Project title:	Tomatoes: Examination of *Macrolophus* damage to commercial crops
Project number:	PC 139
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Report:	Final Report, June 2001
Previous reports:	Annual Reports March 1998, April 1999 and March 2000
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Date commenced:	1 April 1997
Date completed:	31 March 2001
Keywords:	tomato, *Macrolophus caliginosus*, mirid bugs, plant damage.

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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PRACTICAL SECTION FOR GROWERS

Commercial benefits of the project

This project confirmed that the predatory bug, *Macrolophus caliginosus*, could damage tomato crops in the UK and identified the most important factors that contribute to such damage.

The provision of guidelines on when *Macrolophus* may be expected to feed on tomato plants, together with the recommended strategy on the management of the insect populations, will help growers to avoid financial losses associated with the direct damage caused by the predator.

By managing *Macrolophus* populations effectively, growers will benefit from the useful contribution that the predator can make to the overall tomato IPM programme. This contribution is reported to result in a general reduction in pest numbers over several years, thereby reducing the need to apply pesticides. This in turn will assist growers to achieve the TGA's long term goal of pesticide free crop production.

Background and objectives

The predatory mirid bug, *Macrolophus caliginosus,* was originally reared for control of whiteflies but has been found to attack a wide range of pest species. It has been released in UK tomato crops under Department of Environment (DETR) license since 1995 and has provided a useful contribution to the overall Integrated Pest Management (IPM) programme. However, in the latter half of the 1996 season some tomato growers became concerned that the predator was causing direct damage to their plants. In 1997, the Horticultural Development Council (HDC) commissioned a project to investigate the damage to tomato plants caused by *Macrolophus*.

The scientific objectives were:

1. To determine the mechanism by which *Macrolophus* damage tomato plants.

2. To identify the most important factors contributing to *Macrolophus* damage to tomato crops.

3. To devise a means of managing *Macrolophus* populations in tomato crops, which will optimise pest control with minimal plant damage.

Summary of results and conclusions

In the first year of the project, a survey of tomato crops, together with a series of small-scale experiments, showed that *Macrolophus* caused several types of damage, the most serious being premature flower and fruit drop. Economic losses were reported in all cherry tomato crops monitored and 20% of round tomato crops. A number of factors influenced damage, including numbers of *Macrolophus* present, type and abundance of invertebrate prey, tomato cultivar and plant quality. The most severe damage occurred to cherry tomato crops, shortly after pest outbreaks had been controlled leaving large numbers of *Macrolophus* without invertebrate prey. It was also shown that *Macrolophus* survive between crops within glasshouse blocks and can over-winter outside in southern UK. Another grower survey was completed in the third year of the project. As well as confirming many of the previous findings, this survey revealed significant fruit scarring damage towards the end of the season after the growing points of the plants had been "stopped".

In the second year of the project, experiments measured aspects of *Macrolophus* population growth and damage on a range of tomato types / cultivars in the absence of invertebrate (insect and mite) prey. The results showed that *Macrolophus* lived longer on cherry tomato cultivars than on classic round types and could breed on cherry tomato trusses but not on classic round tomato trusses. Cherry tomatoes were also more susceptible to damage caused by *Macrolophus.*

In the third year of the project, experiments determined the effect of prey type and prey availability on *Macrolophus* development and damage to tomato crops. *Macrolophus* laid twice as many eggs in the cherry tomato cultivar Favorita than in the classic round cultivar Solairo, when fed on the same numbers of leaf miners or whiteflies. On Favorita, *Macrolophus* laid seven times more eggs when fed on whitefly scales, four times more when fed on leaf miner larvae and 1.6 times more eggs when fed on spider mites than when there were no invertebrate prey. These effects were broadly consistent with crop observations and published data. In other experiments, *Macrolophus* per truss reduced the numbers of marketable fruit in cv Favorita but not cv Solairo. When leaf miners and spider mites were available as prey there was no significant overall fruit loss and it is likely that the predators fed on invertebrate prey in preference to the plant when such prey was available. On both cultivars there were two to three times as many dropped fruit on plants that were infested with leaf miners compared to other prey types, which was possibly the result of more plant probing when the predators were feeding on leaf miners.

There is no doubt that *Macrolophus* can have an important role in the tomato IPM programme by providing effective control of white flies and leaf miners, and contributing to the control of spider mites. Some growers have reported a gradual decline in pest numbers after *Macrolophus* have been present on their nurseries for several seasons. However, all these benefits must be balanced against the potential damage that may be caused after the pests have been controlled.

Studies in years 2, 3 and 4 sought effective control measures that could be used against *Macrolophus* after pest populations had declined. A review of published data indicated that a number of products could be useful, including Hostaquick (heptenophos), Nicotine 40% shreds (nicotine), Dynamec (abamectin) and Luxan Dichlorvos Aerosol 15 (dichlorvos). However, none of these were considered to provide a long-term solution due to their side effects on biological control and pollination. Furthermore, Hostaquick and Luxan Dichlorvos Aerosol 15 are no longer available to UK growers, while the possibility of a SOLA for Dynamec on cherry tomatoes is still under discussion. A number of IPM compatible options were screened as possible alternatives to broad spectrum insecticides.

Three fungal biological control options were evaluated (*Verticillium lecanii* [2 strains] and *Beauveria bassiana*) in laboratory bioassays but none were considered to provide sufficient control to be taken forward in larger-scale studies. Eradicoat, a glucose polymer that has a physical effect on invertebrates by blocking their breathing tubes, reduced numbers of *Macrolophus* nymphs by 23% at 70% RH but had no measurable effect at 90% RH. Such treatments had no effect on *Macrolophus* adults at either 70% or 90% RH.

Chess (pymetrozine), an anti-feedant chemical specific to some plant sucking relatives of *Macrolophus*, was evaluated against the predator in a series of small-scale and crop-scale experiments. Chess (40g product 100l water) reduced numbers of *Macrolophus* nymphs by up to 70% on tomato cultivars Solairo and Favorita, but had no measurable effect on numbers of adults. Increasing the rate from 40g to 80g product per 100l water, or applying the product twice, resulted in some further reductions but these were small and inconsistent. These effects on *Macrolophus* populations only resulted in very small improvements in the numbers of good fruit harvested from cv Solairo and no measurable improvement on cv Favorita. This may be because the adults are responsible for most of the damage to trusses and fruit. Chess (pymetrozine) is not currently approved for use on tomato crops in the UK. It seems unlikely to be worth pursuing a specific off-label approval (SOLA) for the use of Chess against *Macrolophus* on tomatoes unless further work shows that applications at other timings provide greater reductions in fruit damage.

In the absence of any truly IPM compatible control measures, the management of *Macrolophus* populations on tomatoes will depend on restricting the development of their invertebrate prey. It has been shown that where leaf miner and whitefly populations are kept small throughout the season, *Macrolophus* rarely reach numbers that cause plant damage. This may be achieved by releasing sufficient numbers of other natural enemies, such as *Encarsia formosa* and *Diglyphus isaea*, during the winter and spring.

Action points for growers

- *Macrolophus* cause more damage to cherry tomatoes and truss-ripened crops than to classic round tomatoes, and growers are strongly advised not to release the predators on these crops.

- On classic round tomato crops, *Macrolophus* is a valuable addition to the IPM programme for its contribution to the control of whiteflies, leaf miners and spider mites. However, populations of the predator must be carefully managed.

- *Macrolophus* can survive on a predominantly vegetarian diet but their reproductive rate is far greater when they have an abundance of insect prey. Large numbers of the predators, sometimes over 300 per plant, have been associated with infestations of whiteflies or leaf miners in mid-summer. The predators do not usually damage plants while invertebrate prey are available. Growers should therefore monitor pest populations carefully and anticipate if / when the predator's will become short of invertebrate food.

- Where leaf miner and whitefly populations are kept small throughout the season, *Macrolophus* rarely reach numbers that cause plant damage. Growers should restrict the growth of leaf miner and whitefly populations by releasing sufficient numbers of other natural enemies, such as *Encarsia formosa* and *Diglyphus isaea*, during the winter and spring.

- Although *M. caliginosus* populations grow primarily in response to pest populations, surveys suggest that the risk of damage may be reduced by releasing the predators later in the year (April rather than January), by releasing low rates (less than 0.25/m^2) and by only releasing into hot-spots' of pest activity.

- Where *M. caliginosus* have survived between crops, no further releases should be required.

- Control measures are advisable when there are many *Macrolophus* and prey are scarce, particularly in cherry tomato and truss-ripened cultivars. As a last resort, *Macrolophus* populations can be reduced during the cropping season using Nicotine 40% shreds or Dynamec but these chemicals must be used with care as they can disrupt IPM programmes and pollination by bumble bees. Please note that Dynamec (abamectin) is not currently approved for use on cherry tomatoes in the UK. A SOLA is being sought by the HDC.

- Monitoring work within this project has shown that *Macrolophus* can survive between crops in the empty glasshouse. Furthermore, live *Macrolophus* have been found on weeds (eg nettles and thistles) outside glasshouses throughout the winter in southern England. To eradicate the predator, control programmes should therefore focus on chemical control treatments at the end of the season, insecticide space treatments in the empty glasshouses and on weed control outside the glasshouses.

Anticipated practical and financial benefits

The provision of guidelines on when to expect *Macrolophus* to feed on plants, together with the strategy to manage the predator populations will help growers to:

- prevent direct damage caused by the predator.
- avoid financial losses associated with the damage (growers have lost as much as £3000 / 1000 m^2 as a direct result of the predators' feeding, with the worst damage occurring in cherry tomato and truss ripened crops).
- reduce the number of secondary problems (*ie* breakdown in biological pest control and biological pollination) resulting from the application of broad spectrum chemical pesticides against *Macrolophus*.
- benefit from the considerable contribution that *Macrolophus* can make to the control of whiteflies and leaf miners on tomato crops.
- benefit from the contribution that *Macrolophus* can make to the treatment of "hot spots" of spider mite activity.
- obtain other pest control benefits, including a reported general reduction in pest numbers after *Macrolophus* have been present on the nursery for several seasons.
- achieve the Tomato Growers' Association's long term goal of pesticide free crop production.

SCIENCE SECTION

INTRODUCTION

Background

The predatory mirid bug, *Macrolophus caliginosus,* was originally reared for control of whiteflies, but has been found to attack a wide range of pest species (Sampson & King, 1996). It has been released in UK tomatoes under DETR licence since 1995 and has provided a useful contribution to the overall IPM programme. However, in the latter half of the 1996 season some tomato growers became concerned that the predator was causing direct damage to their plants (Hayman and Jacobson, 1996). In 1997, the Horticultural Development Council (HDC) commissioned a project to investigate the damage to tomato plants caused by *M. caliginosus*. The overall objective of this project was to improve the knowledge of the mechanism and effects of *M. caliginosus* feeding on tomato plants as a first step in optimising pest control strategies based on this predatory bug.

Scientific/technical targets of the project

Year 1

- Determine commercial significance of the problem and identify gaps in the existing knowledge.
- Obtain data on damage in commercial crops.
- Examine truss damage with different populations of *M. caliginosus.*
- Monitor the survival of *M. caliginosus* within greenhouses between crops
- Monitor the survival of *M. caliginosus* outside and re-invasion.
- Prepare article for HDC News.

Year 2

- Identification and small scale evaluation of IPM compatible control measures including pymetrozine, buprofezin, abamectin, *Verticillium lecanii* and *Beauveria bassiana.*
- Determine the relative intrinsic rate of increase of *M. caliginosus* and amount of damage caused on specific cultivars of cherry, plum, beefsteak and standard round tomatoes in the absence of pests.

Year 3

- Determine the effect of prey type and prey availability on *M. caliginosus* development.
- Determine the effect of prey type and prey availability on damage caused by *M. caliginosus*.

- Evaluate two IPM compatible control measures for *M. caliginosus*; pymetrozine and a glucose polymer.
- Review tomato crop damage caused by *M. caliginosus* in selected commercial nurseries during the 1999 season.

Year 4

- Evaluate the antifeedant chemical, pymetrozine, as an IPM compatible control measure for *M. caliginosus* in tomato crops.

SUMMARY OF WORK COMPLETED IN YEARS 1, 2 AND 3.

Monitoring *M. caliginosus* populations and damage in commercial crops:

A survey of eight cherry tomato and ten classic round tomato crops in 1997 revealed several types of damage that were influenced by numbers of *M. caliginosus* on plants, size of pest infestations, type of invertebrate prey and tomato cultivar (Jacobson and Sampson, 1998; Sampson and Jacobson, 1998; Sampson and Jacobson, 1999a):

Types of damage

Macrolophus caliginosus probe leaves to feed on sap, which leads to distorted growth and down-curled terminal leaflets. This was observed in all cherry tomato crops monitored and 40% of classic round tomatoes but was not thought to affect yield. Excessive feeding on leaves destroyed vascular tissue, resulting in necrotic patches. The predators also fed on flowering trusses, which resulted in failed set and premature flower or fruit drop. This was observed in every cherry tomato crop monitored and in 20% of round tomatoes. In a separate study, *M. caliginosus* were observed and filmed feeding on tomato flowers and pedicels. The predator penetrated the anther cone of the flower with its stylets and damaged the ovary or young fruit within. It also probed the abscission point on the pedicel and on one occasion fed there continuously for over ten minutes. The damaged flowers subsequently became detached at the abscission point. Scars on the surface of maturing fruit were observed in one of the cherry tomato (cv Favorita) crops monitored and on round tomatoes (cv Criterium) in a small scale experiment. In both cases, the fruit were down-graded from class 1 to 2.

Numbers of *M. caliginosus*

All damaged crops had over 50 *M. caliginosus* per plant but this should not be considered a definitive damage threshold. There are several other factors that influence damage and the threshold will vary according to which of these occur at any time.

Pest infestations

The number of *M. caliginosus* at the peak of the population and the consequent damage were more closely related to pest numbers than to the initial number of *M. caliginosus* released in the crop. *Macrolophus caliginosus* can survive and produce offspring on a predominantly vegetarian diet but their reproductive rate is far greater when they have an abundance of insect prey (Foglar *et al.*, 1990). Large numbers of *M. caliginosus*, sometimes over 300 per plant, were associated with pest infestations in mid-summer. Damage to tomato plants usually occurred four to six weeks after *M. caliginosus* had achieved control of the pest infestation. At that time, there were still large numbers of predators but few prey.

Type of invertebrate prey

Pest type influenced damage, which was most severe after large numbers of *M. caliginosus* had developed on infestations of *Liriomyza bryoniae* (tomato leaf miner) or *Trialeurodes vaporariorum* (glasshouse whitefly). There were fewer predators and less plant damage associated with infestations of *Tetranychus urticae* (two-spotted spider mites), which was consistent with other studies (Koskula *et al.*, 1999), including some that have shown that *M. caliginosus* perform less well on *T. urticae* (Fauvel *et al.*, 1987).

Plant cultivar

Cherry tomatoes were more seriously damaged than classic round tomatoes but this may be related to the numbers of predators found in each type of crop. For example, at the end of July, the average numbers of predators were 65 per plant in cherry tomatoes and 30 per plant in round tomatoes. Several factors may have contributed to this. Pests tend to be more prolific on cherry tomatoes and these support larger populations of predators. Cherry tomato plants may also be more nutritious for *M. caliginosus* than round tomatoes. Furthermore, predators were found more commonly on trusses on cherry tomatoes than round tomatoes and the narrower pedicels of cherry tomato flowers may be more vulnerable to damage.

Time of damage

Although the first record of plant damage in 1997 was in a cherry tomato crop in early June, the majority of cases occurred towards the end of the season, after mid-August.

Economic loss

All the cherry tomato growers in the survey reported an economic loss due to *M. caliginosus* damage and in the most extreme case this was estimated to be equivalent to £3 per m^2. Growers quantified their losses in different ways; one grower lost half a truss per plant over three weeks, another lost four fruits per plant, and a third reported 17% reduction in yield over five weeks compared to a similar crop that was not infested with *M. caliginosus.* Most damage observed in classic round tomato crops was in patches that corresponded to areas of pest activity. In the worst case, the grower reported 20% fruit loss over four weeks and an additional 2% loss due to down-graded fruit. Several growers restricted the damage by applying insecticides but indicated that this disrupted IPM and resulted in secondary problems with other pests. It was impossible to quantify the predator's contribution to pest control because there were no untreated areas for comparison.

Survival between crops

Many growers who had suffered damage in 1996 decided not to release *M. caliginosus* in their crops in 1997. However, *M. caliginosus* recolonised many of the new crops and some of the worst damage in 1997 occurred where the predators had not been released since the previous season. Monitoring work within this project has shown that *M. caliginosus* can survive between crops in the empty glasshouse. Furthermore, live *M. caliginosus* adults and nymphs have been found on weeds outside glasshouses until late December in the north of England and through to April in the Isle of Wight.

Effect of tomato cultivar on *M. caliginosus* population growth and damage:

Studies in 1998 using a range of tomato types/cultivars, grown to commercial standards in experimental glasshouses, measured *M. caliginosus* performance and damage in the absence of invertebrate prey (Sampson and Jacobson, 1999b):

<u>Performance of *M. caliginosus* on different cultivars</u>

The longevity and fecundity of *M. caliginosus* was determined on the cultivars Solairo (classic round), Santa (cherry plum) and Favorita (cherry). On average, *M. caliginosus* were short-lived (10 days) in the absence of invertebrate prey, in comparison to about 85 days with prey. However, adults lived twice as long on the cherry tomato cultivar than on the round tomato cultivar, with the cherry plum cultivar intermediate. Just less than half the females produced young and there was a trend towards more offspring on cherry type cultivars. In addition, *M. caliginosus* reproduced on trusses of cherry tomato and cherry plum, but not on round tomato trusses.

<u>Damage by *M. caliginosus* to different cultivars</u>

As observed in commercial crops, cherry-type tomatoes were more sensitive to damage from *M. caliginosus* than classic round types. Six *M. caliginosus* per truss caused significant fruit loss to the cultivars Favorita, Nectar, Aranca, Santa and Red Currant but not to Espero, Solairo, Solution and Trust. When the number of *M. caliginosus* was increased to 12 per truss, damage was observed in both cherry and round tomato types. However, this should not be considered as a definitive threshold as the amount of damage may vary with the condition of the plant at the time of the assessment, as well as the amount of invertebrate prey available.

Effect of prey type and availability on *M. caliginosus* population growth and damage:

Laboratory and glasshouse scale-studies in 1999 measured *M. caliginosus* performance and damage on tomato cultivars Solairo and Favorita in the presence of various invertebrate prey types (Sampson and Jacobson, 2000a):

<u>Performance of *M. caliginosus* with different prey types</u>

Laboratory experiments showed that the tomato cultivar, as well as the availability and species of prey, affected how long *M. caliginosus* lived and how many offspring they produced. *Macrolophus caliginosus* laid twice as many eggs in the cherry tomato cultivar Favorita than in the classic cultivar Solairo, when fed on the same numbers of leaf miners or whiteflies. On Favorita, *M. caliginosus* laid seven times more eggs when fed on whitefly scales, four times more when fed on leaf miner larvae and 1.6 times more eggs when fed on spider mites than when there were no invertebrate prey. The difference between the numbers of eggs laid when fed on spider mites compared to no prey were not statistically different on excised leaves but were significantly different in an experiment using whole plants.

Damage by *M. caliginosus* with different prey types

In a crop scale experiment, 20 *M. caliginosus* per truss reduced the numbers of marketable fruit in Favorita but not Solairo. Overall fruit loss (mis-set fruit plus dropped fruit) on Favorita was only significant in the absence of invertebrate prey or when whitefly scales were available. However, in this experiment, whiteflies were applied as loose scales which fell off the leaves into the surrounding cage. Although they were still available, the predators did not move off the plant to attack them. This made the "whitefly treatment" equivalent to the "no prey treatment". When leaf miners and spider mites were available, there was no significant overall fruit loss and it is likely that the predators fed on the invertebrate prey in preference to the plant. On both cultivars, there were two to three times as many dropped fruit on plants that were infested with leaf miners compared to other prey types but this difference was only significant to the 90% confidence limit. These data are consistent with previous unpublished experiments and it is likely that the increased dropped fruit is the result of increased plant probing when the predators are feeding on leaf miners.

Control measures:

Control with chemical insecticides

Information collected from reviews of published literature and grower surveys identified several products that had the potential to reduce populations of *M. caliginosus* on tomato crops (Sampson and Jacobson, 1999b):

- Heptenophos (Hostaquick) – This has provided over 95% control of active life cycle stages. However, eggs were not affected and repeated applications were required to prevent numbers increasing again. The product has very short persistence. Although Approved at the time of the review, Hostaquick is no longer available to UK growers.
- Nicotine (Nicotine 40% Shreds) – The results against motile stages and eggs were equivalent to heptenophos and the applications required less labour. It has short persistence.
- Abamectin (Dynamec) – This product was less effective against motile stages, reducing numbers by up to 70%, but it also had some effect on eggs. It has an estimated residual effect of 18 days, although this will vary depending on environmental conditions (Jacobson *et al*, 2000). The possibility of a SOLA for cherry tomatoes is currently under discussion.
- Dichlorvos (Luxan Dichlorvos Aerosol 15) – This product has been used effectively as a clean-up treatment in the empty glasshouse between crops. It has short persistence. The product is no longer available to UK growers.

All of these products have a broad spectrum of insecticidal activity and are harmful to many of the natural enemies used against other pests in the tomato IPM programme and to the bees used for biological pollination. Heptenpohos, nicotine and dichlorvos all have short persistence and can be integrated at certain crop stages by careful timing. None of these products were considered to provide a long-term sustainable option for the management of *M. caliginosus*.

IPM compatible insecticides

Several novel and IPM compatible insecticides have been evaluated against *M. caliginosus* with varying success (Sampson and Jacobson, 1999b; Sampson and Jacobson, 2000a):

- Buprofezin (Applaud) – Some growers have reported an apparent reduction in numbers of *M. caliginosus* in tomato crops following the use of this insect growth regulator against *T. vaporariorum* (glasshouse whitefly). However, laboratory studies indicate low direct toxicity to all life cycle stages and carefully monitored field studies have shown no significant effect on the development of *M. caliginosus* populations.
- Pirimicarb (Pirimor) – Young larvae were not killed by pirmicarb in ventilated petri-dishes but 20% mortality was recorded in closed dishes; the difference was attributed to the accumulation of vapours in the closed dishes. In the field, there was no significant control of *M. caliginosus* populations.
- Fenbutatin oxide (Torq) - Low direct toxicity to larvae. In the field, applications had no significant effect on the development of *M. caliginosus* populations.
- Glucose polymer (Eradicoat) – This product kills by physical action; both by blocking insect spiracles (breathing tubes) and by desiccation. It is usually most effective against small, slow moving invertebrates. At 70% relative humidity (RH), Eradicoat treatment resulted in 23% reduction in the numbers of *M. caliginosus* nymphs but did not control adults. At 90% RH there was no control of nymphs or adults.
- Pymetrozine (Chess) – This product is an anti-feedant chemical that is specific to some plant-sucking insects. In the absence of invertebrate prey, application of pymetrozine at the rate approved for aphid control in the UK (40 g per 100 litres of water) resulted in 45% reduction in the numbers of *M. caliginosus* nymphs but no significant reduction in the numbers of adults. However, there was no significant control where abundant spider mites, whitefly scales or leaf miner larvae were available as prey. The predators probably feed on invertebrate prey when it is available in preference to tomato plants and therefore imbibe much smaller quantities of the chemical. Of all the IPM compatible chemicals investigated, pymetrozine was considered to have the greatest potential against *M. caliginosus* and it was further evaluated in year 4 of the project.

Biological control

Three species/strains of entomopathogenic fungi were screened for activity against *M. caliginosus* in laboratory bioassays (Sampson and Jacobson, 1999b). Single applications of Mycotal (*Verticillium lecanii*), Vertalec (*V. lecanii*) and Naturalis (*Beauveria bassiana*) reduced numbers of motile stages of *M. caliginosus* by 40%, 12% and 10% respectively compared to untreated controls.

USE OF PYMETROZINE AGAINST *M. CALIGINOSUS* IN TOMATO CROPS.

Experiment title:

Evaluation of pymetrozine as an IPM compatible method of reducing damage by *M. caliginosus* in tomato crops.

Background:

Pymetrozine has been identified as an IPM compatible chemical that may be used to manipulate *M. caliginosus* populations on tomato crops and reduce crop damage caused by the predators feeding on flowering and fruiting trusses. The chemical is imbibed by sucking insects and acts on the nervous system to prevent further feeding. The insects die of starvation over several days. Pymetrozine (as Chess) is not currently approved for use in the UK on tomato crops.

When used at the application rate recommended in France for control of whiteflies (ie 120g product per 100l of water), pymetrozine reduced numbers of *M. caliginosus* nymphs by up to 80% (Trottin-Caudal, pers. comm., 1999) but was less effective against adults. It is not known whether these contrasting responses were due to differences in the body weight or the feeding behaviour of the life cycle stages.

In the UK, pymetrozine (Chess) is registered for the control of aphids on cucumbers and ornamentals at the lower application rate of 40g product 100l water. Studies in the UK in 1999 showed that a single application of pymetrozine (40g/100l) reduced numbers of *M. caliginosus* nymphs by 45% but did not significantly reduce numbers of adults (Sampson and Jacobson, 2000). However, this reduction was only observed in the absence of invertebrate prey. It was hypothesised that the predators feed on invertebrate prey when available rather than the tomato plants and so imbibe much smaller quantities of the chemical.

The timing of pymetrozine applications relative to the size of the populations of insects on the crop will be critical to the success of the control measure. It is known that *M. caliginosus* damage to tomato plants usually occurs four to six weeks after the predators have achieved control of the pest infestation. It is also known that the chemical has little effect on the predator population while there is still abundant invertebrate prey. Therefore, to prevent *M. caliginosus* damage, pymetrozine must be applied shortly after the pest population has been controlled.

It may not be necessary to kill *M. caliginosus* to prevent the damage to tomato crops. For example, pymetrozine does not directly kill *Lygus rugulipennis* (European plant bug) but applications to cucumber crops prevent this pest damaging the growing points of the plants (Jacobson, 2000). The present experiment was therefore designed to measure the impact of four pymetrozine application programmes on both the numbers of *M. caliginosus* and the amount of damage caused to the tomato trusses.

Objectives:

- To determine the effect of pymetrozine sprays on crop damage caused by *M. caliginosus* and on the numbers of *M. caliginosus* adults and nymphs on a cherry tomato (cv Favorita) and classic tomato (cv Solairo) crops.
- To compare the efficacy of two application rates of pymetrozine.
- To compare the efficacy of one and two applications of pymetrozine.

Experiment manager:

Ms Clare Sampson

Materials and Methods:

Site: HRI, Stockbridge House

Glasshouses: MFU zones 1 and 2 (each 190m^2).

Treatments:

Treatment reference number	Number of applications		Rate of application		Cultivar	
	1	2	40g/100l	80g/100l	Favorita	Solairo
1						
2	✓		✓		✓	
3	✓			✓	✓	
4		✓	✓		✓	
5		✓		✓	✓	
6	✓		✓			✓
7	✓			✓		✓
8		✓	✓			✓
9		✓		✓		✓

Application: All treatments were applied high volume to maximum leaf retention using a fully calibrated Oxford Precision sprayer. The first and second sprays were applied on 15 and 31 August 2000 respectively.

Growing Conditions: The plants were grown hydroponically in rockwool slabs with excess feed solution running to waste. The plants were grown at the density of 2.7 per m^2 and were trained by the cordon-V system. The aerial environment was computer controlled with minimum day:night temperatures of 19°C:16°C and ventilators opening at 20-21°C. Temperature and relative humidity were recorded in both glasshouses throughout the experiment.

Insect Populations: The numbers of insects were manipulated until there were sufficient *M. caliginosus* to cause plant damage but with few prey remaining. *Trialeurodes vaporariorum* (glasshouse whitefly) were released at 5/m² on 26 April and 2 June 2000. *Liriomyza bryoniae* (tomato leaf miner) and *Macrosiphum euphorbiae* (potato aphid) invaded the crops naturally. *Macrolophus caliginosus* was released at 10/m² on 25 May, at 5/m² on 9 June and at 2.5/m² on 18 July 2000. In late June, the whitefly and leaf miner populations reached damaging numbers and *Diglyphus isaea* and *Encarsia formosa* were released to help suppress the populations. In addition, Applaud and Savona were applied on 3 July 2000 and 15 July 2000. By 9 August 2000 there were over 100 *M. caliginosus* per plant and very few prey. Curled leaves, consistent with the early stages of *M. caliginosus* damage, were starting to appear.

Assessments: Detailed assessments were done at weekly intervals from 14 August to 20 October 2000. On each occasion, 20 plants were selected at random from the untreated controls (Treatment 1) and 10 plants from each pymetrozine treatment (Treatments 2-9). The numbers of *M. caliginosus* adults and nymphs were recorded on each selected plant on 14, 21 and 29 August, 4, 12 and 18 September, and 2 October. In addition, the numbers of good marketable fruit, dropped fruit, mis-set fruit, scarred but marketable fruit, and scarred fruit were recorded on each truss on each selected plant on 4, 13 and 19, 25 September, and 3 and 19 October.

Experimental design: The experiment was done in two adjacent glasshouse blocks. Each glasshouse contained four alternate double rows of Favorita and Solairo, with an additional single guard row against the glass at each side. Each double row of either Solairo or Favorita constituted a single plot. To avoid movement of *M. caliginosus* between pymetrozine treated and untreated areas, all treated plots were in one glasshouse and all untreated control plots were in the other glasshouse. Within the treated glasshouse, there was one plot per treatment. Plastic partitions were erected between plots in the treated glasshouse immediately before applications of pymetrozine and these remained in place for the rest of the experiment.

Analysis of data: All data were analysed by Dr Julie Jones, HRI, Wellesbourne. There was no formal replication in this experiment. In the analysis, the 'between row' variance of the control was used as error variance for treatments, and the 'between plant within row' variance as a sampling error. All conclusions must be treated with caution. The analysis was a simple analysis of variance, with the following contrasts being used to check the effects of:

1. Control v. mean of 4 pymetrozine treatments
2. One v. two applications of pymetrozine
3. High v. low rates of pymetrozine application
4. Interaction of concentration and number of applications
5. Effect of time post treatment
6. Interaction of date and (control and mean of treatments)
7. Interaction of date and number of applications
8. Interaction of date and rate of application
9. Interaction of date, rate of application and number of applications

Results and Discussion:

Effect of pymetrozine on numbers of *M. caliginosus*

The mean numbers of *M. caliginosus* nymphs and adults on plants throughout the experimental period are shown in Figures 1 and 2 respectively. To demonstrate the overall trend, all pymetrozine Treatments (Treatments 2-9) have been combined for comparison with the untreated controls (Treatment 1). Figures 1 and 2 show a general decline in *M. caliginosus* numbers between mid-August and mid-September in all Treatments on both cv Favorita and cv Solairo. This is consistent with population patterns previously observed on commercial nurseries (Sampson and Jacobson, 1998).

The numbers of *M. caliginosus* nymphs on the plants treated with pymetrozine declined more rapidly than the numbers on the untreated controls (Figure 1). The significance of this trend is explored in the more detailed analyses reported below. There was only a small difference between numbers of adults on pymetrozine treated plants and untreated controls (Figure 2).

Statistical analyses of numbers of *M. caliginosus* recorded on both tomato cultivars over the whole experimental period are summarised in Tables 1 and 2. The data presented in Table 1 shows mean numbers of nymphs and adults on both cultivars, with and without pymetrozine treatments, following application of the chemical. Applications of pymetrozine reduced ($P<0.05$) numbers of nymphs by 65% and 70% on cvs Favorita and Solairo respectively, thus confirming the overall trends observed in Figure 1. Pymetrozine reduced ($P<0.05$) numbers of adults by 25% on cv Favorita but the reductions observed on cv Solairo were not significant. This contrasting response of nymphs and adults to pymetrozine was consistent with the results of previous smaller scale studies (Sampson and Jacobson, 2000a; Trottin-Caudal, pers. comm., 1999).

The effects of rate and number of applications of pymetrozine were further explored by the analyses shown in Table 2. On cv Favorita, the higher application rate was 35-37% more ($P<0.05$) effective than the lower application rate against both nymphs and adults. However, there appeared to be no advantage in making two applications. On cv Solairo, the only significant difference among the four combinations of pymetrozine treatments was against nymphs at the two extremes; *ie* two high rate applications were 31% more effective ($P<0.05$) than a single low rate application. There were no such differences in the effects against adults on cv Solairo.

Figure 1. The effect of pymetrozine on the mean numbers of *Macrolophus caliginosus* nymphs on tomato cultivars Solairo (S) and Favorita (F) throughout the experimental period. The arrows indicate the timing of the pymetrozine applications.

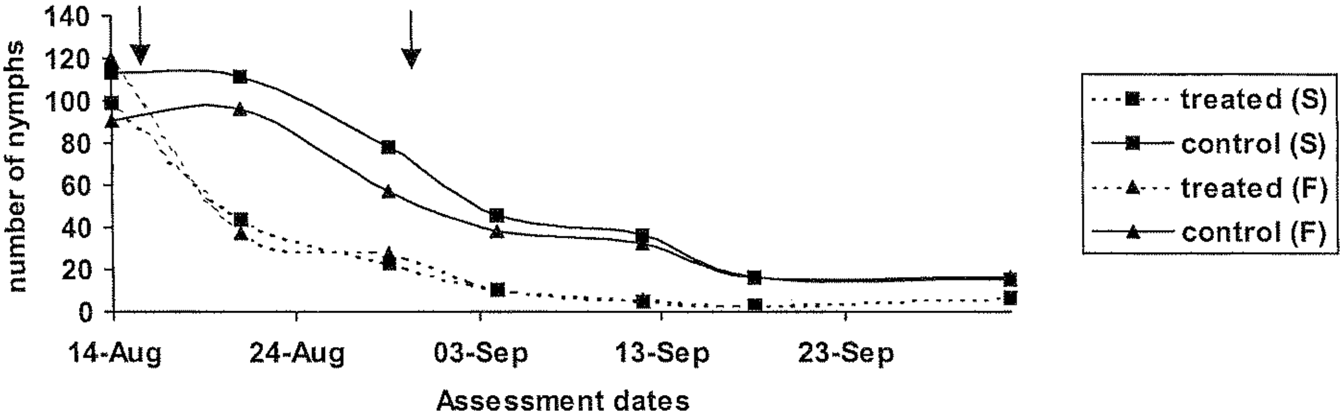

Figure 2. The effect of pymetrozine on the mean numbers of *Macrolophus caliginosus* adults on tomato cultivars Solairo (S) and Favorita (F) throughout the experimental period. The arrows indicate the timing of the pymetrozine applications.

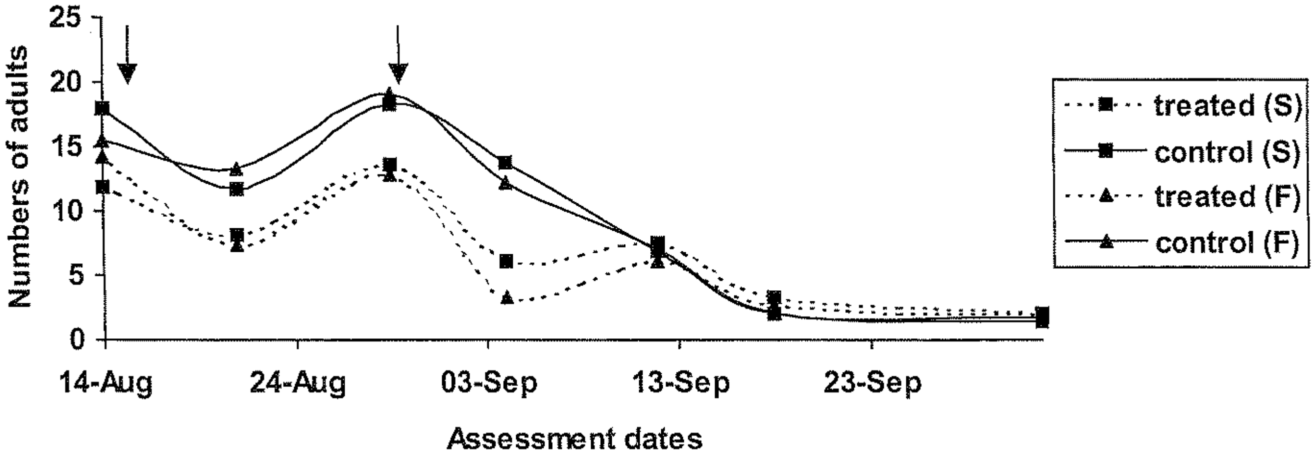

Table 1. The effect of pymetrozine on the mean numbers (square root transformed data) of *Macrolophus caliginosus* adults and nymphs on tomato cultivars Solairo and Favorita after the first applications of the chemical.

Treatment	Solairo		Favorita	
	Adults	Nymphs	Adults	Nymphs
Untreated control (Treatment 1)	9.03 (2.71)	50.42 (6.60)	9.35 (2.72)	43.11 (6.14)
Pymetrozine (Treatments 2-9)	6.75 (2.40)	15.03 (3.34)	5.70 (2.08)	15.25 (3.35)
(SED, 3df)	(0.121)	(0.158)	(0.121)	(0.153)
LSD	(0.38)	(0.50)	(0.38)	(0.49)

Table 2. The effect of single (x1) and double (x2) applications of pymetrozine at high (80g / 100l water) and low (40g / 100l water) rates on the numbers (square root transformed data) of *Macrolophus caliginosus* adults and nymphs on tomato cultivars Solairo and Favorita.

Treatment	Solairo		Favorita	
	Adults	Nymphs	Adults	Nymphs
Untreated control	9.03 (2.71)	50.42 (6.60)	9.35 (2.72)	96.15 (6.14)
Pymetrozine				
Low rate x1	8.13 (2.66)	18.90 (3.88)	6.43 (2.27)	38.40 (3.75)
Low rate x2	7.53 (2.52)	16.25 (3.46)	7.62 (2.46)	52.20 (3.90)
High rate x1	5.80 (2.25)	13.77 (3.33)	4.95 (1.98)	22.50 (3.08)
High rate x2	5.55 (2.17)	11.18 (2.69)	3.82 (1.59)	36.50 (2.67)
(SED, 3df)	(0.197)	(0.258)	(0.197)	(0.250)
LSD	(0.62)	(0.82)	(0.63)	(0.79)

Effect of pymetrozine on crop damage

There were differences in the amount of damage caused by *M. caliginosus* to the two tomato cultivars, which should be reported before considering any possible effects of the applications of pymetrozine. More ($P<0.05$) good quality marketable fruit were harvested from cv Solairo than cv Favorita (*ie* 84% and 81% respectively). There were also more ($P<0.05$) scarred but marketable fruit harvested from cv Solairo than cv Favorita (*ie* 6% and 1% respectively). Of the lost/unmarketable fruit, the largest difference was seen in the number that dropped due to weakness at the abscission point on the pedicel. Fewer ($P<0.05$) had prematurely dropped from Solairo than Favorita (*ie* 3% and 15% respectively). These differences in the susceptibility of classic round and cherry-type tomatoes to *M.caliginosus* were consistent with observations that have been made throughout this project (Sampson and Jacobson, 1998; Sampson and Jacobson, 1999b; Sampson and Jacobson, 2000a; Sampson, C. and Jacobson, R., 2000b).

The data presented in Table 3 summarises the *M. caliginosus* damage to both tomato cultivars, allowing comparison between the untreated controls (Treatment 1) and the combined pymetrozine treatments (Treatments 2-9). The damage is expressed as the numbers of good marketable fruit, dropped fruit, mis-set fruit, damaged but marketable fruit, and unmarketable fruit. A few significant effects of the applications of pymetrozine were noted but these were very small and not consistent with the recorded effects on the insect populations. For example, there were approximately 3% more ($P<0.05$) good fruit on cv Solairo plants that had been treated with the chemical than on the untreated controls, but no such significant effects for cv Favorita. More detailed analyses of the crop damage data did not reveal any further significant effects of rate or number of applications of pymetrozine.

Table 3. The effect of applications of pymetrozine on the numbers (square root transformed) of fruit in five categories of damage caused to tomato cultivars Solairo and Favorita by *Macrolophus caliginosus*.

Fruit damage catergory	Solairo			Favorita		
	Control	Pymetrozine treated	(SED, 3df)	Control	Pymetrozine treated	(SED, 3df)
Good	7.00	7.25		13.01	13.29	
	(2.63)	(2.68)	(0.007)*	(3.59)	(3.63)	(0.030)
Dropped	0.41	0.24		2.54	2.36	
	(0.33)	(0.23)	(0.037)	(1.45)	(1.36)	(0.055)
Mis-set	0.23	0.25		0.22	0.34	
	(0.19)	(0.22)	(0.041)	(0.19)	(0.29)	(0.022)#
Scarred but	0.71	0.62		0.21	0.13	
marketable	(0.47)	(0.43)	(0.045)	(0.15)	(0.11)	(0.008)#
Scarred -	0.44	0.32		0.15	0.11	
unmarketable	(0.32)	(0.26)	(0.031)	(0.12)	(0.10)	(0.044)

* Differences between the means are significant ($P<0.05$)
# Although significantly different ($P<0.05$), these small effects were the reverse of what may have been expected.

Conclusions:

Applications of pymetrozine reduced the size of *M.caliginosus* populations on tomato cultivars Solairo and Favorita, largely due to the chemical's effect on nymphs. Increasing the rate from 40g to 80g product 100l water, or applying the product twice, resulted in some further reductions but these were generally small and inconsistent. It is possible that some treatment effects may have been masked by the natural decline in the *M. caliginosus* populations between mid-August and mid-September.

This reduction in *M. caliginosus* numbers resulted in a very small improvement in the number of good fruit harvested from cv Solairo but there was no such measurable effect on cv Favorita. This could be because the greatest effect was on nymphs while adults may be responsible for most of the damage to trusses and fruit. It is also possible that pymetrozine treatments applied earlier in the season, while *M. caliginosus* populations are still growing naturally, would have a greater impact on marketable yield.

TECHNOLOGY TRANSFER

Publications

- Jacobson, R. and Sampson, C. (1998). Use of Macrolophus in tomato crops.*HDC News*. April 1998. *4-5.*
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CONCLUSIONS

Damage to tomato plants

Macrolophus caliginosus can cause damage when they feed on tomato plants. Several types of damage have been recorded in crops and confirmed in small scale experimental studies:

- **Distorted and discoloured leaves** – *Macrolophus caliginosus* feed by sucking on leaf veins and petioles resulting in distorted growth and yellowing at tips of leaflets. This has been observed in every cherry tomato crop monitored and in 40% of classic round tomato crops but is not thought to affect yield.
- **Failed set** – *Macrolophus caliginosus* feed on flowering trusses causing premature flower drop and reduced fruit set. This damage was seen in every cherry tomato crop monitored and in 20% of classic round tomato crops.
- **Scarred fruit** – *Macrolophus caliginosus* occasionally feed on developing fruit causing scarring and subsequent down grading.

Factors that influence plant damage

Macrolophus caliginosus do not always cause damage to plants, even when present in large numbers. The following factors are known to influence the amount and type of damage:

- **Numbers of *Macrolophus*** - In a crop survey, little damage was observed where there were less than 30 *M. caliginosus* per plant but this should not be considered to be a definitive threshold. More significant damage has been seen when there were more than 50 *M. caliginosus* per plant but the worst damage has occurred when large *Macrolophus* populations, sometimes over 300 per plant, have been present. The latter usually occurred in mid-summer.
- **Prey type** - *Macrolophus caliginosus* can survive and produce offspring on a predominantly vegetarian diet but their reproductive rate is far greater when they have invertebrate prey. The abundance and species of prey available influences the population growth; for example *M. caliginosus* laid more eggs when they fed on leaf miners than spider mites and still more when they fed on whiteflies.
- **Prey availability** - Damage is most likely to occur after pests have been controlled as *M. caliginosus* appear to increase plant feeding when there are no invertebrate prey available. This occurs most commonly after the predators have controlled infestations of leaf miner or whitefly.
- **Cultivar** – *Macrolophus caliginosus* cause more damage to cherry tomato cultivars than to classic round cultivars. The predators' produce twice as many eggs on cherry tomatoes than on classic round tomatoes when whitefly or leaf miner prey are available. Furthermore, they can reproduce successfully on trusses of cherry tomato cultivars but not on trusses of classic round cultivars.

Benefits of *Macrolophus caliginosus*

- **Whitefly and leaf miner control** - *Macrolophus caliginosus* can provide effective control of white flies and leaf miners on tomato crops.

- **Improved spider mite control** – Although spider mites are not the preferred prey for *M. caliginosus*, growers have reported that the predator has improved control when released in 'hot-spots' of pest activity. This has been particularly true during warm, dry periods when *Phytoseiulus persimilis* is less effective at the tops of the plants. *Macrolophus caliginosus* nymphs have been released in these situations because they are less able than adults to leave the spider mite infested plants.
- **General decline in pest numbers** - Some growers have reported a gradual decline in pest numbers after *M. caliginosus* have been present on their nurseries for several seasons.
- **Reduced "carry-over" of pests** - When *M. caliginosus* numbers have remained high at the end of the season there has often been a reduction in the numbers of pests, particularly leaf miners and whiteflies, that survive to infest the next crop.

Management of *Macrolophus caliginosus* populations

- **Can plant damage be avoided?** - Where leaf miner and whitefly populations are kept small throughout the season, *M. caliginosus* rarely reach numbers that cause plant damage. This may be achieved by releasing sufficient numbers of other natural enemies, such as *Encarsia formosa* and *Diglyphus isaea*, during the winter and spring. Although *M. caliginosus* populations grow primarily in response to pest populations, surveys suggest that the risk of damage may be reduced by releasing the predators later in the year (April rather than January), by releasing low rates (<0.25/m^2) and by only releasing into hot-spots' of pest activity. Where *M. caliginosus* have survived between crops, no further releases should be required.
- **Control of *Macrolophus caliginosus*** - Control measures are advisable when there are many *M. caliginosus* with few invertebrate prey, particularly in cherry tomato and truss-ripened cultivars. *Macrolophus caliginosus* populations can be managed during the cropping season using nicotine or abamectin but these may disrupt IPM programmes and pollination by bumble bees. Please note that Dynamec (abamectin) is not currently approved for use on cherry tomato crops in the UK. A SOLA is being sought by the HDC.
- **IPM compatible control measures** – No truly IPM compatible control measures for *M. caliginosus* have been identified. The anti-feedant chemical, pymetrozine, has been shown to reduce the size of *M. caliginosus* populations, largely through its effect on nymphs. However, the benefits in terms of reduced damage in the experimental crops, were minimal. Pymetrozine (as Chess) is not currently approved for use on tomato crops in the UK. *Verticillium lecanii* (Mycotal) reduced numbers of motile stages of *M. caliginosus* by 40% in laboratory bioassays but this product has not been evaluated on a crop scale to determine whether the effects on the insects would be translated into reduced crop damage.
- **Eradication of *Macrolophus*** - Monitoring work within this project has shown that *M. caliginosus* can survive between crops in the empty glasshouse. Furthermore, live *M. caliginosus* have been found on weeds (eg nettles and thistles) outside glasshouses throughout the winter in southern England. To eradicate the predator, control programmes should therefore focus on chemical control treatments at the end of the season, insecticide space treatments in the empty glasshouses and on weed control outside the glasshouses.

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ACKNOWLEDGEMENTS

The authors are grateful for the assistance and co-operation provided by the Tomato Growers' Association, Gerry Hayman, Derek Hargreaves, Nigel Dungey, Phil Morley, Chris Durnford, BCP Ltd, Syngenta Bioline Production Ltd and all the individual tomato growers who contributed to the surveys and practical experimentation.