Project title:	Protected lettuce: an integrated approach to aphid and caterpillar control
Report:	Final Report, January 2001
Project number:	PC 132
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Date commenced:	1 June 1997
Expected completion:	31 December 2001
Key words:	Protected lettuce, aphids, caterpillars, integrated pest management, IPM, biological control, currant lettuce aphid, *Nasonovia ribisnigri*, peach potato aphid, *Myzus persicae*, glasshouse potato aphid, *Aulocorthum solani*, potato aphid, *Macrosiphum euphorbiae*

Authentication

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

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CONTENTS

Practical Section for Growers

Science section

PRACTICAL SECTION FOR GROWERS

Commercial benefits of the project

The project has laid the foundation for a new supervised pest control strategy that could ultimately reduce insecticide usage by over 75% compared to routine spray programmes in protected lettuce. In the longer term, this will help to satisfy customer demands for a more general reduction in pesticide residues and should therefore improve the competitiveness of the UK product. However, the strategy will increase production costs by an estimated £1,737 per 1000m^2 per annum, which will not be financially viable for growers unless food retailers and consumers recognise that the products have added value and therefore warrant a premium price.

Background and objectives

Protected lettuce crops are vulnerable to sporadic invasions of winged aphids and moths, which colonise the plants rapidly. Customers are very sensitive to the presence of insects on the produce and their standards demand total freedom from pests. To achieve such standards, the growers are currently dependent on routine, and often intensive, applications of insecticides. The leading food retailers are urging growers to reduce their usage of insecticides but the technologies are not yet available to do so.

The commercial aim of the work was to develop an integrated pest management strategy for the control of aphids and caterpillars in protected lettuce crops. To this end, three lines of investigation were pursued:

(i) determine which were the most important species of aphids and caterpillar and when they presented the greatest threat to lettuce crops,
(ii) develop methods of reducing the pest invasion pressure,
(iii) investigate the potential of biological alternatives to chemical insecticides for aphid control.

Summary of the work and main conclusions

1. Identifying the main aphid and caterpillar species infesting lettuce crops

The first objective of this project was to determine which were the most important species of aphid and caterpillar and when they presented the greatest threat to protected lettuce crops. Such knowledge would assist in the development of pest forecasting systems and is essential in developing successful biological control measures.

Studies in the first three years of this project showed protected lettuce to be the host plant for at least four important 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*), the glasshouse potato aphid (*Aulocorthum solani*) and the potato aphid (*Macrosiphum euphorbiae*) occur on a range of different plant species.

Examination of sequentially-planted crops that were not treated with insecticide showed that the populations peaked at different times of the year but the largest numbers were usually found in August and September. Monitoring of commercial crops with water traps inside the glasshouses did not reveal any consistency in population peaks of the different aphids.

Conclusion

Despite four years of continuous monitoring, it has not been possible to identify consistent periods of population peaks for aphids invading protected lettuce crops. It is essential therefore that protected lettuce crops receive continuous protection from foliar-feeding aphids from April through to November to satisfy the strict standards set by produce retailers.

The larvae of several moth species were also found to infest protected lettuce crops, including the silver Y (*Autographa 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. Pheromone trapping studies in the early stages of this project showed the silver Y, tomato moth and tortrix moths to be the more common species and subsequent studies focused on these species. These species of moth were present from April through to October. No consistent activity patterns have been noted for any of the three main moth species over the four year period in which the trap monitoring was conducted.

Very few caterpillars were found in an unsprayed experimental lettuce crop in Yorkshire despite adult moths being recorded in traps outside the glasshouses. There were also fewer caterpillars than anticipated collected from commercial crops in other parts of the country. The latter can be explained by the inclusion of cypermethrin in the aphid spray programmes used by the growers (cypermethrin controls caterpillars in addition to aphids). More caterpillar damage was seen where cypermethrin was not used as part of the pest control programme for protected lettuce crops. Where growers waited until caterpillar damage was clearly visible on the crop before the application of control measures, inevitably there was some crop loss before control was achieved.

Conclusion

The Silver Y, tomato moth and totrix moths present the greatest risks to protected lettuce crops. Despite four years of continuous monitoring with pheromone traps, it has not been possible to identify any consistent activity patterns and hence lettuce crops will be at risk from April through to October. This means that continuous protection is also required against caterpillars during the risk period in order to satisfy the strict standards set by produce retailers.

2. Reducing the pest invasion pressure on protected lettuce crops

There may be three routes by which lettuce in a production house can become infested with aphids and moths / caterpillars :-

(i) Firstly, by insects surviving on lettuce debris or weeds within the glasshouse after harvest and transferring to the new crop as soon as it is planted.
(ii) Secondly, by plants becoming infested during propagation and then being transferred to the production house,
(iii) Thirdly, by winged pests flying in through the vents of the greenhouse.

Carry over from crop debris and weeds

The importance of the survival of pests on crops debris and on weeds must not be underestimated. Even a few small weeds in the least accessible places, such as the base of roof supports, may provide pests with a green bridge between crops. Furthermore, rotovating crop debris into the soil may not prevent recolonisation as aphids can work their way back to the surface. The risk can only be eliminated by the removal of all crop debris and weeds from the greenhouse immediately after harvest, using for example, a weed control spray of Gramoxone 100 (see SOLA 0225/2002) in the empty greenhouse or by burning off the crop debris with propane burners. This is a matter of good crop husbandry.

Conclusion

Removal of weeds and crop debris from the propagation and production glasshouses for lettuce crops is critical to the control of aphids and caterpillars to prevent a green bridge from crop to crop.

Infestation of plants in propagation

Regular examination of young unsprayed plants before they were placed in the production house confirmed that there was a potential risk of introducing aphids on propagated plants. This risk remained, though was much reduced, when the propagation glasshouse had screened ventilators. The risk of introducing pests on propagated plants that had received routine insecticide treatments was minimal.

Conclusion

Screening of the ventilators in the propagation glasshouse will reduce but not eliminate the risk of introducing aphids to the production greenhouse on propagated plants. This risk will be minimised also if a routine insecticide treatment is applied in propagation.

Infestation by winged pests flying in through the greenhouse vents and doors

Much of the work in this project focused on the development of an integrated control strategy based on screening glasshouse ventilators to exclude aphids and moths from the production glasshouse. For three seasons, pest establishment was monitored in unsprayed sequentially sown crops in both screened and unscreened experimental glasshouses. Where glasshouse ventilators and doors were screened with Agralan Enviromesh S48, the number of aphids on the lettuce crops were substantially reduced. Infestations that did occur in the screened house could usually be traced back to introduction on young plants or entry through damaged screens. For example, in lettuce crops that were grown sequentially from March 1999 to

March 2000, there was only one unexplained record of aphids in the screened glasshouse, which was in July 1999 when five potato aphids were found on a single lettuce plant.

Screening ventilators and doors in experimental glasshouses had no apparent effect on temperature or relative humidity. There was a small effect of screening on accumulated light over the duration of each crop, which was most noticeable during the summer months. There was 2-5% reduction of accumulated light in crops between December and April, 10-11% reduction in crops between May and July, and 7% reduction in crops between August and October. There is probably less effect of shading from materials on the roof in the winter because the sun is lower in the sky and shines through the glasshouse side walls for a greater proportion of the day.

Is screening of the greenhouse vents and doors effective in providing pest control of protected lettuce crops ?

The screening studies were scaled up from small experimental glasshouses to commercial production glasshouses in 2000/2001, using Mevalon 0.6mm UV stabilised polyethylene netting on roof ventilators and PVC strip curtains on doors. The experiment compared a pest control strategy based on screening to reduce pest invasion with a routine spray programme. The studies continued to monitor effects of screening on the glasshouse environment and were extended to determine whether any loss of light affected marketable yield.

A strict and intensive pest monitoring protocol was put into practice. The crops were monitored for the presence of pests at two-weekly intervals between November and April, and at weekly intervals from May to October. On each occasion, all paths were walked and plants scanned for obvious damage symptoms (eg insect specimens, holed leaves, honeydew, etc). In addition, the crop was divided into sampling units of 30 x 13 (390) plants which were clearly bound by the glasshouse posts. Within each unit, four plants were selected at random and the presence (but not number) of aphids and caterpillars were recorded on each. This sampling process was non-destructive. Pests were identified to species level. When pests were found, an appropriate short persistence insecticide was applied to the infested crop. Monitoring then continued the following week.

See Appendix 1 for the sampling procedure used in the trials.

No aphids were collected from traps in the screened commercial glasshouse but live aphids were found on plants on five occasions between October 2000 and October 2001. On two such occasions, the plants had most probably become infested between the propagation and production glasshouses. On one occasion, small numbers of aphids were thought to have survived on debris in the soil from a previous infestation. On the other two occasions, very small numbers were found either just before or during harvest. It is not known how these aphids gained entry but no action was deemed necessary.

By contrast, aphids were collected from water traps in four of the five crops in the unscreened glasshouse. Despite the routine insecticide spray programme in this glasshouse, aphids were also found on plants on seven occasions, with most invasions occurring in late July and August.

The use of pheromone traps showed that moths were active from 1st May through to the end of October with the crops under greatest threat from mid-May to late-August. Despite this, caterpillars were very rarely found on the plants demonstrating that the protection provided by either the screens or the routine spray programme was effective.

Over the whole year, the mean number of insecticide applications was 1.0 and 2.6 per crop in the screened and unscreened glasshouses respectively. If the plants had always arrived un-infested (free from aphids and caterpillars) from propagation, then the mean number of applications in the screened glasshouse would have been reduced further. These results demonstrate that insecticide usage can be much reduced, though not eliminated, by screening glasshouses.

Screening ventilators and doors had no apparent effect on temperature or humidity in the commercial glasshouse but there was a reduction in accumulated light over the duration of each crop. The light reduction trends over the year were broadly consistent with the results from the experimental glasshouses, although the funnel shaped screens in the commercial glasshouse did cast more shade than the flat screens in the experimental glasshouse. The reduction in light did not affect the time taken for plants to reach marketable weight or the proportion of the crops that were marketable. Obviously year on year, the screens will collect dirt and therefore there will be a further potential loss of light. There was no apparent difference in disease incidence in the screened and unscreened glasshouses and the number of fungicides required was similar in both.

Conclusion

Screening of the vents and doorways of a commercial scale greenhouse will not prevent colonisation of lettuce crops by aphids or the intrusion of an occasional caterpillar. Screening must be supported by effective crop monitoring procedures, good cultural control practices and will require the occasional use of insecticides. Overall, this approach can reduce insecticide use by up to 75% compared to routine insecticide spray programmes.

Cost benefit analysis

The fact that pests do occasionally breach the defences in a screened glasshouse means that the pest control programme must be supported by effective monitoring procedures to determine when insecticides are required. The monitoring procedure used in this experiment was effective but may prove to be too time consuming (and therefore too expensive) for growers to adopt more generally. The time required clearly increases as the crop matures and it becomes more difficult to inspect each plant, but the average time was 2 hours per 1000m^2 per sampling occasion. In this project, pest monitoring was done weekly from May to October, and at two weekly intervals from November to April. There were 33 monitoring checks over the year covering five crops and the annual cost was £528 per 1000m^2 calculated using a labour rate of £8 per hour.

The cost of screening this glasshouse was £12,300 but it was a "one-off" and we anticipate that this would be reduced by approximately 50% if it became a more routine service provided by several competitive suppliers. The materials are guaranteed against UV breakdown for five years and this has been used as a conservative estimate of their life

expectancy. Based on these assumptions, the capital cost (excluding interest) is estimated to be £1,230 per 1000m^2 per annum. The annual bill for pest monitoring work is £528 per 1000m^2, giving a total additional cost of £1,758 per 1000m^2 per annum. The potential savings in terms of reduced insecticide sprays are quite small (£21 per 1000m^2 per annum) because there is no reduction in labour. This is because the routine insecticide applications would normally be applied as tank mixes with fungicides and the latter will still be applied. The balance is an additional cost to the grower of £1,737 per 1000m^2 per annum compared to a routine insecticide spray programme.

Conclusion

There are cost implications for growers who wish to adopt the vent screening and crop monitoring approach in the control of pests of protected lettuce crops. This 'supervised' pest control programme is estimated to cost an extra £1,737 per 1000 m^2 of greenhouse area per annum. This investment would require an approximate 9% increase in the wholesale price for round lettuce.

3. Is it possible to control aphids on protected lettuce crops using biological control measures ?

Studies were conducted in order to find robust and effective biological control measures for aphids infecting lettuce crops that could be reliably used to replace chemically based insecticides.

Biological control agents such as parasitoids tend to be specific to each species of aphid and hence suitable candidates were sought. A review of the scientific literature identified a range of parasitoids that attack *M. persicae* and *M. euphorbiae*, including three species that are commercially available (*Aphidius colemani*, *A. matricariae* and *A. ervi*). Only one species, *Lysiphlebus fabarum*, had been recorded from *A. solani*, although the authors have personal experience of *Aphelinus* spp. parasitising this aphid. *Lysiphlebus fabarum* is not commercially available. No parasitoids had been recorded from *N. ribisnigri*. However, the authors have since found an as yet unidentified parasitoid attacking a population of *N. ribisnigri* on a lettuce crop in Yorkshire. Experimental studies with parasitoids initially focused on *A. colemani*. In laboratory experiments, this species provided 20% parasitism of *M. persicae* but was not effective against either *M. euphorbiae* or *N. ribisnigri.*

As the literature review and initial laboratory studies revealed little chances of success with finding suitable and effective insect parasitoids for use against the four main lettuce aphids in the short term, resources were diverted to the evaluation of the efficacy of entomopathogenic fungi.

The pathogenicity of five isolates of the entomopathogenic fungi, *Verticillium lecanii*, *Metarhizium anisopliae*, *Paecilomyces fumosoroeus* and *Beauveria bassiana*, to *M. persicae* and *N. ribisnigri* were determined in laboratory bioassays. The most effective strains, in terms of the speed of kill and the dose of fungi required to kill, were the commercially available strains of *V. lecanii*. One such strain, together with a commercially available formulation of *B. bassiana*, was subsequently assessed against *N. ribisnigri, M. persicae, A. solani* and *M. euphorbiae* in small glasshouse experiments. The results in the glasshouse were disappointing, with neither of the pathogens providing control of the aphids. Further

experiments were done using higher application rates of the fungi and a series of applications at 3-6 day intervals. The experiments demonstrated that the entomopathogenic fungi have some effect on *M. euphorbiae*, *N. ribisnigri* and *M. persicae* population growth but the level of control was inadequate for commercial crops.

The poor control was thought to be due to a combination of three factors. First, the spores of entomopathogenic fungi must contact the pests to be effective, so spray coverage must be very thorough. However, aphids on lettuce are largely protected from sprays by the architecture of the plant and contact is probably quite limited. Second, the pathogens are relatively slow to act, usually taking about 5 days to kill the pests and the aphids are able to continue to produce offspring for at least part of this time. Third, the aphids have an extremely rapid reproductive rate and may produce several live young per day during the summer. This means that an infected aphid can still produce enough young to cause an increase in the population before it dies.

Conclusion

A thorough review of the scientific literature together with laboratory studies identified some insect parasitoids which attack *M. persicae* and *M. euphorbiae*. Other species of parasitoids of *A. solani* and *N. ribisnigri* have been observed. The ability of these parasitoids to provide adequate control of aphid populations in commercial lettuce crops remains to be proven.

Entomopathogenic fungi such as *Verticillium lecanii* do not offer effective alternatives to chemical insecticides for the control of aphids in commercial lettuce crops. These fungi require direct contact with the aphids and at least 5 days to kill the pest by which time the aphids will have produced more offspring and the population will still be able to increase.

This project has demonstrated that effective and robust biological control agents and application methods are not currently available, and are unlikely to be available for some time, to replace chemical insecticides for the control of aphids on lettuce.

Action and Information Points for Industry

- There are three routes by which lettuce in a production house can become infested with aphids and moths/caterpillars :- (i) firstly, by insects surviving on lettuce debris or weeds within the glasshouse, (ii) secondly, by plants becoming infested during propagation and then being transferred to the production house, and (iii) thirdly, by winged pests flying in through the vents of the greenhouse.

- The importance of the survival of pests on crops debris and on weeds must not be underestimated.

    - Ensure the removal of all weeds from the glasshouse taking note of those in the least accessible places, such as the base of roof supports. If necessary, use a weed control spray of Gramoxone 100 (see SOLA 0225/2002) in the empty greenhouse.
    - Rotovating crop debris into the soil may not prevent recolonisation as aphids can work their way back to the surface. The risk can only be eliminated by the removal of all crop debris and weeds from the greenhouse immediately after harvest, using for example a weed control spray of Gramoxone 100 in the empty greenhouse (see SOLA 0225/2002) or by burning off the crop debris with propane burners.

- Growers should consider screening ventilators in the propagation greenhouse in order to reduce the risk of introducing aphids to the production greenhouse on propagated plants. However, screening of the vents will not eliminate this risk and an insecticide treatment during propagation is required.

- Despite four years of continuous monitoring, it has not been possible to identify consistent patterns of population peaks for aphids invading protected lettuce crops. It is essential therefore that protected lettuce crops receive continuous protection from foliar-feeding aphids from April through to November to satisfy the strict standards set by produce retailers.

- Water traps may be helpful in providing prior warning of potential invasions of aphids from crops surrounding the greenhouse such as sugar beet, potatoes and field lettuce. In these situations, complete closure of the ventilators may be required but is impractical. However, closure of the windward vents and opening of the leeward vents may be helpful in preventing aphids from coming into the greenhouse.

- The Silver Y, tomato moth and totrix moths present the greatest threats to protected lettuce crops. Despite four years of continuous monitoring with pheromone traps, it has not been possible to identify any consistent activity patterns and hence lettuce crops will be at risk from April through to October. This means that continuous protection is also required against caterpillars during the risk period in order to satisfy the strict standards set by produce retailers.

- Screening of the vents and doorways of a commercial scale greenhouse will reduce but not eliminate colonisation of lettuce crops by aphids or the intrusion of an occasional caterpillar. Screening must be supported by effective crop monitoring procedures, good cultural control practices and will require the occasional use of insecticides. Overall, this approach can reduce insecticide use by up to 75% compared to routine insecticide spray programmes.

- Recent experience with commercial nurseries has demonstrated that the judicious use of insecticides based on crop monitoring alone is not feasible without the additional control offered by screened ventilators.

- There are cost implications for growers who wish to adopt the vent screening and crop monitoring approach in the control of pests of protected lettuce crops. This 'supervised' pest control programme is estimated to cost an extra £1,737 per 1000 m^2 of greenhouse area per annum. This investment would require an approximate 9% increase in the present wholesale price for round lettuce.

- The crop monitoring process in the 'supervised' pest control programme is unlikely to improve disease control in lettuce crops due to limitations in the current approvals for fungicide use.

- This project has demonstrated that effective and robust biological control agents and application methods are not currently available, and are unlikely to be available for some time, to replace presently used chemical insecticides for the control of aphids on lettuce.

- Industry wide discussions should take place, possibly through the auspices of the Assured Produce Scheme, to consider these research findings and their implications for integrated crop management practices in protected lettuce production in the UK.

Anticipated practical and financial benefits from the study

The work in this project has demonstrated that unlike other protected salad crops, the adoption of integrated pest management practices and biological control measures is much more difficult for protected lettuce crops. It is important for growers and retailers to take note of the unsuccessful areas of study in addition to the successful developments from the project.

The work has indicated that it is not feasible to develop forecasting systems to predict invasions of aphids and moths and that lettuce crops are at risk from these pests from the beginning of April until the end of November. Thus it is essential that crops receive continuous protection from these pests during the entire risk period.

This project has demonstrated that current biological control measures and their application methods are not effective in providing reliable control of aphids on lettuce in order to meet the strict standards set by the produce retailers. However, due to the loss of short persistence chemical insecticides and the desire of consumers for reduced pesticide use, it is appropriate to reconsider the use of parasitoids and in particular to develop novel release methods that will maintain natural enemy populations in the glasshouse before the pests arrive.

The project has developed a new 'supervised' pest control strategy involving the screening of glasshouse vents and doorways. To be effective, this strategy must be supported by routine crop monitoring, good cultural practices and the occasional use of chemical insecticides. The downside of this new strategy is the extra investment and running costs involved. Production costs will increase by an extra £1,737 per annum per 1000m^2. Such investments will not be financially viable for growers unless food retailers and consumers recognise that the products have added value and therefore warrant a premium price.

This project has laid the foundation for an integrated control programme for aphids and caterpillars on protected lettuce. Further R&D work and investments by growers is required to develop the work so to deliver a reliable integrated pest control programme for lettuce crops.

Consumers will benefit from the efforts of growers to reduce insecticide use whilst delivering produce to the required standards. Reduced insecticide use will also have environmental benefits and reduce the risk of pest tolerance problems.

Appendix 1 **SAMPLING METHOD**

Background notes

- Retailers are very sensitive to the presence of insects on lettuce leaves and their standards demand almost total freedom from pests.
- The intensity of sampling must increase as the threshold for rejection of produce due to presence of pests decreases. Nevertheless, all sampling methods have to be a compromise between precision and practicality.
- The sampling technique used in the commercial crop scale experiment considered the presence or absence of aphids or caterpillars on individual plants.
- The procedure was based on a simple risk assessment that assumed that the pests would be reasonably evenly distributed. If no pests were found using the sample size described below, the "worst case" on 95% of occasions would be 1% of plants infested.
- However, the actual risk of missing a significant infestation in any crop was much less than this because the sampling procedure was repeated at weekly intervals during the critical months of the year.

The sampling procedure

- The crops were monitored for the presence of pests at two-week intervals between November and April, and at weekly intervals from May to October.
- On each occasion, all paths were walked and plants scanned for obvious damage symptoms (eg insect specimens, holed leaves, honeydew etc). At the same time, any disease symptoms were noted and reported to the grower.
- In addition, the crop was divided into sampling units of 30 x 13 (390) blocks of plants, which were clearly bound by the glasshouse posts. Within each unit, four plants were selected at random on every occasion and the presence (but not number) of aphids and caterpillars were recorded on each plant. Specimens were identified to species but not life cycle stage.
- When pests were found, monitoring ceased, the grower was notified within 24 hours, and he applied an appropriate short persistence insecticide to the infested crop.
- Monitoring then continued the following week.

Extrapolating method for use in commercial crops

- This sampling procedure was designed for use by experienced entomologists in experimental situations. While fit for purpose, it was time consuming and therefore expensive (£528 per 1000m^2 per annum).
- The method could be refined for use in commercial crops but this would require further risk assessments, coupled to the improved knowledge of labour requirements, to provide a cost-effective system.

SCIENCE SECTION

INTRODUCTION

Background

Growers of protected lettuce crops are currently dependent on routine, and often intensive, applications of insecticides to control aphids and caterpillars on lettuce foliage. The leading food retailers, reflecting consumer demand, are urging the growers to reduce their usage of insecticides but the technologies are not yet available to do so. This subject has been identified by the Lettuce Technology Group as a high research priority.

Scientific / technical targets of the project

The overall aims of the project were to identify aphid control options that were compatible within an integrated control programme for protected lettuce, the result being less insecticides applied to the crop, and to identify the species of caterpillars that damage lettuce. Specific objectives were:

1. Obtain data on aphid phenology from water traps at four sites and crops at one site, and identify species infesting protected lettuce.
2. Obtain data on phenology of selected moth species from pheromone traps at up to four sites, and identify caterpillars from lettuce at one site.
3. Identify whether plant propagation is a source of aphid infestation in production houses.
4. Obtain data on the effect on aphid and caterpillar populations of screening glasshouse ventilators.
5. Determine the impact of screening ventilators on temperature, humidity and light in the glasshouse environment.
6. Investigate the potential for parasitoids to control aphids on protected lettuce.
7. Investigate the potential of entomopathogenic fungi to control aphids on protected lettuce.

Summary of work completed in Years 1, 2 and 3 (Tatchell, 1998; Tatchell, 1999; Jacobson, 2000)

Studies in the first three years of this project showed protected lettuce to be the host plant for at least four 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*), the glasshouse potato aphid (*Aulocorthum solani*) and the potato aphid (*Macrosiphum euphorbiae*) occur on a range of different plant species. 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 or weeds within the glasshouse after harvest and transferring to the new crop as soon as it is planted. The importance of this third process of

colonisation must not be underestimated. Even a few small weeds in the least accessible places, such as the base of roof supports, may provide pests with a green bridge between crops. Furthermore, rotavating crop debris into the soil may not prevent recolonisation as aphids can work their way back to the surface. The risk can only be eliminated by the removal of all crop debris and weeds from the greenhouse immediately after harvest. This is a matter of good crop husbandry and was not investigated further in this project.

Water traps placed in crops in Sussex, Hertfordshire, Lancashire and Yorkshire were used to monitor crop invasion by aphids. The numbers of aphids caught were quite small at all sites and these data failed to reveal consistent activity patterns for the four most important species (*N. ribisnigri*, *M. persicae*, *A. solani* and *M. euphorbiae*).

Examination of sequentially-planted crops that were not treated with insecticide proved to be a more effective though more expensive method of monitoring aphid activity. All four species of foliar feeding aphids were found on lettuce plants in Yorkshire. Although the populations peaked at different times of the year, the largest numbers were usually found in August and September. The results indicated that protected lettuce crops require continuous protection from foliar-feeding aphids between April and November. However, the control measures must be directed towards different species at different times.

The larvae of several moth species also infest protected lettuce crops, including the silver Y (*Autographa 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. Trapping studies in the early stages of this project showed the silver Y, tomato moth and tortrix moths to be the more common species and subsequent studies focused on these species. Crops become infested with moths and caterpillars by the same routes that they become colonised by aphids.

Pheromone traps were placed outside glasshouses at sites in Sussex, Hertfordshire, Lancashire and Yorkshire to monitor the activity patterns of adult moths. The numbers of the different species of moths caught varied between sites and seasons, but potentially damaging species were present from April to October.

No caterpillars were found in the unsprayed crop in Yorkshire despite adults being recorded in pheromone traps outside the glasshouses. There were also fewer caterpillars than anticipated collected from commercial crops. These results indicated that caterpillars do not present as great a threat to protected lettuce crops as previously thought. However, the strict standards set by produce retailers mean that crops must receive continuous protection throughout the risk period.

Regular examination of young unsprayed plants before they were placed in the production house confirmed that there is a potential risk of introducing aphids on propagated plants. This risk remains, though is much reduced, when the propagation glasshouse has screened ventilators. The risk of introducing pests on propagated plants that have received routine insecticidal treatments is quite small.

Much of the work in this project has focused on the development of an integrated control strategy based on screening glasshouse ventilators to exclude aphids and moths from the production glasshouse. For three seasons, pest establishment was monitored in unsprayed sequentially sown crops in both screened and unscreened experimental glasshouses. Where

glasshouse ventilators and doors were screened with with Agralan Enviromesh S48, the number of aphids on the lettuce crops were substantially reduced. Infestations that did occur in the screened house could usually be traced back to introduction on young plants or entry through damaged screens. For example, in lettuce crops that were grown sequentially from March 1999 to March 2000, there was only one unexplained record of aphids in the screened glasshouse, which was in July 1999 when five *M. euphorbiae* were found on a single lettuce plant.

Screening ventilators and doors in experimental glasshouses had no apparent effect on temperature or relative humidity. There was a small effect of screening on accumulated light over the duration of each crop, which was most noticeable during the summer months. There was 2-5% reduction of accumulated light in crops between December and April, 10-11% reduction in crops between May and July, and 7% reduction in crops between August and October. There is probably less effect of shading from materials on the roof in the winter because the sun is lower in the sky and shines through the glasshouse side walls for a greater proportion of the day. It seemed unlikely that such light reductions would prolong the crop production period but this had to be confirmed by further experimentation.

The screening studies were scaled up from small experimental glasshouses to commercial scale production glasshouses in 2000/2001.

A review of the scientific literature in 1998 identified a range of parasitoids that attack *M. persicae* and *M. euphorbiae*, including three species that are commercially available (*Aphidius colemani, A. matricariae* and *A. ervi*). Only one species, *Lysiphlebus fabarum*, had been recorded from *A. solani*, although the authors have personal experience of *Aphelinus spp.* parasitising this aphid. *Lysiphlebus fabarum* is not commercially available. No parasitoids had been recorded from *N. ribisnigri*. However, the authors have since found an as yet unidentified parasitoid attacking a population of *N. ribisnigri* on a lettuce crop in Yorkshire.

Practical studies with parasitoids initially focused on *A. colemani*. In laboratory experiments, this species provided 20% parasitism of *M. persicae* but was not effective against either *M. euphorbiae* or *N. ribisnigri.* The project review panel then terminated studies with parasitoids and diverted resources to an evaluation of the efficacy of entomopathogenic fungi.

The pathogenicity of five isolates of the entomopathogenic fungi, *Verticillium lecanii, Metarhizium anisopliae, Paecilomyces fumosoroeus* and *Beauveria bassiana*, to *M. persicae* and *N. ribisnigri* were determined in laboratory bioassays. The most effective strains, in terms of the speed of kill and the dose of fungi required to kill, were the commercially available strains of *V. lecanii*. One such strain, together with a commercially available formulation of *B. bassiana*, was subsequently assessed against *N. ribisnigri, M. persicae, A. solani* and *M. euphorbiae* in small glasshouse experiments. The results in the glasshouse were disappointing, with neither of the pathogens providing control of the aphids. Further experiments were done using higher application rates of the fungi against *N. ribisnigri* but the results were still poor. However, successful pest control strategies based on entomopathogenic fungi often require a series of applications at 3-6 day intervals, and another experiment was designed to evaluate such spray programmes in the final year of the project.

Work plan for years 4/5 (2000/2001)

The following work plan was agree at the Project Management Meeting on 6 March 2000, with points of detail confirmed in subsequent correspondence:

1. Obtain fourth years' data on aphid phenology:
   - From water traps at three commercial sites in Sussex, Lancashire and Hertfordshire. The traps will be emptied by growers and the contents will be sent to HRI (Wellesbourne) for sorting and identification (until March 2001).
   - From water traps at grower trial site in Yorkshire (see item 3 below).

2. Obtain fourth years' data on moth phenology:
   - From pheromone traps (for silver-Y moth, tomato moth and carnation moth) at 3 commercial sites in Sussex, Lancashire and Hertfordshire. Traps will be emptied by growers weekly from May to October 2000 and sent to HRI (Wellesbourne) for sorting and identification.
   - From similar pheromone traps at the grower trial site at Snaith (see item 3 below).
   - Collection of specimens from crops and pack houses (organised by Mr David Stokes).

3. Obtain fourth year's data set on the effect of screening glasshouses to limit aphid and moth invasion. The studies will move to a commercial nursery in Yorkshire using one screened and one unscreened glasshouse. The crops will be planted simultaneously in the two glasshouses and they will receive the grower's routine fungicide programme.
   - Aphid water traps will be set up in both houses and managed by HRI between October 2000 and October 2001.
   - Moth pheromone traps will be set up in the vicinity of the glasshouses and managed by HRI between April and October 2001.
   - Crops will be monitored by HRI for presence (but not number) of aphids and caterpillars. Specimens will be identified to species but not life cycle stage. This will be done at weekly intervals from May to October and at two-week intervals from November to April.
   - Crops in the unscreened glasshouse will receive the grower's routine insecticide programme.
   - If pests are found in the screened glasshouse, appropriate short persistence insecticides will be applied by the grower. Monitoring will continue the following week.

4. Evaluate the effects of screening ventilators of commercial scale glasshouses on temperature, humidity, light, disease incidence and crop duration within the glasshouse:
   - Temperature - using 4 data loggers in aspirated screens per glasshouse.
   - Humidity - using data loggers (as above)
   - Light levels - using two sensors in each glasshouse but no sensor outside.
   - Disease incidence - To be monitored by HRI, simultaneous to pest monitoring, under the guidance of plant pathologists..
   - Crop duration – The grower will monitor lettuce head weights as the crops approach harvest following his normal practice. When the lettuces in the unscreened house reach about 170gm, he will notify HRI staff. HRI will then take

comparative samples from each house.

5. Treatment of propagated plants destined for screened and unscreened houses at the commercial nursery:
   - Plants will be sprayed by the grower (as routine) with a short persistence insecticide about 24 hours before leaving the propagation house.
   - Plants will be covered with fleece while being moved from the propagation house to the production house.
   - Plants will be monitored by HRI for presence of pests between spraying and planting.

6. Evaluate the potential of entomopathogenic fungi to control aphids:
   - Glasshouse experiment on small to medium sized plants
   - The most important aphids and two pathogens to be included.
   - Plants sprayed 3 times at 3 day interval.
   - Aphids assessed 5-7 days after the third application.

MONITORING APHID INVASION IN LETTUCE CROPS

Objective

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

Methods

Two yellow water traps were placed in a sequence of lettuce crops from 1 April 2000 to 31 March 2001 at each of the following three sites:

1. Darnicle Hill Nursery, Hertfordshire
2. Sevenoaks Salads, Lancashire
3. Madestein UK Ltd., Sussex

It was intended that the traps would be emptied at weekly intervals throughout the year. However, this was not always possible in the commercial production houses where the trapping periods were sometimes extended. The contents of the traps were sent to HRI Wellesbourne where the aphids were identified to species and counted.

Results and discussion

As in previous years, the numbers of winged aphids caught in water traps was quite small. Due to variations in the trapping periods at the commercial sites, the numbers caught have been expressed as aphids per trap per day. Small numbers (0.1/trap/day) of *N. ribisnigri* were caught in Sussex in late June 2000, which was consistent with results in 1999. There were also small numbers (0.02/trap/day) of *N. ribisnigri* caught in Lancashire during September 2000. None of the other important aphid species were recorded in water traps at any of the monitored sites.

Examination of sequentially planted crops between 1997 and 1999 proved to be a more effective though more expensive method of monitoring aphid activity. This work continued at a commercial site in Yorkshire between September 2000 and October 2001 (see page 14 of this report).

MONITORING MOTH ACTIVITY

Objective

To identify 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.

Use of traps

Introduction

The methodology for using pheromone traps around glasshouses was developed at HRI Stockbridge House in the first year of this project. The trapping studies were confined to those species that had been relatively abundant in year 1, namely *Autographa gamma* (silver-Y moth), *Cacoecimorpha pronubana* (carnation tortrix moth) and *Laconobia oleracea* (tomato moth), for which pheromone traps were commercially available.

Methods

Trapping was done at the same three sites used for monitoring aphid infestations (see page 11 of this report).

Pheromone traps were placed around the glasshouses during July 2001. At the sites in Hertfordshire and Sussex, the traps were emptied weekly until 31 October 2001 and the contents sent to HRI Wellesbourne where the moths were identified to species and counted. The same procedure was followed at the site in Lancashire but the trapping intervals were less regular. The pheromone lures were changed at intervals of six weeks. Trapping was not continued through the winter months as low temperatures outdoors usually prevent the flight of adults of these species even if they are present. The traps used for each moth species were:

A. gamma: Two Oecos funnel traps on poles 0.8m above ground, about 20m apart and 5m from the glass.

C. pronubana: Two Oecos delta traps on poles approximately 0.8m above ground. The two traps were orientated at right angles to each other (one facing west the other south) and positioned approximately 20m apart. The traps were placed close to the glasshouses where the lettuce was grown but as far apart as possible from traps for other moth species to avoid conflicting pheromone plumes.

L. oleracea: Two Oecos delta traps mounted on poles approximately 0.8m above ground and arranged as those for *C. pronubana*.

Results and discussion

The mean numbers of adult *A. gamma*, *C. pronubana* and *L. oleracea* per pheromone trap per day at the three monitoring sites are shown in Figures 1, 2 and 3 respectively.

The numbers of *A. gamma* caught at all three sites were generally smaller than during 1999 but slightly larger than 1998. Moths were present at all three sites throughout the trapping

period with three population peaks observed; *i.e.* early July and early August in Sussex and late September at all three sites. The largest numbers were again caught at the Sussex site, but otherwise there have been no consistent patterns over the three monitored years.

Overall, the numbers of adult *C. pronubana* were comparable to 1998 and 1999 at all sites. However, the activity was sporadic with sustained catches only recorded in Hertfordshire between late August and late September.

Numbers of *L. oleracea* recorded in 2000 were larger than 1998 and 1999 in Hertfordshire, but comparable in Lancashire and Sussex. There were peaks of activity in mid-July in both Hertfordshire and Sussex, and in late July in Lancashire.

No consistent activity patterns have been noted for any of the three species over the three monitored years.

Samples from commercial crops

Methods

This was a continuation of similar study in 1999. A caterpillar information sheet, previously prepared at HRI Stockbridge House, had been circulated by David Stokes to growers with an explanatory letter in an attempt to increase the number of samples submitted by growers. Specimens were sent by David Stokes and growers to HRI Stockbridge House for identification. Where necessary, the specimens were reared to adults to confirm the identification.

Results and discussion

Specimens were submitted from sites in Essex and Cambridgeshire during July. As in previous years, *A. gamma* was the most commonly found caterpillar on commercial protected lettuce crops.

Overall conclusion

Although these results, together with those from previous years, demonstrate that lettuces are at risk from attack by moths and caterpillars between April and November, the threat of serious damage is probably not as great as previously thought. However, even very small numbers of caterpillars are obvious to customers and the strict standards set by produce retailers demand that the crops receive continuous protection throughout the period of risk.

EXCLUSION OF MOTHS AND APHIDS

Objective

To monitor the effect of screening glasshouses on pest invasion and the growing environment.

Methods

Site:

Mr Peter Hardwick, 26 West Bank, Snaith, Goole

Glasshouses:

Two glasshouses (A and B) of similar size, structure and orientation were used in the experiment. Both were Venlo structures designed and built by HOK Engineering in 1984/5. They were 36m long with 6m wide bays and were approximately 2.7m high to the gutters. There were 30 plants across each bay and 156 plants along the full length of the glasshouse. In the first crop, there was a single central 0.3m wide longitudinal access path in each bay. In all subsequent crops, there were two such paths evenly spaced in each bay. Glasshouse B consisted of 5 bays, with a total of 23,400 plants. Glasshouse A was slightly larger, having an extra half length bay and a total of 25,740 plants. The two glasshouses were linked by a common north/south wall. A was not joined to any other glasshouses but B was linked by common walls to other glasshouses to the north and east.

House A was screened to prevent the entry of winged aphids and moths. There were 132 roof ventilators (each 0.73m x 0.83m) with "Belgium-type" vent bar design, and all were individually screened with Mevolon 0.6mm x 0.6mm UV stabilised polyethylene insect netting. The netting was prefabricated for each ventilator and fixed to the inside of the opening with aluminium strips fastened by self drilling screws. The arms of the ventilator passed through sockets in the netting and were clamped with two stainless steel clamps per vent arm. There were two doors (each 2.9m x 2.4m) in the east wall of the glasshouse. The doors were fitted with clear PVC strip curtains, each consisting of 15 overlapping 0.3m wide strips, suitable for tractor and forklift traffic. House B remained unscreened.

Lettuce crops:

Lettuce crops were planted sequentially throughout the year, as follows:

	Planting began:	Harvest began:
Crop 1	13 October 2000	19 February 2001
Crop 2	7 March 2001	9 May 2001
Crop 3	30 May 2001	2 July 2001
Crop 4	20 July 2001	28 August 2001
Crop 5	7 September 2001	After end of project

Pest assessments:

The presence of winged aphids in the production glasshouses was monitored with yellow water traps. Two such traps were placed within the lettuce crop in each glasshouse. The traps were emptied when visiting to monitor crops (see below) and the contents sent to HRI Wellesbourne, where the aphids identified and counted. The results are expressed as the number of aphids per trap per day.

Pheromone traps were placed in the vicinity of the glasshouses from 19 April 2001 to monitor activity of *A. gamma*, *C. pronubana* and *L. oleracea*. See page 12 of this report for details of methods.

The crops were monitored for the presence of pests at two-week intervals between November and April, and at weekly intervals from May to October. On each occasion, all paths were walked and plants scanned for obvious damage symptoms (eg insect specimens, holed leaves, honeydew etc). At the same time, any disease symptoms were noted and reported to the grower. In addition, the crop was divided into sampling units of 30 x 13 plants, which were clearly bound by the glasshouse posts. Within each unit, four plants were selected at random and the presence (but not number) of aphids and caterpillars were recorded on each. Specimens were identified to species but not life cycle stage. When pests were found, the grower was notified within 24 hours, and he applied an appropriate short persistence insecticide to the infested crop. Monitoring then continued the following week.

Glasshouse environment assessments:

The effect of the screening on the environment within the glasshouse was also monitored. Temperature and relative humidity in the screened and unscreened glasshouses were recorded throughout the experiment using four data loggers in aspirated screens per glasshouse. Readings were taken every 30 minutes, downloaded at the end of each crop and converted to daily averages.

Solar radiation was measured at crop level in both screened and unscreened glasshouses using tube solarimeters connected to Delta-T loggers. Two tubes were placed in each glasshouse standing 30cm above the crop facing north-south. All tubes were correctly calibrated and interchanged at the end of each crop to minimise errors. Readings were converted to MJm^2 and are presented cumulatively for each crop.

Lettuce head weight assessments:

Assessments were done at the end of each crop to compare lettuce head weights in the screened and unscreened houses. The grower monitored lettuce head weights as the crops approached harvest following his normal practice. When the lettuces in the unscreened house reached about 170gm, he notified Stockbridge Technology Centre Ltd (STC) staff, who instigated a procedure recommended by HRI Biometrician, John Fenlon.

Ten samples were taken from each glasshouse. A single sample consisted of one complete row of plants across a bay (ie 30 lettuce heads), thus taking into account possible positional effects caused by shading from glasshouse gutters. The samples were chosen by first selecting at random two sampling units bound by glasshouse posts (see details in pest assessment section above) per bay and then using a random number between 1 and 13 to

select the row within each chosen unit. Within each sample, the lettuces were cut just above the peat block and trimmed following the grower's normal practice, and then each head was categorised as marketable Class I, marketable Class II or unmarketable. The number and total weight in each category was recorded.

The data were analysed by Mr John Fenlon, HRI, Wellesbourne. For each crop, separate analyses of variance were done on total weights, number of lettuce heads and unit head weight for Class I, Class II and unmarketable categories of produce. The differences between means were compared using least significant difference (LSD).

Plant propagation:

Procedures were established to reduce the risk of importing pests into the production glasshouses on young plants from the propagation unit. All plants were sprayed by the grower with a short persistence insecticide about 24 hours before leaving the propagation house. The plants were covered with fleece while being moved from the propagation house to the production house. As a further precaution, the plants were checked by STC staff for presence of pests between spraying and planting.

Summary of results:

The results are summarised for each crop. Full data sets will be archived at STC for future reference.

Crop 1 (13 October 2000 to 19 February 2001)

General notes:
The season was very wet with floods in the surrounding area and an exceptionally high water table throughout the monitored period. Growing conditions were generally poor, which resulted in an extended crop duration.

Summary of P&D incidence:

- No insects or disease symptoms were seen on the plants prior to planting.
- *Nasonovia ribisnigri* were caught in water traps in the unscreened glasshouse between 24 January and 19 February 2001 at the rate of 0.04/trap/day. No aphids were caught in traps in the screened glasshouse.
- No aphids were found on plants during the assessments but at harvest nursery staff found small numbers (thought to be *M. euphorbiae*) on three plants under a gutter in the centre of the screened glasshouse and on three plants in one corner. It was not clear how these aphids gained entry to the glasshouse.
- On 10 January 2001, a single moribund caterpillar was found on a plant in the screened glasshouse. No others could be found in the area. The specimen was taken to Stockbridge House but died before pupating. It is thought that this individual must have been in the glasshouse when the crop was planted. No other caterpillars were found in the glasshouses.
- Slug damage was evident at the edge of the screened house and this was controlled as well as possible with slug bait.

- Approximately 140 and 350 plants were lost in the screened and unscreened glasshouses respectively due to poor root formation and Botrytis infection. This represented 0.5% and 1.3% of the crops respectively. Most of the damage occurred towards the end of the crops in January 2001. The grower thought that cutworms may be (at least in part) responsible for the initial root damage but no specimens were found and this could not be confirmed from the symptoms seen. The Botrytis infections were exacerbated by the poor growing conditions.
- Sclerotinia was confirmed on one plant in the unscreened glasshouse in late November.

Insecticides applied:
No insecticides were applied in the screened glasshouse. In the unscreened glasshouse, Toppel 10 was applied against caterpillars and Aphox against aphids on 27 and 30 October respectively. Both crops were treated six times with fungicides.

Harvest data:
The harvest data for crop 1 is shown in Table 1. There was no apparent difference in the time taken to reach marketable weight or in the proportion of the crop that were marketable. The lower than expected proportion of Class I produce in both glasshouses was attributed to the poor weather. There were 30% more ($P<0.05$) Class I lettuces in the screened than unscreened glasshouse. This was largely due to one bay in the unscreened house, which yielded half as many Class 1 lettuces than any other bays.

Table 1. Harvest data from the first crops grown in the screened and unscreened glasshouses

Catergory		Screened	Unscreened	LSD
Class I	Weight	2431	1870	404.8
	Number	14.8	11.4	2.4
	Unit wt	164.0	163.8	9.1
Class II	Weight	1382	1713	251.5
	Number	10.0	13.1	2.3
	Unit wt	137.9	131.7	11.0
Unmarketable	Weight	573	605	391.9
	Number	5.1	5.8	3.4
	Unit wt	110.6	102.1	12.5

Environment data:
Light – The accumulated MJ/m^2 over the 17 week crop production period showed an 8% reduction in light recorded in the screened glasshouse compared to the unscreened house.
Temperature – The temperatures in the two monitored glasshouses were very similar during the crop production period (Figure 5). The overall means were 7.1^{o}C in both glasshouses.
Humidity - The RH in the two monitored glasshouses were very similar during the crop production period (Figure 6). The overall means were 95.7% and 94.1% in the screened and unscreened glasshouses respectively.

Crop 2 (7 March to 9 May 2001)

General notes:
These crops contained a larger than nomal proportion of weak plants due to a poor batch of seed. Some of these plants died during production and/or became infected with Botrytis. Crops in the unscreened house began to receive the grower's routine insecticide spray programme from early April.

Summary of P&D incidence

- No insects or disease symptoms were seen on the plants prior to planting.
- *Macrosiphum euphorbiae* were caught in water traps in the unscreened glasshouse between 2 and 8 May 2001 at the average rate of 0.08/trap/day. No aphids were caught in traps in the screened glasshouse.
- On 18 April 2001, *M. euphorbiae* were found on a small cluster plants in one location in the screened house. This was the same position that they had been found at the end of the previous crop and it is assumed that some survived on the soil or on crop debris. In accordance with the contract, monitoring ceased in that glasshouse, the grower was informed and the crop sprayed with a short persistence insecticide. Monitoring recommenced the following week.
- Pheromone traps were placed around the glasshouses on 19 April 2001. Very small numbers of *L. oleracea* were caught just before the crop was harvested (Figure 4).
- No caterpillars were found in the crops.
- Approximately 80 plants (0.3% of crop) became seriously infected with Botrytis in each glasshouse.

Insecticides applied:
Hostaquick was applied against aphids in the screened glasshouse on the 18 April 2001. In the unscreened glasshouse, Aphox was applied twice (18 March and 22 April 2001) and Hostaquick once (15 April 2001) against aphids. Both crops were treated five times with fungicides.

Harvest data:
The harvest data for crop 2 is shown in Table 2. There was no apparent difference in the time taken to reach marketable weight or in the proportion of the crop that were marketable. However, the overall weight of Class I lettuces was almost 20% greater ($P<0.05$) in the screened than unscreened glasshouse. This difference was consistent across the glasshouses and could not be attributed to any one area as in crop 1.

Table 2. Harvest data from the second crops grown in the screened and unscreened glasshouses

Catergory		Screened	Unscreened	LSD
Class I	Weight	7207	6053	1084.6
	Number	26.4	24.6	3.6
	Unit wt	273.0	244.5	26.0
Class II	Weight	366	774	548.5
	Number	2.4	5.3	3.4
	Unit wt	149.4	141.6	36.3
Unmarketable	Weight	122	25	121.0
	Number	07	1.0	0.6
	Unit wt	99.0	58.0	77.3

Environment data

Light – The accumulated MJ/m^2 over the nine week crop production period showed 9% reduction in light in the screened glasshouse compared to the unscreened house.

Temperature – The temperatures in the two monitored glasshouses were very similar during the crop production period (Figure 7). The overall means were 9.7^{o}C and 9.8^{o}C in the screened and unscreened glasshouses respectively.

Humidity - The RH in the two monitored glasshouses were very similar during the crop production period (Figure 8). The overall means were 87.1% and 85.8% in the screened and unscreened glasshouses respectively.

Crop 3 (30 May to 2 July 2001)

General notes:

Due to a period of very hot weather during the latter stages of propagation, the young plants grew more quickly than anticipated and were larger than normal when planted.

Summary of P&D incidence:

- No insects or disease symptoms were seen on the plants prior to planting.
- *Hyperomyzus* spp. were caught in water traps in the unscreened glasshouse between 1 and 6 June 2001 at the rate of 0.1/trap/day. No aphids were caught in traps in the screened glasshouse.
- On the first assessment in the production houses (6 June 2001), winged and wingless *N. ribisnigri* were found in both the screened and unscreened glasshouses. The plants were thought to have become infested during transport between the propagation and production glasshouses. The grower spayed both crops with pirimicarb and monitoring continued the following week.
- Very small numbers of aphids were found in both glasshouses at the last assessment but this was too close to harvest to apply insecticides. This did not affect marketing.
- An average of approximately one *L. oleracea* was caught per pheromone trap per day throughout this crop. Very small numbers of *A. gamma* and *C. pronubana* during the same period. (Figure 4).
- There were no records of caterpillars in either glasshouse.

- On the last assessment (27 June 2001), 17 plants in the screened house were found to be infected with *Sclerotinia* and 2 plants with *Botrytis*. On the same occasion, 30 plants were infected with *Sclerotinia* in the unscreened house.
- A small number of plants in each glasshouse developed symptoms of calcium deficiency during hot weather.

Insecticides applied:
Aphox was applied against aphids in the screened glasshouse on the 6 June 2001. In the unscreened glasshouse, Aphox was applied twice (6 June and 16 June 2001) against aphids. Both crops were treated five times with fungicides.

Harvest data:
The harvest data for crop 3 is shown in Table 3. There was no apparent difference in the time taken to reach marketable weight or in the proportion of the crop that were marketable. The overall weight of Class I lettuces was approximately 6% greater (P<0.05) in the screened than unscreened glasshouse. This difference was consistent across the glasshouses and could not be attributed to any one area as in crop 1.

Table 3. Harvest data from the third crop grown in a screened or unscreened glasshouse

Catergory		Screened	Unscreened	LSD
Class I	Weight	7299	7108	420.6
	Number	29.5	27.8	0.6
	Unit wt	247.5	255.9	17.3
Class II	Weight	32	322	256.7
	Number	0.2	1.5	0.5
	Unit wt	*	*	*
Unmarketable	Weight	42.0	41.0	97.4
	Number	0.2	0.3	0.6
	Unit wt	*	*	*

* not available

Environment data:
Light – The accumulated MJ/m^2 over the four week crop production period showed a 18% reduction in light recorded in the screened glasshouse compared to the unscreened house.
Temperature – The temperatures in the two monitored glasshouses were very similar during the crop production period (Figure 9). The overall means were 17.3^{o}C and 17.2^{o}C in the screened and unscreened glasshouses respectively.
Humidity - The RH in the two monitored glasshouses were very similar during the crop production period (Figure 10). The overall means were 79.9% and 78.9% in the screened and unscreened glasshouses respectively.

Crop 4 (20 July to 28 August 2001)

Summary of P&D incidence:

- No insects or disease symptoms were seen on the plants when they were inspected in propagation on 18 July 2001. Planting commenced on the 20 July 2001.
- Both *A. solani* and *N. ribisnigri* were caught in water traps in the unscreened glasshouse between 25 July and 1 August 2001 at the rate of 0.04/trap/day. No aphids were caught in traps in the screened glasshouse.
- Aphids were found during the first assessment in both production glasshouses (25 July 2001). Approximately 13% of the plants were infested with *N. ribisnigri* and this included a large proportion of winged individuals. The plants are believed to have become infested between the inspection in propagation and planting. The grower spayed both crops with pirimicarb and monitoring continued the following week.
- *Nasonovia ribisnigri* were found in the unscreened glasshouse on the third assessment (8 August 2001) and the crop was sprayed with pirimicarb the same day. No aphids were found in the screened glasshouse.
- Small numbers of *M. euphorbiae* were found on four plants in the unscreened glasshouse on the fourth assessment (15 August 2001). As harvest was approaching, the grower decided not to spray but to inspect plants while trimming and packing and dispose of any that were found to be infested. No aphids were found in the screened glasshouse.
- Numbers of both *L. oleracea* and *A. gamma* on pheromone traps peaked during this crop. Very small numbers of *C. pronubana* were caught on one occasion. (Figure 4).
- A small unidentified caterpillar was found in the screened greenhouse on the first assessment. The egg must have been laid while the plant was in propagation.
- A silver Y caterpillar was found in the unscreened glasshouse on the 30 July 2001. In this case, the egg must have been laid on the plant in the production house.
- Very small numbers of plants were found to be infected with Sclerotinia in both glasshouses on the last assessment before harvest.

Insecticides applied:

Aphox was applied against aphids in the screened glasshouse on the 27 July 2001. In the unscreened glasshouse, Aphox was applied twice (27 July and 8 August 2001) against aphids, and Toppel 10 was applied once (8 August 2001) against caterpillars. Both crops were treated five times with fungicides.

Harvest data:

The harvest data for crop 4 is shown in Table 4. There was again no apparent difference in the time taken to reach marketable weight or in the proportion of the crop that were marketable. However, the number and overall weight of Class I lettuces were approximately 45% and 37% greater ($P<0.05$) in the screened than unscreened glasshouse respectively. As in crops 2 and 3, this difference was consistent across the glasshouses.

Table 4. Harvest data from the fourth crop grown in a screened or unscreened glasshouse

Catergory		Screened	Unscreened	LSD
Class I	Weight	5634	3523	790.3
	Number	25.1	17.2	3.6
	Unit wt	224.8	206.5	22.2
Class II	Weight	1539	1065	562.3
	Number	4.9	11.9	3.3
	Unit wt	162.3	158.8	30.2
Unmarketable	Weight	0	172	305.5
	Number	0.0	0.9	1.4
	Unit wt	*	*	*

*not available

Environment data:

Light – The accumulated MJ/m^2 over the four-five week crop production period showed a 17% reduction in light recorded in the screened glasshouse compared to the unscreened house

Temperature – The temperatures in the two monitored glasshouses were very similar during the crop production period (Figure 11). The overall means were 20.6ºC and 20.5ºC in the screened and unscreened glasshouses respectively.

Humidity - The RH in the two monitored glasshouses were very similar during the crop production period (Figure 12). The overall means were 78.4% and 75.9% in the screened and unscreened glasshouses respectively.

Crop 5 (7 September to 17 October 2001)

General notes:

As this crop would not be harvested before the end of the project, the grower changed from planting the two glasshouses simultaneously to planting batches of plants in sequence as this was more appropriate to his future cropping schedule. Pest, disease and environmental monitoring were done from planting until mid-October.

Summary of P&D incidence:

- No aphids were found in water traps in either glasshouse.
- On the first assessment date (19 September 2001), small numbers of unidentified aphid nymphs were found on three plants in the unscreened house. The grower applied the routine pirimicarb spray two days later. No aphids were found in the screened house.
- On the third assessment date (3 October 2001), small numbers of dead aphids were found on three lettuces from the oldest batch of plants in the screened house. The grower was informed but no action was considered necessary. No aphids were found in the unscreened house.
- Small numbers of unidentified winged aphids were found in the unscreened glasshouse on the fourth assessment (10 October 2001) and the crop was sprayed with pirimicarb. No aphids were found in the screened house.

- Small numbers of *A. gamma* were caught on pheromone traps throughout this crop (Figure 4).
- No caterpillars found in either glasshouse.

Insecticides applied:
Aphox was applied twice against aphids in the screened glasshouse (13 and 30 September 2001), and three times in the unscreened glasshouse (24 September, 13 and 20 October 2001). The screened and unscreened crops received six and five fungicide applications respectively – the extra one in the screened glasshouse was necessary because the crop was planted a week earlier.

Environment data:
Light – The data for this period had to be discounted due to a fault with the equipment.
Temperature – The temperatures in the two monitored glasshouses were very similar during the crop production period (Figure 13). The overall means were 14.4ºC in both glasshouses.
Humidity - The RH in the two monitored glasshouses were very similar during the crop production period (Figure 14). The overall means were 90.1% and 89.9% in the screened and unscreened glasshouses respectively.

Discussion and conclusions:

Aphid establishment

No aphids were collected from traps in the screened glasshouse but live aphids were found on plants on five occasions between October 2000 and October 2001. On two such occasions, the insects had most probably been brought in with the plants from propagation. On one occasion, small numbers were thought to have survived on debris in the soil from a previous infestation. On the other two occasions, very small numbers were found either just before or during harvest. It is not known how these aphids gained entry but no action was deemed necessary.

By contrast, aphids were collected from water traps in four of the five crops in the unscreened glasshouse. Despite the routine chemical spray programme in this glasshouse, aphids were also found on plants on seven occasions, with most invasions occurring in late July and August.

Moth / caterpillar establishment

The use of pheromone traps showed that moths were active from May to October (inclusive) with the crops under greatest threat from mid-May to late-August. There was a resurgence of *A. gamma* activity in late-October. Despite this, caterpillars were rarely found on the plants demonstrating that the protection provided by either the screens or the routine spray programme was effective.

Disease incidence:

There was no apparent difference in disease incidence in the screened and unscreened glasshouses.

Number of pesticide sprays required:

Over the whole year, the mean number of insecticide applications was 1.0 and 2.6 per crop in the screened and unscreened glasshouses respectively. If the plants had always arrived uninfested from propagation, then the mean number of applications in the screened glasshouse would have been reduced to 0.6 per crop. These results demonstrate that insecticide usage can be much reduced, though probably not eliminated, by screening glasshouses.

The cost of the additional sprays in the unscreened glasshouse has been calculated to be £21 per 1000m^2 per annum.

The number of fungicides applied was similar in both glasshouses.

Crop monitoring:

The fact that pests do occasionally breach the defences in a screened glasshouse means that the pest control programme must be supported by effective monitoring procedures to determine when insecticides are required. The monitoring procedure used in this experiment was effective but may prove to be too time consuming (and therefore too expensive) for growers to adopt more generally. The time required clearly increases as the crop matures and it becomes more difficult to inspect each plant, but the average time was 2 hours per 1000m^2. In this project, pest monitoring was done weekly from May to October, and at two week intervals from November to April. There were 33 monitoring checks and the annual cost was £528 per 1000m^2. Crop monitoring has the additional benefit of providing topical information about disease incidence, which may help growers to move towards supervised disease control strategies too.

Temperature and humidity:

Screening ventilators and doors had no apparent effect on temperature or humidity in the glasshouse. The glasshouse environment computer probably compensated for any restriction in air movement through the screens by opening the ventilators earlier or by a greater amount.

Effect of screening on light:

Screening ventilators had an effect on accumulated light over the duration of each crop, which was most noticeable in the summer months. The trends were broadly consistent with previous results from the experimental glasshouses although the light reduction was greater in the screened commercial glasshouse than screened experimental glasshouse. This was probably due to the funnel shaped design of screens in the commercial glasshouse creating more shade than the flat screens in the experimental glasshouse.

Yield:

Screening, and the associated reduction in light, did not effect the time taken for plants to reach marketable weight or the proportion of the crop that were marketable. Therefore, income from produce in a screened glasshouse should not be directly affected.

Economics of screening glasshouses:

It is impossible to do an accurate cost benefit analysis of screening glasshouses at this stage because several of the components of the calculations are unknown. However, it is possible to make the following estimations:

The additional costs are the capital outlay and the labour for the pest monitoring work. The cost of screening this glasshouse was £12,300 (ex VAT). However, this was a "one-off" and we anticipate that the cost would be reduced by approximately 50% if it became a standard service that was provided by several competitive suppliers. The materials are guaranteed against UV breakdown for five years. As it has been difficult to gain reliable information regarding any further life expectancy, it has been assumed that the screens will have to be replaced after five years and the capital cost (excluding interest) is therefore estimated to be £1230 per 1000m^2 per annum. The annual bill for pest monitoring work has been estimated to be £528 per 1000m^2. The total additional costs are therefore £1758 per 1000m^2 per annum.

The capital cost (excluding interest) for a typical 12000m^2 nursery would be about £75,000, which would only be practicable over a 4-5 year investment plan.

The potential savings in terms of reduced insecticide sprays are estimated to be £21 per 1000m^2 per annum.

This "supervised" pest control programme based on screening and pest monitoring has the potential to reduce insecticide inputs by over 75%, but at an additional cost to the grower of £1,737 per 1000m^2 per annum compared to a routine insecticide spray programme. This would require an approximate 9% increase in the wholesale value of lettuce.

It is important that growers, customers and consumers appreciate that the control methods used require further evaluation and refinement both agronomically and economically before widespread adoption can take place.

It is possible that other forces (eg loss of insecticides and / or customer demand) may drive growers down the reduced pesticide application route regardless of the refinement of knowledge required or the additional costs involved. It is suggested that industry wide discussions (*ie* involving growers, marketing groups and retailers) should take place, possibly through the auspices of the Assured Produce Scheme, to consider these research findings and their implications for Assured Produce Scheme Protocols.

CONTROL OF APHIDS WITH ENTOMOPATHOGENIC FUNGI

Objective:

To determine the effect of programmes of three sprays of two entomopathogenic fungi against four species of aphids on glasshouse grown lettuce.

Materials and methods:

Insects

Nasonovia ribisnigri, A. solani, M. euphorbiae and M. persicae were reared on lettuce (cv Flandria) at 21 ± 2^{O}C and 16L:8D.

Experiment 1
The cultures of *N. ribisnigri, A. solani* and *M. euphorbiae* produced large numbers of wingless aphids for the experiment. Each species was brushed from the culture foliage onto the experimental plants while they were in propagation trays prior to planting. The aphids were monitored after planting for even establishment and numbers were adjusted as necessary.

Experiment 2
The cultures of *M. persicae* performed poorly on the round lettuce and there were insufficient aphids available when the populations of the other three species peaked. As a consequence, *M. persicae* was omitted from the main experiment and included in a separate experiment of smaller design. The plants were infested as described in experiment 1.

Plants

Round lettuce (cv. Flandria) were sown on 13 July 2001 and planted in the experimental glasshouse on 4 August 2001 for experiment 1 and 7 August 2001 for experiment 2. They were irrigated following normal commercial practice.

Entomopathogenic fungi

Two products based on entomopathogenic fungi were tested; Vertalec (*Verticillium lecanii*), which is available commercially in the UK, and Naturalis L (*Beauveria bassiana*), which is available commercially in the USA and was in the process of being registered for use in the UK. The products were prepared according to the manufacturer's recommendations and applied to the point of maximum leaf retention at the following dilutions (*i.e.* manufacturer's recommended rates) using an Oxford Precision Sprayer:

- Vertalec powder - 2g of product per litre of water.
- Naturalis - 4ml per litre of water.

Treatments

Experiment 1
Vertalec and Naturalis were tested against *N. ribisnigri, A. solani* and *M. euphorbiae*, and compared to untreated controls of each aphid species, in a total of nine Treatments. Each product was applied three times at three day intervals, with the first spray applied on 18 August 2001. The untreated controls were sprayed on the same dates using water only.

Experiment 2
Vertalec and Naturalis were tested against *M. persicae* and compared to an untreated control in a total of three Treatments. Other details were as described for the first experiment.

Experimental Procedure

Both experiments were done during August 2001 in a 150m^2 Venlo-style glasshouse (FF8) at HRI Stockbridge House. The plants were grown under ambient growing conditions with permanent roof ventilation. The temperature and humidity in the glasshouse were monitored throughout the experiment.

Aphid assessments were done one day before application of the first sprays and 5 days after application of the third sprays. The pre-treatment assessments were done in situ on 12 and 8 plants per plot in experiments 1 and 2 respectively. The post-treatment assessments were done on the same number of samples but the plants, which now had considerably more foliage, were lifted and dismantled to ensure that all aphids were found. On each occasion the numbers of live aphids per plant head were recorded. Samples of dead aphids were collected from each Treatment, placed on damp filter paper in Petri dishes and incubated without light at 23^{O}C. Fungal growth on the cadavers was subsequently sub-cultured on growth media, incubated until sporulation occurred and identified.

Experimental design and analysis

Experiment 1
The main design was an incomplete Latin square with 4 rows and 3 columns, giving 12 main plots in total. Each main plot was divided into 3 subplots with the two entomopathogenic fungi and water control allocated at random to these subplots. Each subplot contained 48 plants in a 6 x 8 arrangement. The mean numbers of aphids per plant were subjected to square root transformation, analysed using analysis of covariance with the pretreatment counts as the covariate and the differences compared using LSD.

Experiment 2
Due to the limited number of aphids, this experiment was restricted to two plots per Treatment, with 8 plants per plot. The plots were grouped in two blocks, which were in a linear array. The data were analysed as described for experiment 1.

Results and discussion:

The average temperature during the experiments was 18.6^{O}C (ranging from 9.6-42.0^{O}C) and the average relative humidity was 92.2% (ranging from 44-99%).
There were differences in the numbers of aphids per plant before sprays were applied in both experiments, so the data from the post-treatment assessments were analysed by analysis of covariance. These adjustments allowed comparisons to be made between the means of Treatments at the post-treatment assessment.

The presence of fungi was confirmed on over 50% of the dead aphids that were collected at the end of the experiments.

Experiment 1

The aphid populations increased in size in all Treatments during the experiment. Overall, the increase was significantly greater (P<0.05; 23df) on the untreated plants (*i.e.* 6 fold increase) than the plants treated with either Vertalec or Naturalis (5 fold increase). The individual effects of Vertalec and Naturalis against *M. euphorbiae, N. ribisnigri* and *A. solani* are shown in Table 5.

At the post-treatment assessment, the adjusted mean numbers of *M. euphorbiae* per plant were greater (P<0.1) in the untreated controls than the Vertalec and Naturalis Treatments. In terms of population growth, numbers of *M. euphorbiae* had increased 8 and 9 fold in the Naturalis and Vertalec Treatments respectively, compared to the 13 fold increase in the untreated controls.

At the post-treatment assessment, the adjusted mean numbers of *N. ribisnigri* were greater (P<0.1) in the untreated controls and the Naturalis Treatment, than the Vertalec Treatment. The population growth of *N. ribisnigri* being 4 fold in the Vertalec Treatment compared to 8 fold in the untreated control.

Neither of the entomopathogenic fungi significantly reduced the population growth of *A. solani* relative to the untreated controls.

Table 5. The mean numbers of *M. euphorbiae, N. ribisnigri* and *A. solani* per plant following a programme of three sprays of Naturalis, Vertalec or water.

Species of aphid	Mean numbers of aphids (square root transformed and adjusted for covariate) per plant following treatment with:		
	Naturalis	Vertalec	Water (untreated control)
M. euphorbiae	107.94 (11.53)	97.92 (11.30)	161.36 (13.89)
A. solani	290.58 (12.70)	264.13 (11.80)	233.14 (11.70)
N. ribisnigri	41.06 (8.10)	37.14 (7.82)	62.28 (9.94)
LSD (P<0.1)*, 23df	(1.94)		

* Due to the variability of this type of data, differences were considered to be significant at the P<0.1.

Experiment 2

As in experiment 1, the aphid populations increased in all Treatments during this experiment. The individual effects of Vertalec and Naturalis against *M. persicae* are shown in Table 6. At the post-treatment assessment, there were similar numbers of aphids on the plants sprayed with Vertalec and Naturalis, and both were significantly (P<0.1) less than on the untreated controls. In terms of population growth, numbers of *M. persicae* increased 4 fold on the plants sprayed with entomopathogenic fungi, compared to 10 fold on the untreated controls.

Table 6. The mean numbers of *M. persicae* per lettuce plant following a programme of three sprays of Naturalis, Vertalec or water.

Species of aphid	Mean numbers of aphids (sqrt transformed adjusted for covariate) per plant following treatment with:		
	Naturalis	Vertalec	Water (untreated control)
M. persicae	108.7 (10.5)	129.6 (10.6)	161.36 (18.0)
LSD (P<0.1)*, 2df		(8.2)	

* Due to the variability of this type of data, differences were considered to be significant at the P<0.1.

Overall conclusions:

These experiments demonstrated that the entomopathogenic fungi have some effect on *M. euphorbiae*, *N. ribisnigri* and *M. persicae* populations, which is broadly consistent with the results of laboratory bioassays and small-scale glasshouse studies completed in previous years. The previous glasshouse studies showed that a single application of the pathogens did not provide adequate control but it was thought that a series of three spays would be more effective. Unfortunately, the level of control achieved by such spray programmes has now also been shown to be inadequate for commercial crops.

The poor control was thought to be due to a combination of three factors. First, the spores of entomopathogenic fungi must contact the pests to be effective, so spray coverage must be very thorough. However, aphids on lettuce are largely protected from sprays by the architecture of the plant and contact is probably quite poor. Second, the pathogens are relatively slow to act, usually taking about 5 days to kill the pests and the aphids are able to continue to produce offspring for at least part of this time. Third, the aphids have an extremely rapid reproductive rate and may produce several live young per day during the summer. This means that an infected aphid may still produce enough young to cause an increase in the population.

TECHNOLOGY TRANSFER

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Jacobson, R.J. (1999). Biological control of pests and its future. Lettuce Technology Group. April 1999.

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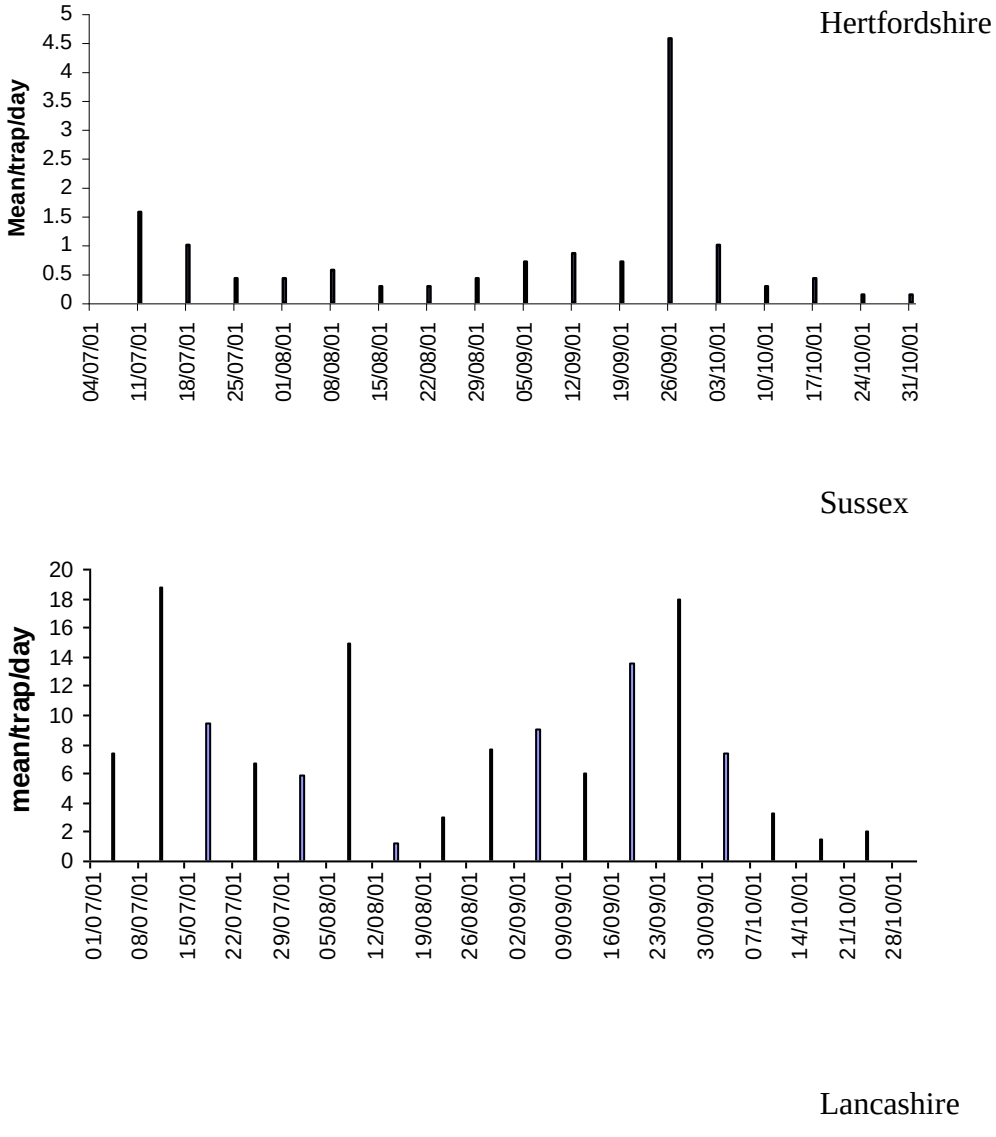
ACKNOWLEDGEMENTS

The authors would like to thank the Lettuce Technology Group for support throughout the project; David Stokes, Derek Hargreaves and Graham Ward for their specific contributions and guidance; all at Darnicle Hill Nurseries, Lovania Salads, Madestein UK and Sevenoaks Salads for their contributions to the pest monitoring studies over several years; and all at HRI and STC who have assisted with the practical work. However, our special thanks must go to Peter Hardwick, who was always so helpful in accommodating the final year's "commercial-scale" studies.

Figures

Figure 1. The mean number of *Autographa gamma* per pheromone trap per day at four locations in England. [Note the different vertical scales]



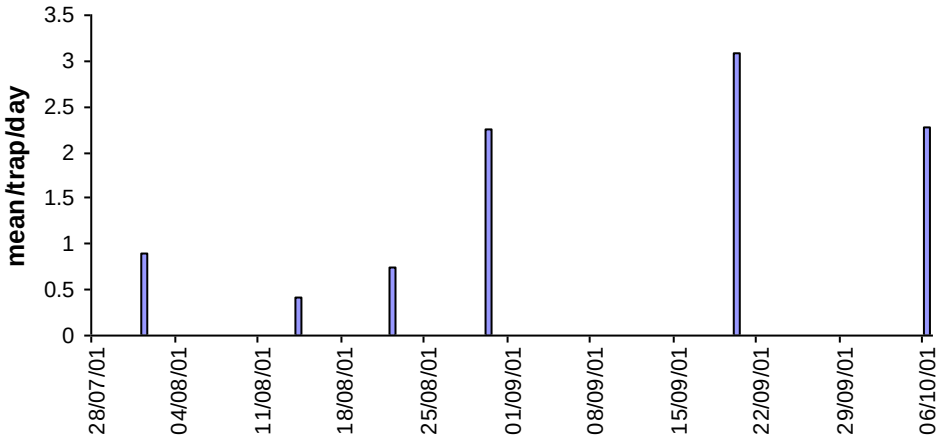


Figure 2. The mean number of *Cacoecimorpha pronubana* per pheromone trap per day at four locations in England. [Note the different vertical scales]

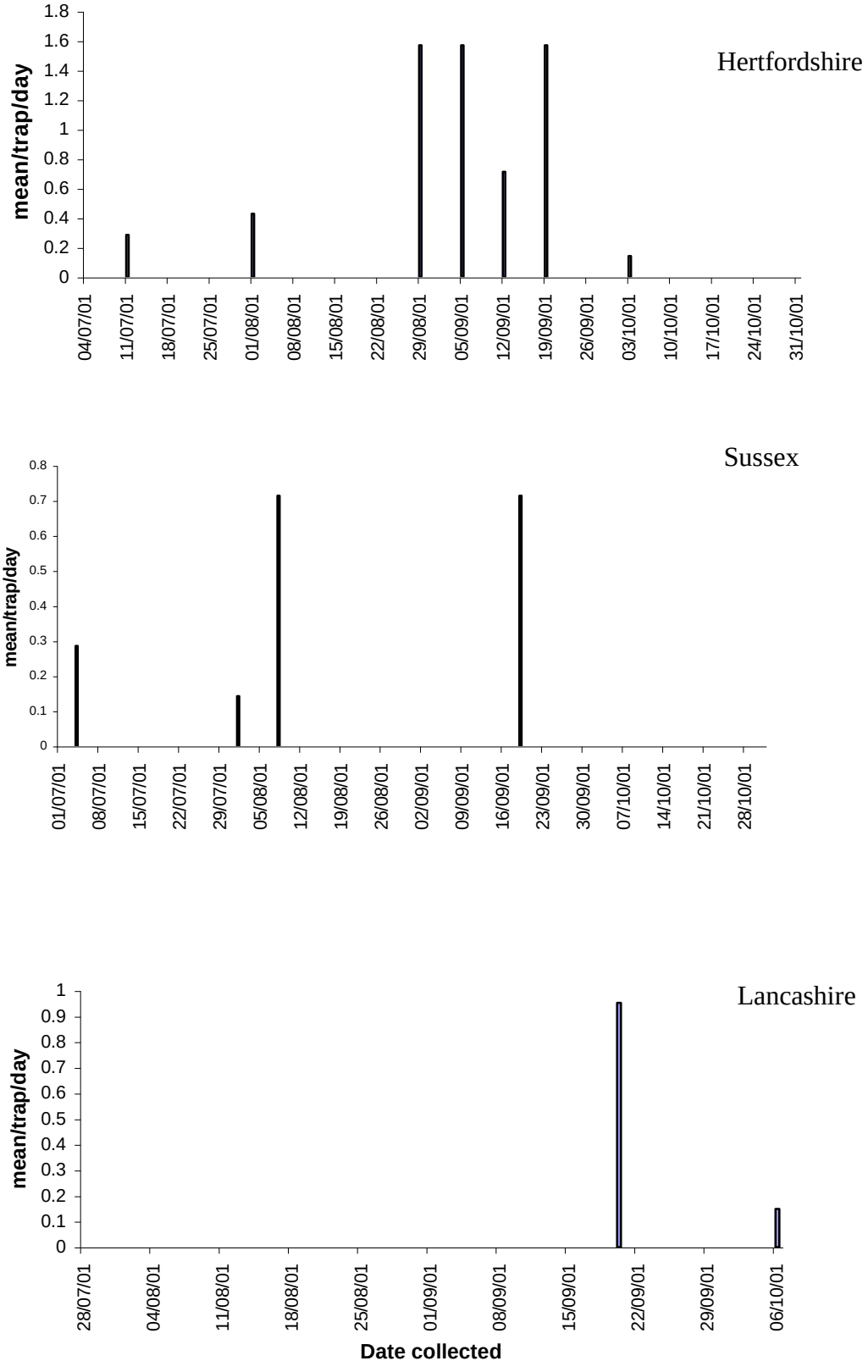
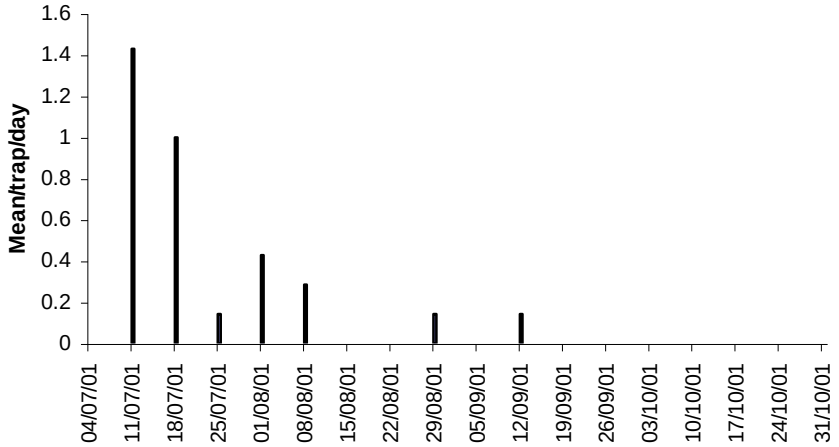
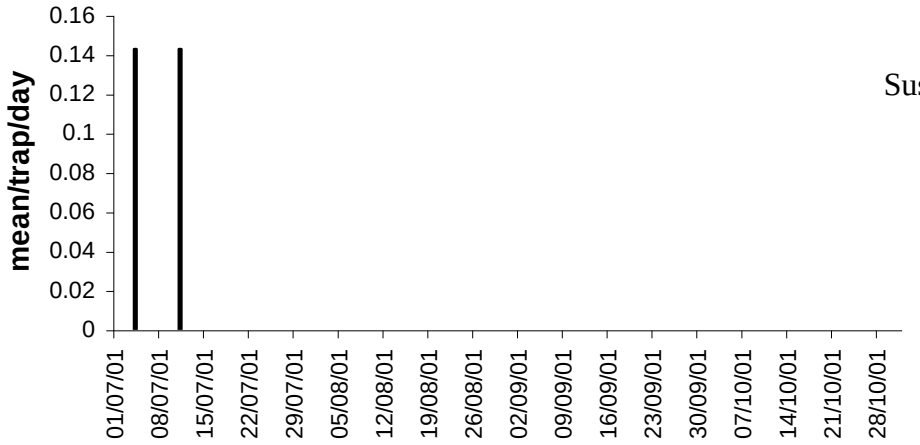


Figure 3. The mean number of *Laconobia oleracea* per phermone trap per day at four locations in England. [Note the different vertical scales]





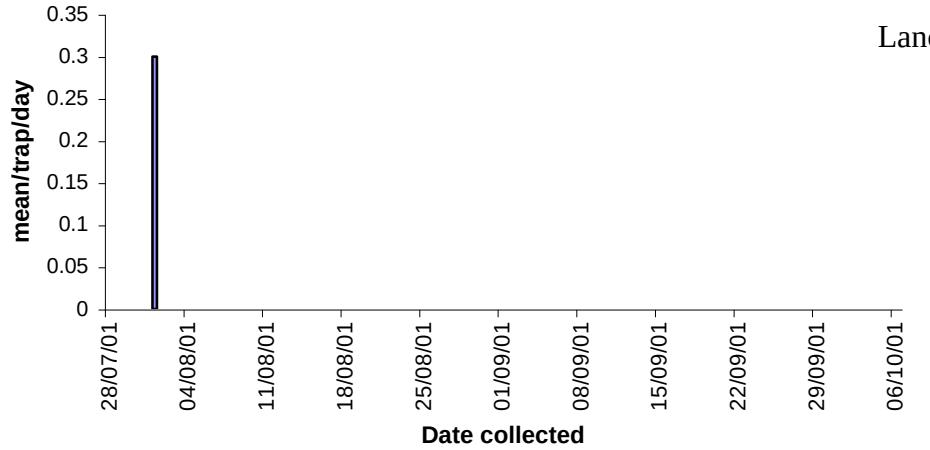
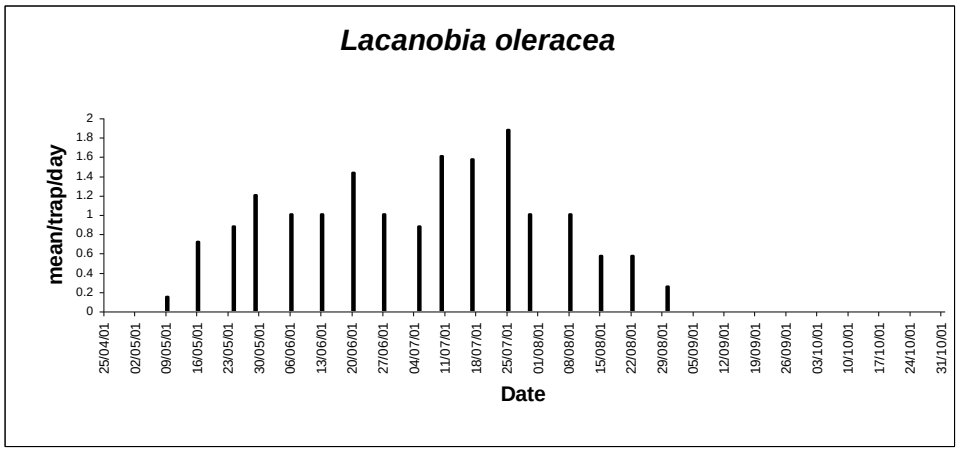
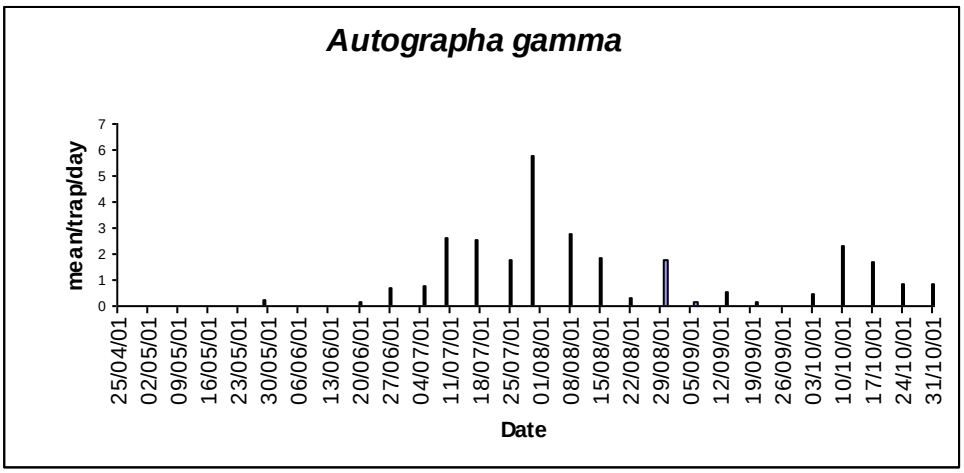


Figure 4. Numbers of moths caught in pheromone traps at Snaith from April to October 2001.





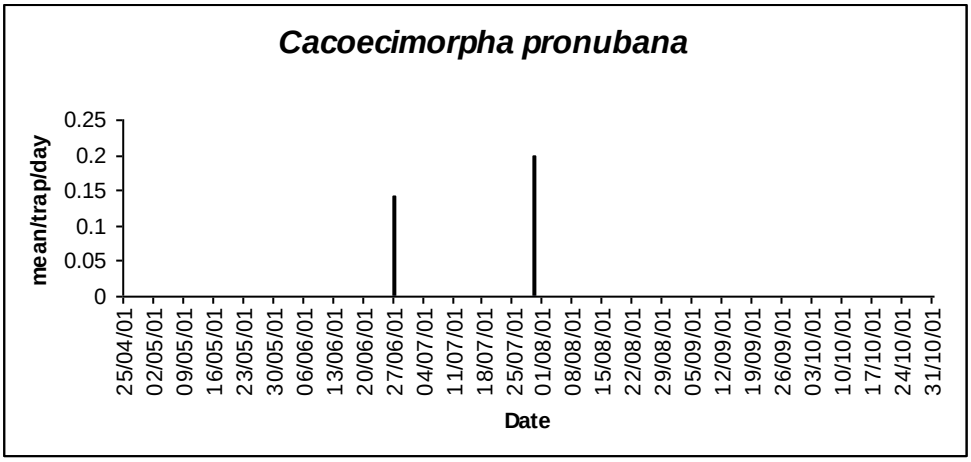


Figure 5. Crop 1 - Average daily temperature in screened & unscreened glasshouses

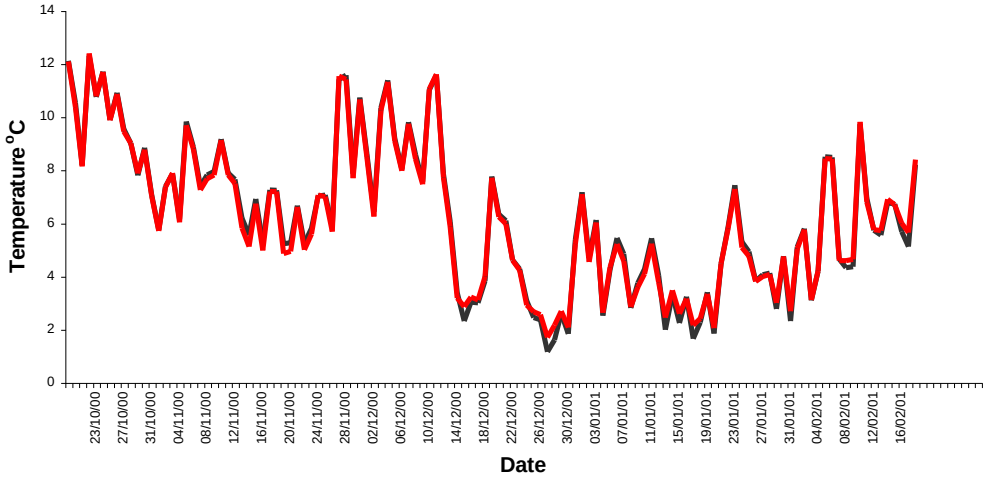


Figure 6. Crop 1 - Average daily RH in screened & unscreened glasshouses

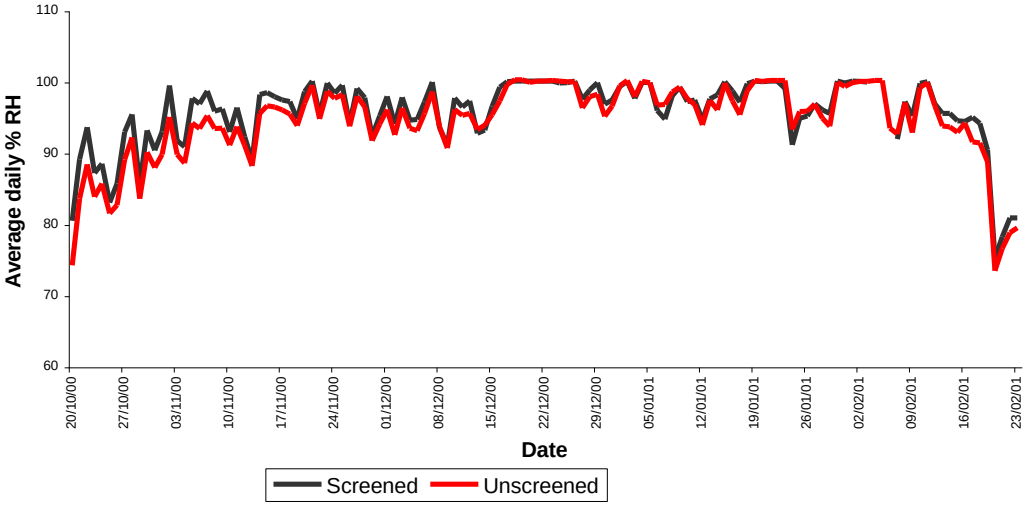


Figure 7. Crop 2 - Average daily temperature in screened & unscreened glasshouses

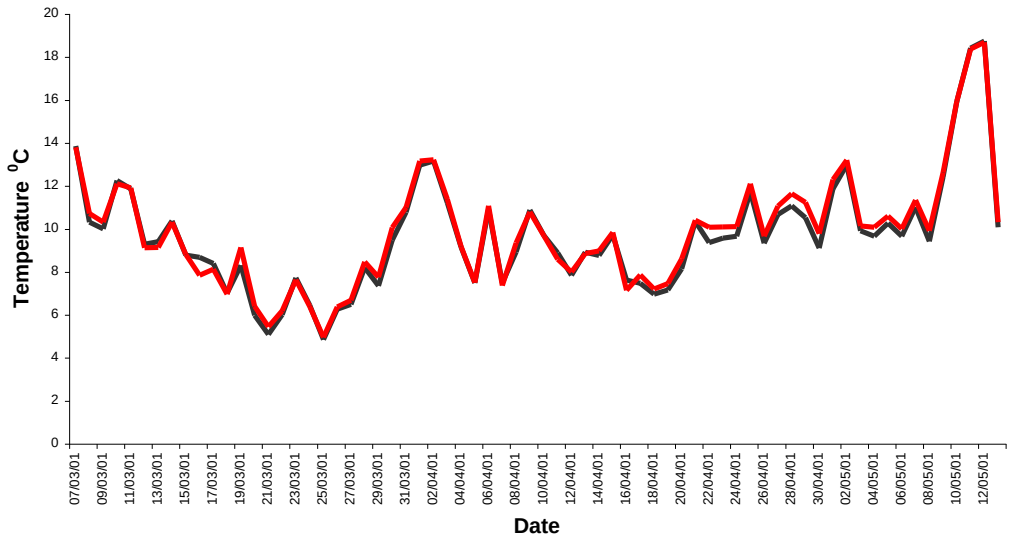


Figure 8. Crop 2 - Average daily RH in screened & unscreened glasshouses

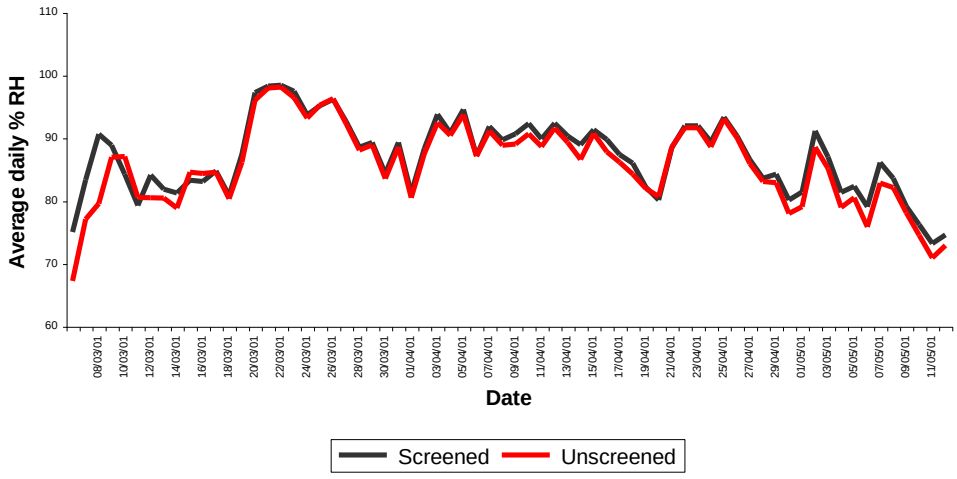


Figure 9. Crop 3 - Average daily temperature in screened & unscreened glasshouses

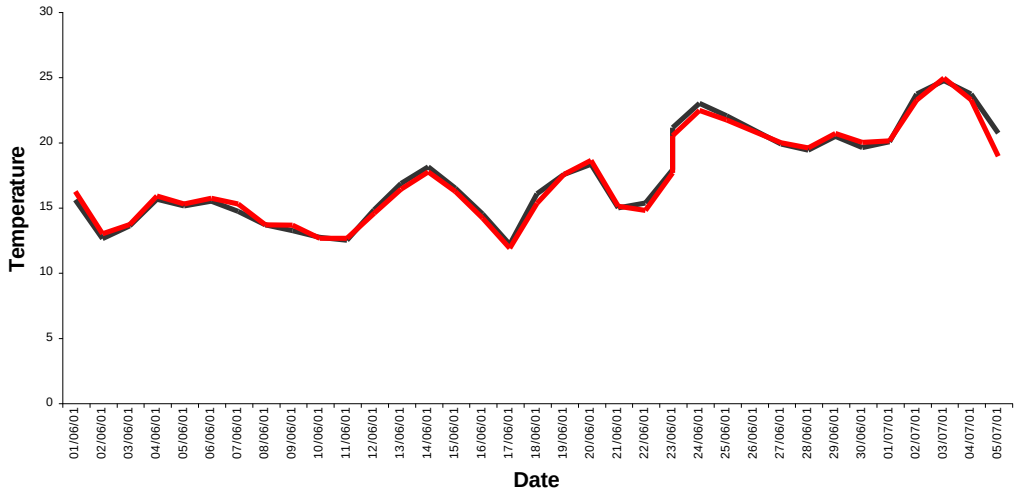


Figure 10. Crop 3 - Average daily RH in screened & unscreened glasshouses

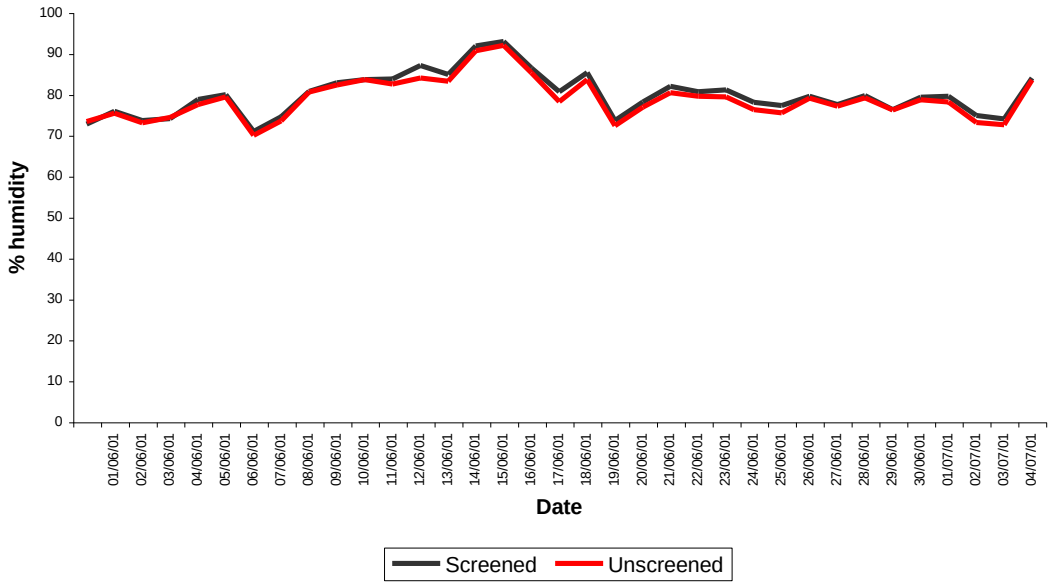


Figure 11. Crop 4 - Average daily temperature in screened & unscreened glasshouses

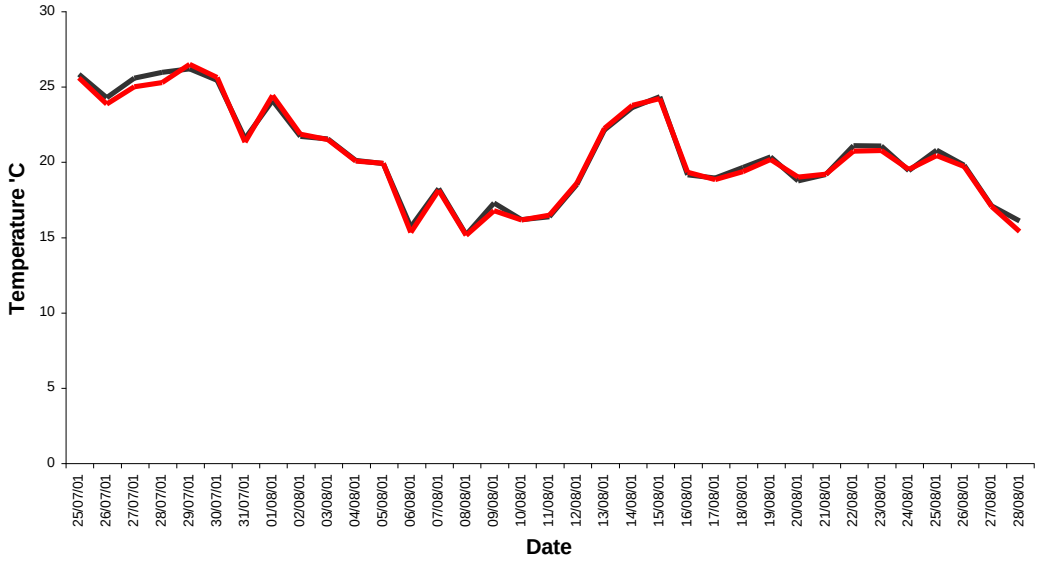


Figure 12. Crop 4 - Average daily RH in screened & unscreened glasshouses

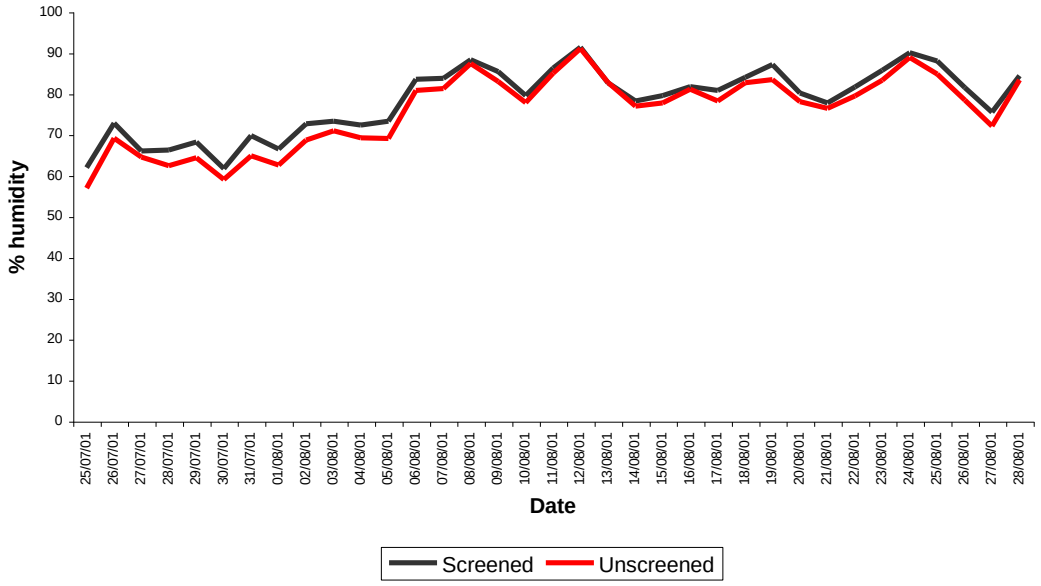


Figure 13. Crop 5 - Average daily temperature in screened & unscreened glasshouses

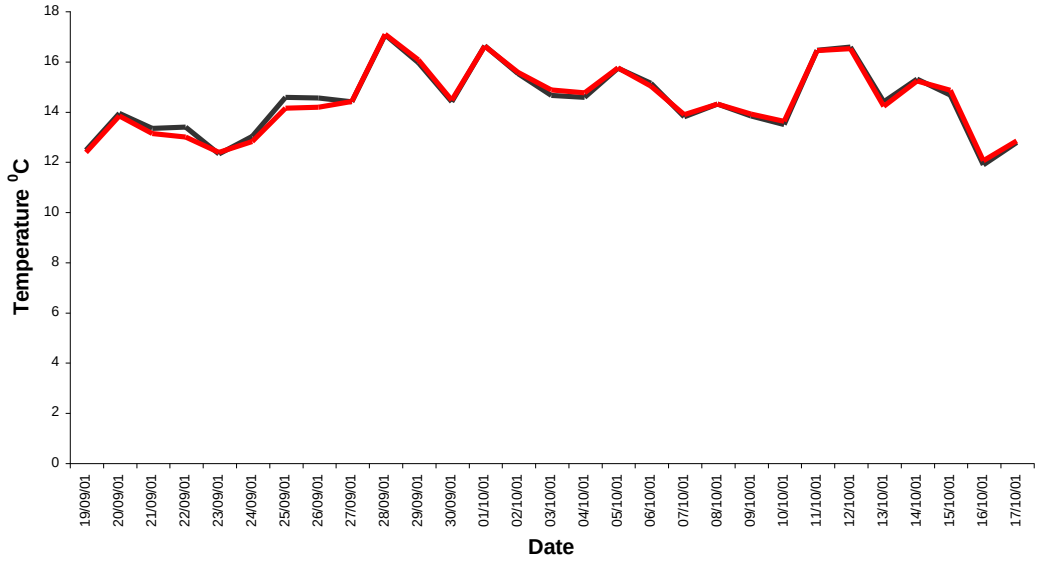


Figure 14. Crop 5 - Average daily RH in screened & unscreened glasshouses