litre of water.

Insects: *Aphidius colemani* adults were sourced from the BCP Ltd production unit.

Application: Treatments were applied on 9 March 2000. For each replicate, ten adult female *A. colemani* were immobilised with CO_2 and placed on damp filter paper in a 90mm Petri dish. The dish was then placed in a Potters Precision Laboratory Spray Tower (Potter, 1952) and 2ml of the relevant spray applied at 0.75 bar.

Incubation: Following treatment, the parasitoids were transferred to a 25ml ventilated plastic tube containing a strip of filter paper soaked with a sugar feed solution. The replicate tubes were incubated at 21°C and 16L:8D for the duration of the experiment.

Experimental Design: Each plastic tube formed a replicate and there were ten replicates per treatment.

Asssessment:
1. Samples were taken from each spray mixture and the number of viable *B. bassiana* spores determined by culturing on growth media.

3. The tubes were examined 1, 4 and 6 days after application of treatments and the number of live and dead adult *A. colemani* were recorded in each replicate. The number of dead *A. colemani* with obvious fungal growth was also recorded at the end of the experiment.

Analysis of Data: The percentage of *A. colemani* that survived in each replicate were calculated. The data were then analysed by analysis of variance (following angular transformation) and differences compared using LSD.

Results and Discussion:

The spray mixture contained 2.9 x 10^5 viable *B. bassiana* spores per ml.

The survival of adult *A. colemani*, measured four days after application of treatments, is summarised in Table 4. There was approximately 65% mortality of *A. colemani* overall but no significant differential between the treatments. No fungal growth was found on any of the dead insects at the end of the experiment.

There was no evidence to suggest that *B. bassiana* will infect adult *A. colemani* or have an adverse effect on the population.

Table 4. The effect of *B. bassiana* on survival of adult *A. colemani*

Mean (angular transformed) percentage of *A. colemani* that survived following treatment with:		LSD
water	*B. bassiana*	
31 (33.4)	36 (33.3)	(15.1)

PART 4 – CONTROL OF *LYGUS RUGULIPENNIS* WITH PYMETROZINE

Experiment title:

To evaluate Chess (pymetrozine) against *Lygus rugulipennis* on cucumber plants.

Introduction:

The antifeedant chemical, pymetrozine, is specific to some plant-sucking insects of the order Hemiptera. Following application of pymetrozine to plants, aphids are reported to die due to starvation within 4 days. This chemical is now registered for use on cucumbers in the U.K. as the product Chess and could be integrated into the IPM programme.

As capsid bugs also belong to the order Hemiptera, preliminary studies were done in 1998/99 to determine whether Chess caused mortality of *L. rugulipennis*. Although the chemical did not kill adult *L. rugulipennis*, the damage to growing points of treated plants appeared to be less severe than untreated controls. This was further investigated in the present experiment.

Materials and Methods:

Site: HRI, Stockbridge House, Glasshouse FF2.

Treatments:
1. Untreated control – *L. rugulipennis* on cucumber plants sprayed with water.
2. *L. rugulipennis* on cucumber plants that had been sprayed with pymetrozine (Chess) at 4g per 10l water.

Application: The treatments were applied on 3 December 1999 when the plants were approximately 0.2m high. The sprays were applied high volume to maximum leaf retention using a fully calibrated Oxford Precision Sprayer.

Plants: Cucumber, cv Sabrina.

Planting date: 31 November 1999.

Growing medium: The plants were grown hydroponically in peat bags with excess feed solution running to waste and were trained by the cordon-V system.

Environment: Supplementary light to provide 16:8 L:D.

Experimental design: One plant per replicate and eleven replicates per treatment. The replicates were in two rows with Chess applied to alternate plants.

Pest infestation: *L. rugulipennis* reared in culture at HRI Stockbridge House and released at the rate of 15 adult females per replicate.

Assessment: Assessments were done 7 and 14 days post-application of Chess. On each occasion, the youngest 10cm of growth was examined and capsid damage recorded using the following index:

0	No visible damage.
1	< 2% of leaf affected by "pin-prick" damage, tearing or distortion.
2	2-10% of leaf affected by "pin-prick" damage, tearing or distortion.
3	10-40% of leaf affected by "pin-prick" damage, tearing or distortion.
4	40-60% of leaf affected by "pin-prick" damage, tearing or distortion.
6	60-80% of leaf affected by "pin-prick" damage, tearing or distortion.
8	80-100% of leaf affected by "pin-prick" damage, tearing or distortion.
10	Growing point killed.

In addition, the height of each plant was recorded at the second assessment.

Analysis of Data: Formal analysis of the data was not possible.

Results:

The mean and range of the damage index at each assessment date and the mean height of plants at the end of the experiment in each treatment are shown in Table 5.

Table 5. Mean and range of damage index at each assessment date and the mean height of plants at the end of the experiment in each treatment.

Treatment	Mean (range) damage index		Plant height (cm) 14 days post-application
	7 days post-application	14 days post-application	
untreated control	4.8 (1 - 10)	5.5 (1-10)	31
Chess (pymetrozine)	0.8 (0 -2)	0.6 (0-3)	47

Discussion:

Although formal statistical analysis of these data was not possible, there was a clear difference between treatments. While the damage to Chess treated plants was commercially acceptable, the damage to untreated plants would have resulted in financial loss.

In this experiment, the insects had a choice of plants with and without Chess. The product should also be tested in a "no-choice" situation in experimental glasshouses.

PART 5 – TO IMPROVE THE KNOWLEDGE OF NATURAL HABITATS AND ACIVITY PATTERNS OF *LYGUS RUGULIPENNIS* AND *LIOCORIS TRIPUSTULATUS*

This section of the report summarises the work completed by Ms Fiona Hunter during the first year of her PhD studies in the Department of Agricultural and Environmental Science, University of Newcastle.

5.1. OVERWINTERING SITES

Studies of potential natural and artificial overwintering sites were undertaken because this aspect of the biology of the species was poorly understood and the information could provide additional opportunities to control the pests.

Materials and methods:

Litter samples (leaves, grass etc.) were collected from two sites that were known to have capsid populations. Samples of approximately 30 cm^3 were taken from each of four locations at Stockbridge House on 18 December 1998, three locations at Close House, Heddon-on-the-Wall on 18 February 1999, and three locations at Stockbridge House on 5 March 1999. In each case, samples were hand sorted or insects expelled using a modified Tullgren funnel.

Artificial overwintering sites were provided for *L. rugulipennis* at Close House on 1 October 1999. A clover plot in which substantial numbers of individuals had been recorded through the summer season was divided into two sections, each approximately 25m by 11m. One section was left uncut and the other was cut on two occasions (1 October 1999 and 18 October 1999) to remove new growth. Potentially suitable items (e.g. bread crates, bundles of garden canes, hollow plastic roofing material, plastic tubes etc.) were scattered similarly within each plot.

Results and discussion:

Only two adult *L. rugulipennis* were found in the litter samples during this overwintering study. They were taken from Stockbridge House on 18 December 1998. The low numbers of capsids found in this study may reflect the low numbers present or the fact that the bugs are widely dispersed (Stewart 1968). Sampling will continue in 2000.

There were only four observations of *L. rugulipennis* inhabiting the artificial sites provided as winter refuges. These individuals were found during the period that the bugs were still active in the field and it is likely that the records were incidental. The vegetation cover in the uncut section of the site was substantial throughout the season and beyond the period of 'activity'. Therefore, it is plausible that the bugs simply took shelter within the clover stand rather than in the artificial refuges. This possibility will be investigated in the winter 2000 field season. There may be a greater incidence of bugs overwintering in the structure or other refuges in a commercial glasshouse, where crops are cleared completely. This will be investigated in the 2000 winter field season.

5.2. SPRING MIGRATION

Capsid bugs were thought to enter glasshouses in the spring but it was not known whether they invaded as soon as they emerged from natural overwintering sites or whether they first spent some time on wild host plants. Therefore, a programme of trapping was carried out to establish the timing of the migration and to determine whether there was a link with environmental factors such as temperature.

Materials and methods:

Cylindrical water traps (white plastic, 16.5 cm diameter; 6 cm deep) were placed in and around a commercial glasshouse, which had suffered damage to cucumber crops in 1998. On 28 April 1999, nine traps were placed within the glasshouse crops, five in the immediate vicinity of the glasshouses, and ten at distances of up to 3km from the glasshouses. All traps outside the glasshouses were placed in areas of mixed vegetation, which included *Urtica dioica* (nettle). The trap contents were examined for the presence of capsids at approximately two week intervals over a period of nine weeks. Sweep net samples (ten 90° sweeps per sample) using a 50cm diameter net were also taken throughout the trapping period at each of the sites.

Following the low catch efficiency of the water traps (see resuts below), plastic water traps of different colours were placed in an area of clover at Close House, in which substantial numbers of *L. rugulipennis* had been found in the summer season. This was an attempt to establish whether the colour of the water traps used in the spring migration sampling was an important factor influencing the numbers caught. On 28 September 1999, three traps each of red, yellow and white, and two each of black and green, were placed in a grid pattern. The traps were examined weekly for the presence of capsids.

Results and discussion:

A total of 6 individuals (all *L. tripustulatus*) were caught in the water traps during the first trapping period. Regular sweep net sampling at these sites indicated that *L. tripustulatus* was present in the field and there were reports of *L. rugulipennis* infestations in the glasshouses during the experiment. The investigation using coloured water traps yielded similarly poor results. It was concluded that water traps were ineffective for monitoring these species of capsids. This work will be modified next year using glasshouses at Close House as a model system.

5.3. POPULATION DYNAMICS

Studies began to establish the population dynamics of capsid bugs in the field through regular sampling. The development of the different nymphal stages was more carefully monitored under controlled conditions in the laboratoy.

5.3.1. Population Dynamics - Field

Materials and methods:

Five locations at Close House (all containing *U. dioica*) were sampled at approximately weekly intervals from 27 July 1999. A further site, which consisted of a clover/cereals mixture (clover predominating), was added on 27 August 1999. Two samples (each comprising ten 90° sweeps with a 50cm diameter sweep net whilst walking at an even pace through the vegetation) were taken on each date.

Results and discussion:

Data from the two samples at each site were pooled. Results from two sites are presented as examples in Figures 2 and 3. Although *L. rugulipennis* is reported as bivoltine in the south of England (Southwood 1959), these results suggest that the species may be univoltine in Northumberland, as it is in Scotland (Stewart 1968). These studies will continue in 2000 and be extended to include additional locations.

Figure 2. Abundance of *L. rugulipennis* and *L. tripustulatus* in mixed vegetation at Close House golf course.

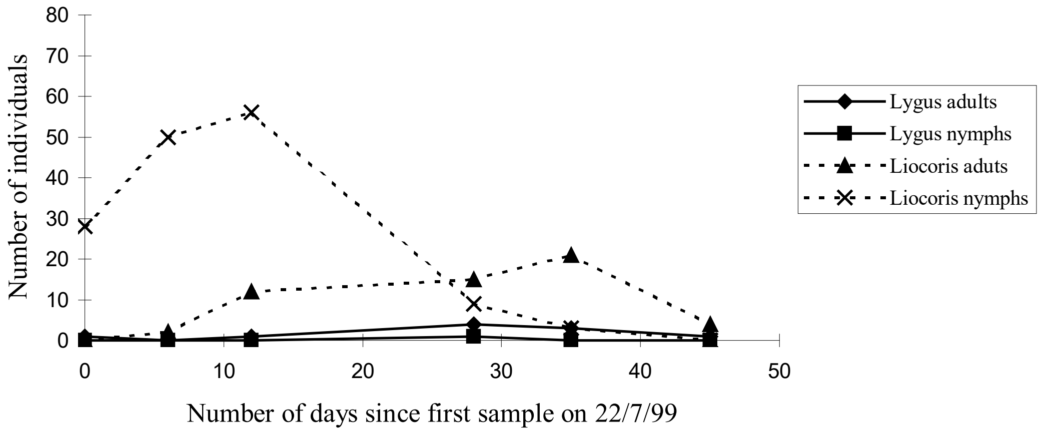
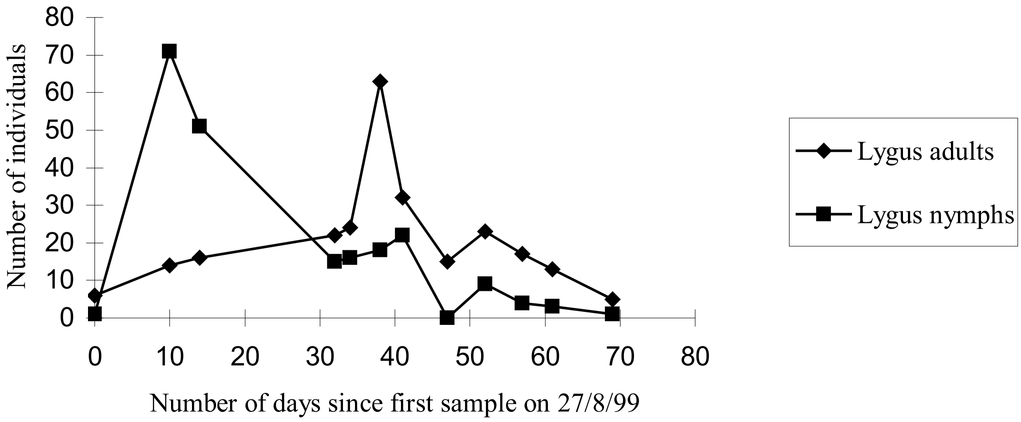


Figure 3. Abundance of *L. rugulipennis* in clover at Close House walled garden.



5.3.2. Population Dynamics - Laboratory

Materials and methods:

Adult *L. rugulipennis* were taken from culture and placed on potatoes for a 24 hr egg laying period. The potatoes were subsequently inspected daily for eggs and nymphs. Nymphs were removed and reared individually in Petri dishes with excess food (fresh green bean every 2 days). Their development was recorded every 1-2 days until they became adults. All stages of this experiment were done in an incubator at 21± 2°C; 18:6 L:D.

Results and discussion:

Preliminary results are summarised in Table 6.

Table 6. Development of life cycle stages of *L. rugulipennis* at 21± 2°C; 18:6 L:D.

Life stage	Egg	1st instar	2nd instar	3rd instar	4th instar	5th instar	Total no. days to reach adulthood
Average no. days at each stage	12	4	2	4	3	5	30
Standard Deviation	0	1.6	1.1	1.6	1.4	1.0	1.5
n	9	7	7	12	11	11	8

These data were collected using females of unknown age. The experiment will be extended to use females of a known age to allow comparison of fecundity. Adult longevity will also be determined.

5.4. HOST PLANT CHOICE

To determine whether *L. rugulipennis* exhibited choice when given the option of two different host plant species, single bugs were tested in a choice chamber.

Materials and methods:

Prior to the choice experiments, *L. rugulipennis* of a single sex were isolated in Petri dishes with moist cotton wool to provide water for 24 hours. Individual bugs were introduced to a rectangular choice chamber (225 mm x 120 mm x 85 mm) lined with paper towel which was replaced after each trial. Activity was recorded using a video camera (Baxall CD9242/IR sensitive to low light levels and infra-red illumination from an array of light emitting diodes) and a Panasonic AG-6040 time-lapse video recorder. A plastic disc (40 mm diameter) with a strip of black card around the rim was placed in the centre of the chamber and single leaves of two different species were placed on either side of the disc. Bugs were introduced to the disc at the start of a trial and the rim of cardboard prevented them from seeing the leaves before the equipment was surrounded with a black out. All trials were recorded for one hour. Video recordings were analysed to establish the species of leaf which the bug first contacted, whether or not this contact involved feeding, and the proportion of the hour long trial that the bugs spent feeding on each leaf. The following choices were tested for each sex:

- Nettle (*U. dioica)* versus White Dead Nettle (*Lamium album)*
- Nettle versus sweet pepper

Results and discussion:

Preliminary results show that male and female *L. rugulipennis* do not show a preference in their choice of host when nettle and white dead nettle are offered (Figures 4 and 5). Both of these plant species are known hosts of the bug in the wild.

Figure 4. Time *L. rugulipennis* females spent on nettle and white dead nettle.

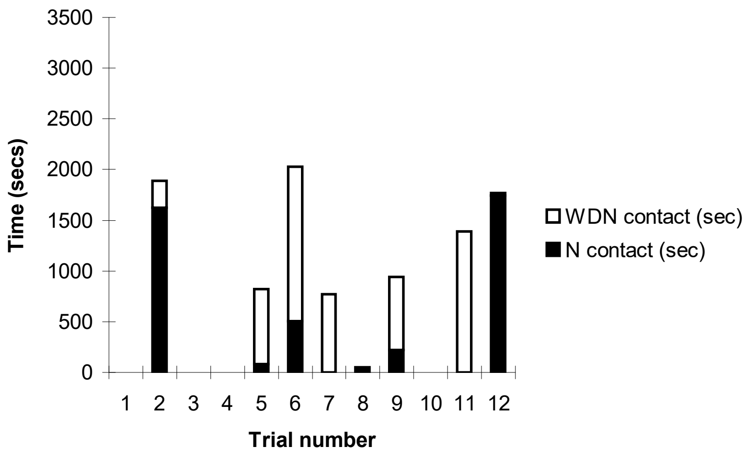
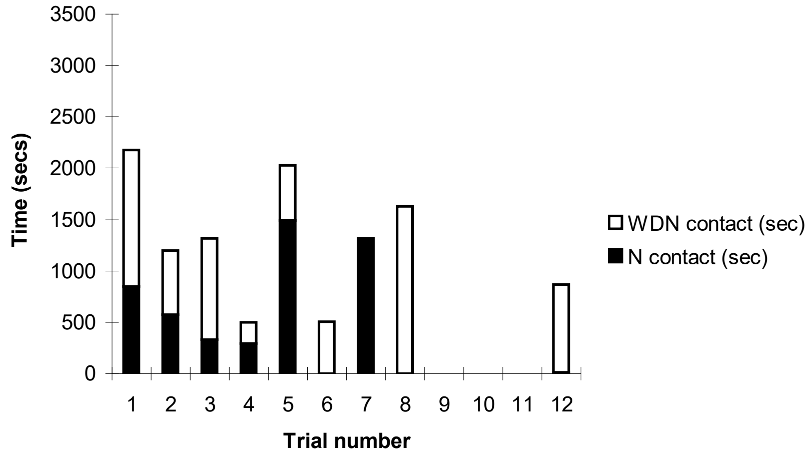


Figure 5. Time *L. rugulipennis* males spent on nettle and white dead nettle.



When offered a choice of nettle and sweet pepper (a crop that has not been reported to be infested by this species in Britain) there was a significant preference for nettle by the males ($p<0.03$) but females chose at random (Figures 6 and 7).

Figure 6. Time *L. rugulipennis* females spent on nettle and pepper.

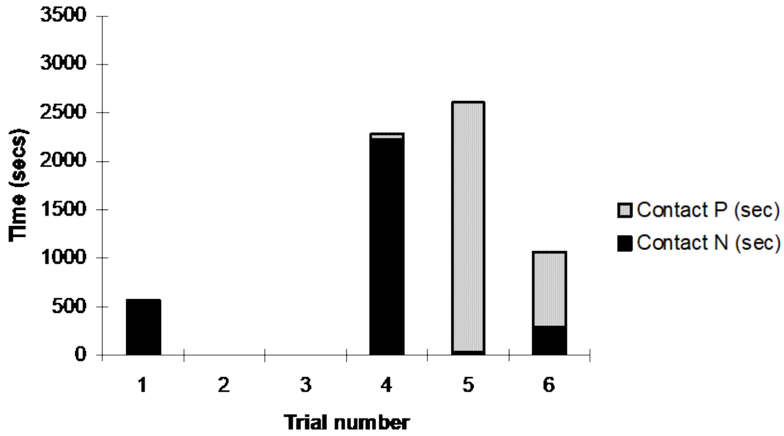
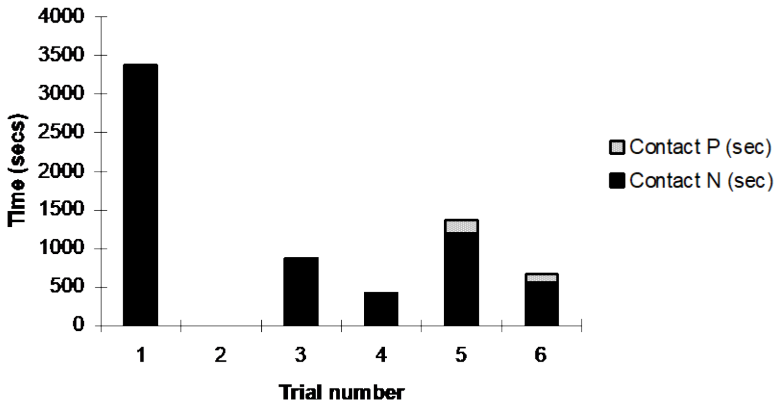


Figure 7. Time *L. rugulipennis* males spent on nettle and pepper.



These trials will be repeated and further host choices tested, including nettle with cucumber, which is the salad host of this species. The trials will be refined to use adults of known age and mating status. If a choice is confirmed, the mechanism (eg olfaction, vision) driving the choice may be investigated.

REFERENCES

Easterbrook, M.A. 1997. The phenology of Lygus rugulipennis, the European tarnished plant bug, on late season strawberries, and control with insecticides. Annals of Applied Biology, 131: 1-10.

Innocenzi, P.J., Hall, D.R., Sumathi, C., Cross, J.V. & Jacobson, R.J. 1998. Studies of the sex pheromone of the European tarnished plant bug, *Lygus rugulipennis* (Het. Miridae). Bri. Crop Prot. Conf.– Pests and Dis. 8: 829-832.

Jacobson, R. J. (1997). Control of capsid bugs within IPM programmes in protected crops. Report of contract work undertaken for HDC, PC 123, April 1997, 32 pp.

Jacobson, R. J. (1998). Control of capsid bugs within IPM programmes in protected crops. Report of contract work undertaken for HDC, PC 123, April 1998, 23 pp.

Jacobson, R. J. (1999). Control of capsid bugs within IPM programmes in protected crops. Report of contract work undertaken for HDC, PC 123, April 1999, 33 pp.

Jacobson, R.J. & Hargreaves, D. 1996. Capsid bugs in protected crops. Horticultural Development Council Fact Sheet 37/96: 4pp.

Potter, C. 1952. An improved laboratory apparatus for applying direct sprays and surface films, with data on the electostatic charge on atomized spray particles. Annals of Applied Biology 39, 1, 1-28.

Southwood, T.R.E. 1956. The nomenclature and life-cycle of the European tarnished plant bug, *Lygus rugulipennis* (Het. Miridae). Bull. Ent. Res. 46:845-848.

Southwood, T.R.E. 1959. The flight activity of Heteroptera. Transactions of the Royal Entomological Society of London 112 (8): 173-220.

Stewart, R.K. 1968. The biology of *Lygus rugulipennis* Poppius (Hemiptera: Miridae) in Scotland. Transactions of the Royal Entomological Society of London 120: 437-453.

Wardlow, L.R. (1985). Mirid Bugs, 97-98. In: Hussey, N.W. & Scopes, N. (eds). Biological Pest Control: The Glasshouse Experience. Blandford Press. Poole.

ACKNOWLEDGEMENTS

The author would like to thank Derek Hargreaves for his help throughout the project; Gordon Port and Fiona Hunter at Newcastle University; Paul Innocenzi for information about capsid sex pheromones and chemical lures; James Hadlow, Karen Russell and other staff at HRI Stockbridge House for practical assistance; John Fenlon for guidance on experimental design and analysis of data; and Mark Tatchell for comments on the script.

