Factsheet 14/10

Tomatoes

Project No. PC 240

Horticultural Development Company

Stoneleigh Park
Kenilworth
Warwickshire CV8 2TL
T: 0247 669 2051
E: hdc@hdc.org.uk

A Robust IPM Programme for Organic Tomatoes

Dr Rob Jacobson, RJC Ltd and Dr Philip Morley, Wight Salads Group

This factsheet describes the development and implementation of a robust integrated pest management (IPM) programme for the six most important pests of commercial organic tomato crops in the UK. The findings also benefit conventional growers, particularly those who are moving towards production without the use of any synthetic pesticides.

Introduction

The last decade witnessed a rapid increase in demand for food produced to an Organic standard. The term 'Organic' is defined by EU law and verified in the UK by certification bodies such as the Soil Association. In simplistic terms, 'Organic' may be defined as food production based on a healthy living soil without synthetic inputs.

Organic production (Figure 1) requires more careful planning than conventional production because there are no 'quick fixes' in the form of chemical fertilisers and synthetic pesticides. This is generally reflected in the price of the produce. For example in 2007 one major UK retailer justified the higher cost of organic products by explaining that i) production areas must go through a conversion phase, ii) organic farming practices produce lower yields and iii) are more labour intensive.

At the start of HDC Project PC 240, the Wight Salads Group (WSG) had over 10ha of glasshouses converted to organic production on the Isle of Wight alone and supplied over half of all fresh organic tomatoes sold by the major UK retailers. WSG highlighted some of the difficulties of growing large scale organic crops when they estimated that losses due to pest attack initially exceeded £100k per ha per year. Those losses were largely attributed to *Macrolophus caliginosus*, mealybugs and leafminers. Furthermore, expenditure on IPM products was double that of WSG's conventionally grown tomatoes.

Conventional tomato growers in the UK have led the world in the development and implementation of an IPM programme which includes control measures for over ten species of pests. Control of each pest is achieved through primary and secondary measures. Primary measures are usually biological and they suppress pest population growth throughout the season. Secondary measures have traditionally been target specific chemicals that are

1 Organic tomato production

2 Macrolophus adult

used to redress the balance between the pest and beneficial populations when damage approaches the economic threshold level. The importance of IPM compatible chemicals to the uptake of IPM in conventional production should not be under estimated. Their availability has provided a 'safety net' and has greatly reduced the risk of failure.

IPM in organic tomato crops has benefited from over 30 years of development in conventional crops but there are two fundamental differences. First, synthetic chemicals are not allowed to be used as second lines of defence in organic systems. This removes the safety net and increases the risk of complete failure. Second, conventional crops are grown hydroponically while organic crops are grown in the soil. The latter provides opportunities for pests that do not exist in conventional production systems. In addition, organic production focuses on speciality cultivars, many of which are very susceptible to pests. For example, the economic viability of vine ripened/vine harvested tomatoes is seriously affected by the loss of individual fruit when *Macrolophus caliginosus* (Figure 2 - front cover) feed on trusses and certain popular baby cherry, cherry and cocktail cultivars are extremely vulnerable to foliar damage by leafminers and spider mites.

Project PC 240 was designed to strengthen the weak links in the organic IPM programme. The studies were largely done within the whole organic system in commercial crops. This immediately highlighted any interactions with current agronomic practice which would have otherwise caused delays when the new technologies were transferred from the experimental to commercial environments. This approach created some challenges in terms of experimental design but they were overcome with the assistance of an experienced biometrician and were far outweighed by the benefits of having such strong industry participation.

This factsheet describes how the project developed cost-effective solutions to the most important pest problems in organic tomato crops and brought the expenditure on IPM products into line with conventional crop production. It combines those results with other aspects of best practice to suggest the most robust IPM programme currently available.

Macrolophus caliginosus

Background

Macrolophus caliginosus (Figure 2 and nymph shown in Figure 3), is a very useful predator and now plays an important role in the control of glasshouse whiteflies, leafminers, spider mites and caterpillars on tomato crops. However, *Macrolophus* also feed on the plant and until 2006 it was considered to be the most important pest of organic tomato crops in the UK. Plant damage is rarely important where the *Macrolophus* population is small or if there are adequate numbers of insect or mite prey on the plants. However, the predator can become a serious pest where large numbers are present and if there is a shortage of invertebrate prey.

The first sign of plant damage is usually a characteristic down turning of the leaf tips as shown in Figure 4. This in itself is not important but should be taken as a warning to watch for signs of activity on trusses. *Macrolophus* feeding on trusses, Figure 5, causes premature flower/fruit drop which can have large financial implications and must be stopped immediately. Towards the end of the season, after plants have been stopped and no more trusses are being formed, *Macrolophus* may feed on the surface of developing fruit causing discolouration and distortion.

Macrolophus is now established on most UK tomato nurseries and individuals survive the winter break to form breeding colonies in the new crop. However, they do not usually produce significant populations until the middle of the season. The purpose of this document is to provide guidance on how to prevent *Macrolophus* causing economic damage to the crop while retaining its beneficial characteristics.

Monitoring population growth and crop damage

Macrolophus can be found at all levels in the crop; typically 50% of the population will be in the top third of the canopy, while 30% are in the middle third and 20% in the lower third. There is a certain amount of movement to and from the tops of the plants depending on ambient conditions so sampling should always be done at the same time of day.

There should be at least 40 sample stations per hectare (say 5 in each of 8 rows). One leaf per station, positioned 4–5 down from the growing point should be beaten four times over a white tray. The combined numbers of adults and nymphs should be recorded and averaged over the whole area. This procedure should be done weekly and the results plotted so that trends in population growth can be followed over time.

It is very difficult to provide precise guidelines on when a *Macrolophus* population is likely to start causing crop damage because this depends on many factors such as the susceptibility of the cultivar and the presence of alternative food. As a general rule for the most vulnerable cultivars (ie cherry and cocktail), an average of 2–3 individuals per sample point is acceptable if there are still whiteflies, leafminers and/or

3 Macrolophus nymph

spider mites in the crop. However, if there are 2–3 individuals per sample point and few invertebrate prey, then monitoring should focus on the plant for early signs of damage.

Culling Macrolophus populations

The objective of 'culling' is to prevent economic crop damage whilst retaining control of other key pests. A culling treatment based on pyrethrins (as Pyrethrum 5EC), which are naturally occurring extracts from African chrysanthemums (*Chrysanthemum cinerarifolium*), was developed within this project and a SOLA was obtained to allow more flexibility in its application to mature organic tomato crops. Natural pyrethrins provide rapid knockdown of *Macrolophus* but have very short persistence and so do not prevent beneficial species re-colonising the treated area. Experimental work has shown that a successful cull can be achieved by the following procedures. When using a robotic pipe rail boom sprayer:

- Use a spray concentration of 1 litre of Pyrethrum 5EC per 1,000 litres water.
- Apply to the upper half of plants.
- Set to run at 80–90% maximum speed delivering about 0.8–0.9 litres of spray per metre length of row.
- Anticipate repeat sprays at 4–5 week intervals.
- The same criteria are appropriate when using a hand lance except the spray should be targeted to the top half to top two thirds of the plant canopy.

Harvesting *Macrolophus*

In some situations, it may be beneficial to collect *Macrolophus* for release elsewhere before culling the population. Consult HDC Factsheet 02/10 for details of the procedure.

Seeking help

Macrolophus is the most difficult insect to manage in tomato crops due to the complex interaction of its beneficial and damaging capabilities. Decisions related to the correct timing of culling *Macrolophus* populations are particularly difficult because so many factors have to be taken into account. If in doubt seek specialist help to interpret each situation.

4 Macrolophus damage to tomato leaves

5 Macrolophus damage to cherry tomato truss

Mealybugs

Background

Mealybugs are probably the most difficult pest to control within an IPM programme for organic tomato crops. More than twenty IPM compatible control measures or combinations of control measures that are acceptable in organic production have been evaluated in a series of HDC funded projects. Many have shown potential when tested against individual mealybugs in the laboratory but have failed at the population level when trials have been scaled up in commercial crops. Control measures based on parasitic nematodes, parasitic wasps and spray applications of Eradicoat, Savona, steam and natural pyrethrins have all proved to be inadequate. This has been due to a combination of the following factors:

- Mealybugs are covered in waxy deposits which make it difficult to wet them with sprays.
- Their cryptic habits, particularly among stem bundles after crops are layered.
- Their resilience in returning to the plants after being knocked off by sprays.
- The fecundity of survivors, which allows rapid resurgence of populations after treatment.

As there is so much difficulty in achieving remedial control during the growing season, more emphasis should be placed on minimising the numbers of mealybugs that survive between crops and successfully colonise new plants.

Crop invasion

Mealybugs survive between crops as egg sacs on greenhouse structures or in the surface layer of soil and then reinvade the crop as young nymphs (Figure 6). The most common places for new infestations to occur are around dolly posts, stanchions, pipework, dwarf walls and the edge of the concrete road. The nymphs may move straight onto the new plants or via volunteer tomato seedlings, which they use as 'refuelling stations' on their journey to the crop plants.

Experience has shown that the main emergence of mealybugs begins soon after heating is switched on. You can expect to find nymphs on new plants 2–3 weeks after they are put in the greenhouse. A second flush may be found after the plastic floor covering is split, to allow planting into the soil.

Invading mealybug nymphs mature and produce egg sacs about 9–10 weeks after heating is switched on. It is vital that all invaders are found and destroyed before this happens.

Action between crops

A propane burner should be used to clean up around pipe supports, stanchions, dollies and perimeter walls, when all debris from the previous crop has been removed. Laces/pegs should be removed from the main irrigation lines and dipped in nitric acid (pH 2 or less). Main lines should be washed with a pressure washer and sprayed over with Thripstick 2, when in their final positions.

Preparation for new crop

Cover the soil with black-backed plastic to prevent growth of volunteer tomato seedlings ensuring that the overlaps between plastic sheets are at least 200 mm and off-set to one side of the beds. The joints in the plastic sheets should be glued by painting with Thripstick 2 (see Figure 7).

Plastic sheeting should be formed up and around dolly posts and dwarf walls. It is best to apply Thripstick 2 to the concrete surfaces beneath the plastic in these positions. Care should be taken to obtain a good fit where pipes pass through the plastic.

Thripstick 2 should be diluted with water (2 parts product: 1 part water) and applied in a band of at least 300 mm down the centre of the bed. Ideally, the band should extend over the joint in the plastic. In addition, Thripstick 2 should be applied over the plastic covering dwarf walls and dolly posts, to pipes, stanchions etc, and at the edge of the concrete roadways.

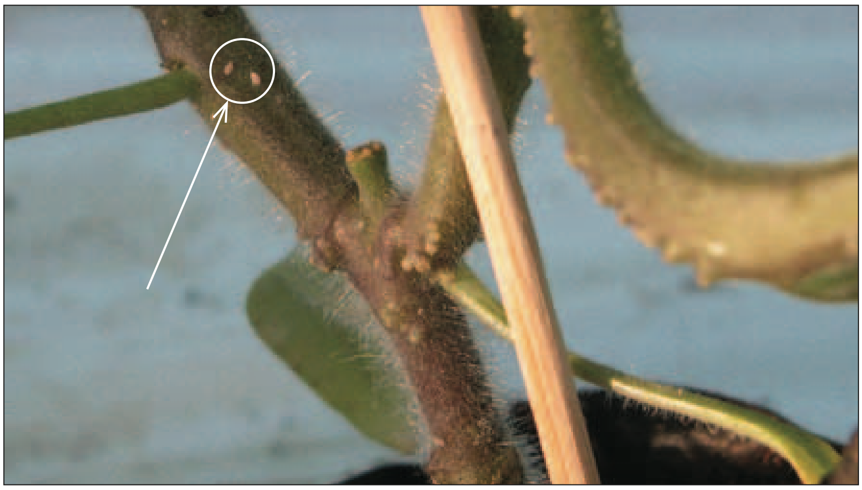
Finally, paint Thripstick 2 up the metal posts to a height of at least 1 m and around points where other metalwork (eg pipe hangers) are attached as all these places provide harbourage for mealybug egg sacs.

After the new plants are stood out

It is vital to avoid any untreated bridge which could allow mealybug nymphs to bypass the sticky barriers. For example:

- When the crop stem supports are put into position, paint the upright sections with Thripstick 2 to stop nymphs using them as a route from beneath the plastic to the foliage.
- Cut off excess strings to avoid them trailing onto untreated plastic.
- When the time comes to plant through the plastic, keep the holes as small as possible (see Figure 8).

Plants should be inspected weekly and any mealybugs squashed immediately. It is vital that crop



6 Young mealybug nymphs having recently arrived on a tomato stem

7 Correct fitting of plastic sheeting over beds

Note off-set position of joint between plastic sheets. This joint has been sealed with Thripstick 2.

workers are properly trained to recognise the pest and they must fully understand the importance of this task. Lower leaves must be removed as soon as possible so that stems can be thoroughly inspected.

Warning – Thripstick 2 is phytotoxic. Avoid direct contact with plants and do not allow stems to droop onto treated plastic. Never spray directly onto plants.

Throughout cropping

Continue to inspect stems at weekly intervals for presence of mealybugs and squash any that are seen. The period leading up to the first mealybug eggs being produced (ie usually 9–10 weeks after the heating is put on) is particularly important. The ultimate objective should be to eliminate mealybugs on plants before the crop is layered because it then becomes increasingly difficult to effect control by any means.

8 Method of planting through plastic which has proved to be very successful

Woodlice

Background

Woodlice live in the surface layers of soil/compost below organic crops. The two most common species found in tomato crops are *Porcellio scaber* and *Armadillidium nasatum* (Figure 9), the latter being the 'pill bug' which rolls into a ball when disturbed. Populations can become extremely large. Woodlice climb plants after dark to graze on stems and leaves. This can seriously damage plant stems and depletes foliage on young plants in the early weeks of the season. In mature crops, they may penetrate stems at weak points (such as deleafing scars) creating entry points for other secondary pathogens.

Several prophylactic methods of controlling woodlice were evaluated in Project PC 240. Chitin compost additives, a silicon-based desiccant dust, three species of parasitic nematodes (*Steinernema feltiae*, *S. carpocapsae*, *Heterorhabditis megidis*) and the predatory beetles, *Atheta* spp., all showed some potential in small-scale experiments but failed to provide adequate protection for commercial crops In addition, a spin off project investigated soil fauna in organic glasshouses paying particular attention to possible natural enemies of woodlice. While this provided valuable information, particularly on *Dysdera* spp. spiders, there were no immediate leads towards effective control measures.

Small scale experiments in 2007 explored the potential of ferric phosphate slug pellets (Ferramol) to protect young plants from woodlice (Figure 10 - overleaf). The pellets are based on wheat flour which acts as an attractant. Once eaten ferric phosphate destroys the slug's mouth parts and the gut lining. Feeding stops immediately. The effect is irreversible causing death within three to six days. Its mode of action against woodlice is unknown but it is presumed to be similar. Large scale trials in 2008 demonstrated this to be an effective control measure. The technique has now been adopted by commercial growers.

9 *Armadillium nasatum* inside a tomato stem creating an infection site for secondary disease organisms

Protecting young plants from woodlice

The physical control measures described to prevent young mealybugs from attacking plants at the start of the season should also prevent damage by woodlice. However, woodlice populations will grow beneath the plastic soil covering and may emerge to cause problems later in the season.

Ferric phosphate slug pellets (Ferramol) have proved effective when scattered around the base of the plants. Leaf grazing has been significantly reduced with rates of 1 g per plant with a small improvement where rates were increased to 2.5 g per plant.

Reducing populations in mature crops

There are no proven control measures that can be guaranteed to prevent crop damage during the summer. However, the following may help to reduce the size of woodlice populations in a mature crop:

- Ferramol slug pellets scattered in breeding sites.
- Simple cardboard traps placed on the soil surface act as a refuge for woodlice and very large numbers will congregate beneath them. They can then be scooped up for disposal outside the glasshouse.
- Alternatively, traps can be baited with Ferramol slug pellets so that the woodlice die in situ.

Natural control

An ecological survey of organic glasshouses on the Isle of Wight revealed the presence of *Dysdera* spp. spiders which are known to predate on woodlice. These spiders are difficult to study because after feeding they spin a silk retreat from which they may not emerge for several weeks. The life cycle of *Dysdera* spp. takes over eighteen months to complete and for part of this time the female is sealed with her eggs within a thick cocoon (Figure 11). It is possible that population growth is disrupted through soil cultivation during this eighteen month period. The conclusion is that *Dysdera* spp. probably coexist with woodlice populations rather than effect control.

10 Ferramol pellets used to protect young plants

11 Female Dysdera spider within her silken retreat

Leafminers

Background

The parasitic wasp, *Diglyphus isaea*, has become the primary biocontrol agent for tomato leafminer in UK tomato crops. It achieves control of leafminers in three distinct phases:

- Phase 1: Establishment – When parasitoids are released to obtain a ‘strike’.
- Phase 2: Population growth - A large *Diglyphus* population is allowed to develop in the crop. The leafminer population will continue to grow during this phase.
- Phase 3: Control - Leafminer numbers crash.

The key to success is correct timing of release of the parasite in phase 1. This is based on detailed crop monitoring, which must be done by properly trained staff with a clear understanding of the importance of this task. The amount of damage suffered during phase 2 will vary according to the cultivar and the time of the year. Additional control measures may be required to support *Diglyphus* in the most susceptible cultivars.

Adult leafminer activity will continue in the head of the plant resulting in numerous feeding marks, for a time after phase 3. However, new mines should be stopped by *Diglyphus* while they are still quite small. Additional control measures may be required to stop adult feeding damage in the most susceptible cultivars. After controlling leafminer populations, large numbers of *Diglyphus* can be collected from the crop for use elsewhere (refer to HDC Factsheet 02/10).

Susceptible cultivars

The following cultivars are examples of those particularly susceptible to leafminer damage:

- Cherry: Claree, Conchita, Jenita, Nectar
- Baby cherry: Piccolo, Ferrarino
- Cocktail: Capri, Campari, Caran, Aranca
- Novelty: Green Tiger

Crop monitoring

At the start of the season, flushes of leafminer activity may be anticipated at about five week intervals. Once the first flush occurs, it should be possible to estimate the timing of the second, which is likely to be the correct time to start releasing *Diglyphus.*

The following monitoring procedure has been developed and refined with a statistician over several years:

- At the start of the season, select appropriate unit areas of about 1,000m². Each unit will be influenced by the size of glasshouse, cultivars being grown and the early development of hot spots of leafminer activity.
- Walk 6 rows per 1,000m² on a weekly basis. Count the number of active mines (ie not pupated) per row. Do not remove the mines. Mark those counted with a felt-tip pen so that the rate of increase in the population can be monitored.
- When the first 'threshold level' is reached (40 mines per row), change to monitoring plots (6 plots of 5 plants per 1,000m²). When the level approaches the following threshold level, release *Diglyphus*: December and January: 1 mine per plant. February: 1 mine per 2 plants. March: 1 mine per 5 plants.
- If a small area becomes a 'hot spot', treat it as an independent unit, releasing *Diglyphus* on a pro-rata basis.

Release of Diglyphus

The release of *Diglyphus* must coincide with the presence of active mines in the leaves or a whole generation of leafminers will be missed. At each early season flush of leafminer activity, there will be a short window of about 8 days when leafminer larvae are active within the mines. This must be detected as early as possible so that there is time to order and release *Diglyphus* at the correct rate per m² within that window of opportunity. If done correctly, this should give a good strike.

Confirmation of Diglyphus population growth

Monitoring procedures change during phase 2 because it is now important to ensure that *Diglyphus* has established and its population is growing. At key times, collect 50 leaflets containing partially developed mines. Examine under magnification and record numbers of mines, active leafminer larvae, dead leafminer larvae and immature *Diglyphus* (Figures 12 and 13). Seek specialist help if the *Diglyphus* population is not growing.

Additional biocontrols

The use of *Macrolophus* in addition to *Diglyphus* has proved to be beneficial in the most susceptible cultivars and has significantly reduced the amount of adult leafminer damage occurring

12 The immature *Diglyphus* latches onto the miner and feeds on it until it is ready to become an adult

13 The immature *Diglyphus* (marked with dash arrow) has moved away from the dead leafminer larva (marked with solid arrow) and is pupating. A closer look through the leaf shows the *Diglyphus* pupae to be turquoise and usually surrounded by distinct pit props, which it creates to stop the mine collapsing

beyond phase 3. *Macrolophus* population growth is slow in the early season and it has proved necessary to supplement the inherent population with purchased material. Nonetheless, releases in weeks 1 and 8 have taken 17 and 12 weeks respectively to reach significant levels. The optimum rate of release of *Macrolophus* is considered to be in the range of 1–2 per m². They should be released as soon as the plants arrive on the nursery.

Reducing damage in the heads of the plant

Adult leafminers move up the plant to feed and lay eggs in the new growth. This can lead to excessive damage in the most susceptible cultivars even after phase 3 has been achieved. The majority of *Diglyphus* are active in the middle and lower strata of the crop, so a well timed spray with a short persistence product (eg Eradicoat or Pyrethrum 5EC) to the heads of the plants can reduce numbers of adult leafminers with minimal impact on parasitoids. Such treatments should not be used repeatedly as this can affect pollination.

Spider Mites

Background

The success of spider mite control strategies depends on careful attention to detail when monitoring crops to detect initial invasion and a follow up of the control measures to check on its effectiveness.

Control of spider mites in organic tomato crops has traditionally been based on the predatory mite, *Phytoseiulus persimilis*, and two 'soft' chemical products, Savona and Eradicoat. The predator provides season long control of the spider mites while the soft chemicals provide a second line of defence that redresses the balance between pest and predator when the damage threatens to become unacceptable. Although the bulk of this document focuses on that strategy, other measures are currently under evaluation. These include other predatory mites, a predatory bug and a fungal pathogen. For example:

- HDC Project PC 240 showed that where *Macrolophus* was released at the start of the season to help combat leafminers on the very susceptible cultivars, it also provided benefits with the mid-season control of spider mites. Further details of release rates are given in the leafminer section of this document.

- HDC Project PC 163 showed that the fungal pathogen, *Beauveria bassiana* (Naturalis L), had potential as an alternative second line of defence against spider mites. This product has recently been approved in the UK and will be evaluated in commercial crop scale trials during 2010 (HDC Project PC 299).

The overall spider mite control strategy will be revised as soon as new procedures are considered to be sufficiently robust to adopt in commercial crop production.

Action early season

Early detection of the pest is critical (see Figure 14). All crop workers must be trained to recognise the early stages of spider mite infestation and they must understand the importance of this task. If an infestation is detected pre-planting (ie at the propagators or upon delivery), plants should be removed from the batch and destroyed.

Where infestations are found after plants have become established in the soil, the worst affected leaves should be removed and the position in the glasshouse clearly marked for further action. Eradicoat should then be applied to the remaining parts of those plants and to adjacent plants. *Phytoseiulus* must be released onto the same plants as soon as possible after the spray has dried aiming at a ratio of approximately 1 predator to 10 spider mites. Continue to monitor the affected area and apply successive introductions of *Phytoseiulus* until a good breeding population of the predator is established. As a general rule, the presence of *Phytoseiulus* eggs is a good indication that this has occurred.

Action mid-season

Small spider mite infestations should be dealt with as described above during the mid-season. It is critical to establish a good breeding population of *Phytoseiulus* as soon as possible. However, spider mite populations will grow more rapidly than in the early season and so it will probably become necessary to follow up the releases of *Phytoseiulus* with spot sprays of Eradicoat or Savona.

14 Spider mites feed on the undersides of leaves and the first sign of attack is a fine speckling which shows through to the upper surface

Hot and dry weather favours the spider mites, making it highly likely for them to breed more rapidly than their predators, particularly in the heads of plants. Under such circumstances, the distribution of spider mites within hotspots of activity should be determined. If spider mites are predominantly on the upper leaves, the top 50 cm of the plants must be sprayed with Eradicoat or Savona without delay. If the pests are more evenly distributed down the plants, then the whole plant should be sprayed within each hotspot of pest activity.

Spider mites can rapidly spread throughout the crop during the summer months. If the number of uncontrolled outbreaks reaches the equivalent of 50 per ha, then it is advisable to change from focusing on individual hotspots to treatment of the whole crop. The procedure is the same as when dealing with hotspots; ie first determine the distribution of spider mites on the plants and, depending on findings, spray either the top 50 cm or the whole plant.

Hyper-necrosis

Regardless of the time of year, spot spray with Eradicoat or Savona immediately if hyper-necrotic symptoms are seen (Figure 15). If numerous outbreaks of hyper-necrosis occur (ie equivalent of over 25 outbreaks per ha) the whole crop should be treated with Eradicoat or Savona.

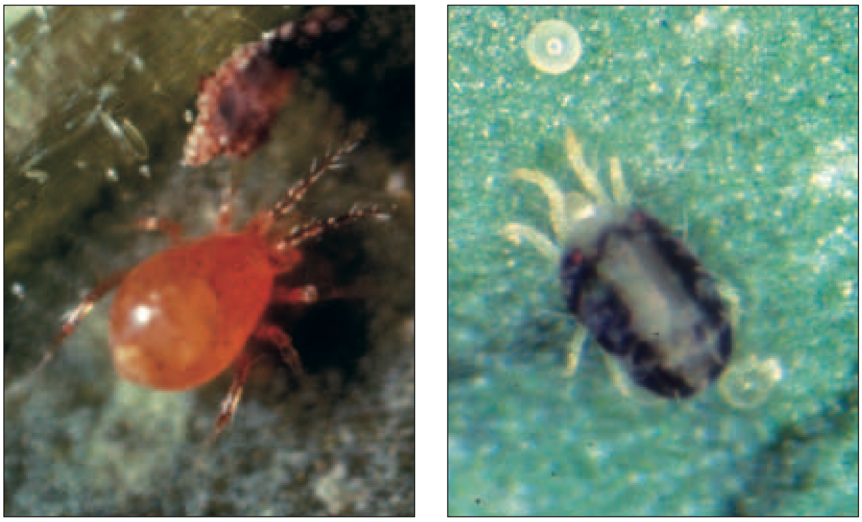
Harvesting Phytoseiulus

After the spider mite population has been controlled by *Phytoseiulus* (Figures 16a and 16b), it is important to collect the predators for use elsewhere. Consult HDC Factsheet 02/10 for details of the procedure.

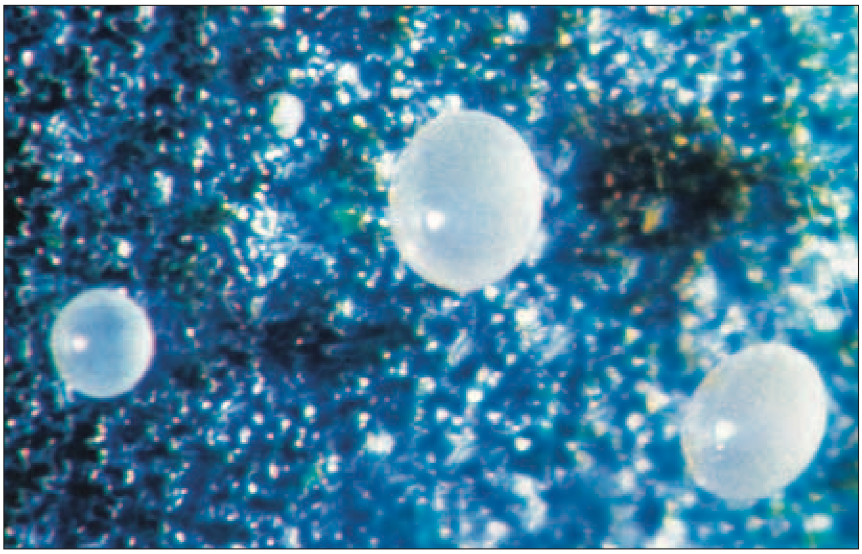
End of season clean-up

Where significant numbers of spider mites are present in mid-late August, two 'clean-up' sprays of Eradicoat or Savona should be applied with a 7–10 day interval to reduce over-wintering within the glasshouse structure. Regardless of the size of the spider mite infestation at the end of the season, the glasshouse should be thoroughly cleaned and all crop debris removed and destroyed.

15 Sometimes damage symptoms are much more severe with leaf yellowing occurring at small spider mite population densities. This may be rapidly followed by death of whole leaves, which has been called 'hyper-necrosis'



16a *Phytoseiulus persimilis* (left) and adult two-spotted spider mite (right)



16b image depicting opaque, round two-spotted spider mite egg (left) and slightly larger, oval *Phytoseiulus persimilis* eggs (right)

Glasshouse Whiteflies

Background

Control of whiteflies, shown in Figure 17, has traditionally been based on the parasitic wasp, *Encarsia formosa* (Figures 18 and 19), supported by careful use of 'soft' chemicals (eg Eradicoat and Savona) when conditions allow the pest population growth to outstrip the natural enemy. Thorough monitoring of whitefly numbers and *Encarsia* establishment are critical to the success of the system. It is therefore vital that all staff are trained to recognise the important life cycle stages of both species. The two most common reasons for failure of this biological system are:

- The use of a pesticide against another pest which harms *Encarsia.*
- Removing leaves before the wasps have emerged from parasitised scales.

Macrolophus is a known predator of whiteflies. It should not be necessary to release this predator specifically for whitefly control but where it occurs naturally, or has been released at the start of the season to help combat leafminers, it will also help to control whiteflies mid-to late season.

Action between crops

Whiteflies survive between tomato crops on live plant material (including many species of weeds) and it is important that all such material is removed from the empty glasshouse. Strimming of weeds on land immediately outside the glasshouses will also help to reduce the carry-over of adult whiteflies from one crop to another.

Action in the new crop

Encarsia should be released at the rate of 0.5 per m² (5,000 per hectare) every week from plant arrival. Numbers of adult whiteflies should be recorded weekly on 25 yellow sticky traps per ha until the crops reach the support wire. The traps should be moved upwards as the plants grow so that they are always at least 0.5 m above the canopy. When whiteflies are found, the rate should be doubled to 1.0 *Encarsia* per m² per week.

Action in mature crop

Once the crop reaches the support wire, monitoring will depend on crop workers recording numbers of adult whiteflies on plant heads as they work the crop. Continue to release *Encarsia* weekly until September unless *Macrolophus* becomes well established. If that happens, consult a specialist to help assess the overall pest situation to determine whether *Encarsia* releases can be terminated.

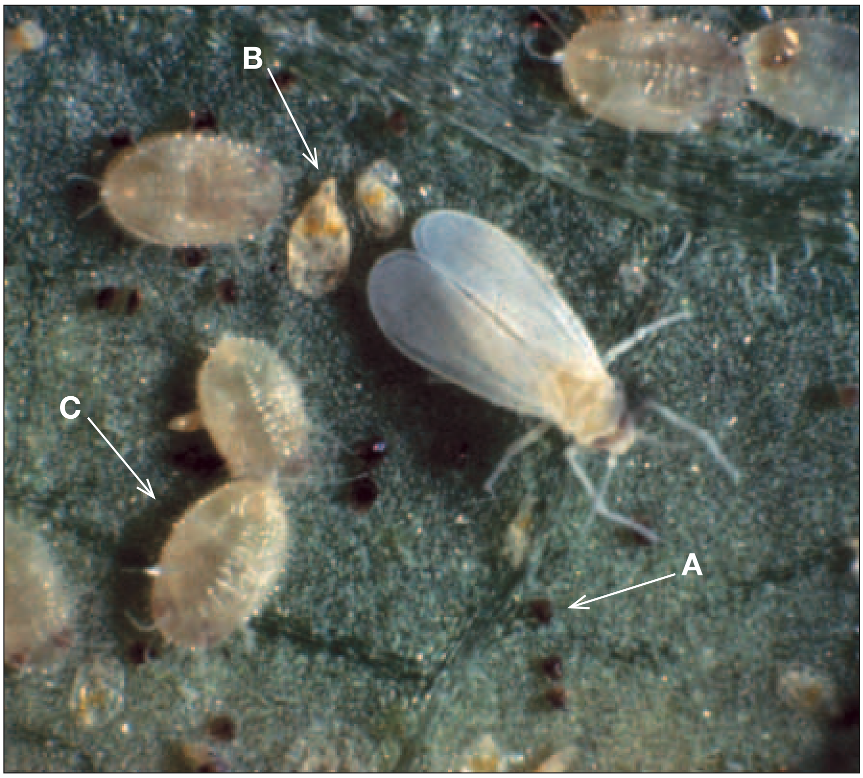
It is important to control the amount of leaf removed from the bottom of the plant each week leaving at least 19 leaves on each plant. Once whiteflies have been found, the number of required leaves can be determined more precisely by checking the level at which black scales are forming and adult wasps are emerging. This is particularly important with all cherry and cocktail varieties. In addition to leaf removal from the bottom of the plant, it is now fairly common practice to thin out younger leaves (ie one of the three between each truss) to control vigour. Although we have no evidence to suggest that this impairs the control of whiteflies with parasitoids, we suggest that growers who practice leaf thinning monitor the establishment of *Encarsia* very carefully.

If the whitefly population reaches an average of 5 adults per head:

- Produce a plan showing the affected area(s).
- Apply Eradicoat or Savona to the top 50 cm of plants in each affected area to reduce the numbers of adults and egg laying. This should be repeated as often as necessary.
- Increase the *Encarsia* release rate in that area to at least 2 per m² per week for 4 weeks.

If whitefly numbers continue to increase despite the above measures:

- Apply Eradicoat or Savona to the top 50 cm of plants throughout the whole crop.
- After treatment, increase the *Encarsia* release rate to 4 per m² per week for 4 weeks.

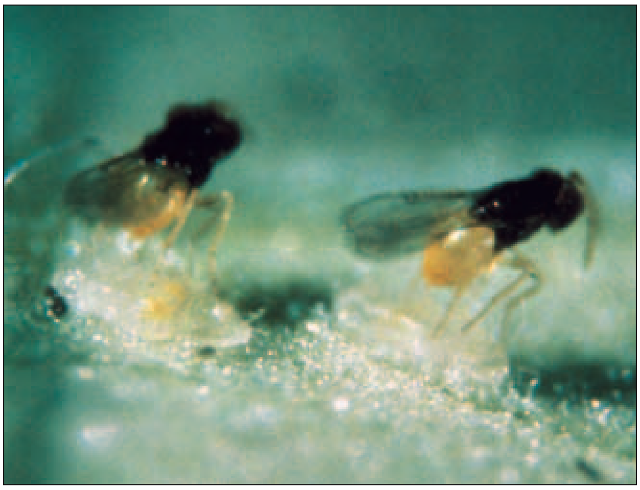


17 Adult whitefly with: A - hatched eggs, B - young scales, C - scales

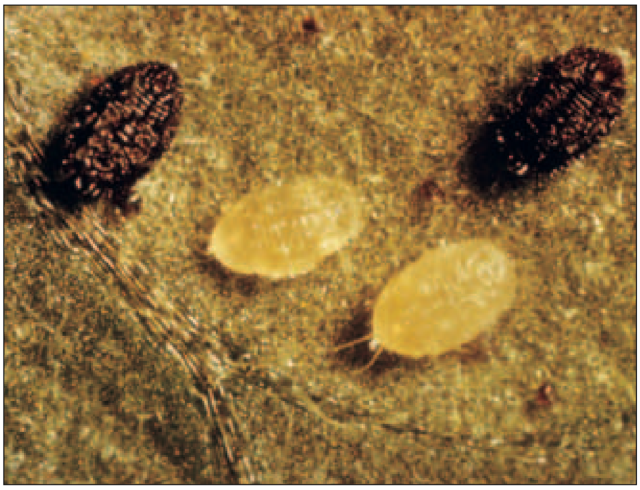
Impact of sulphur

Many IPM practitioners believe that the use of elemental sulphur against mildew impairs the performance of *Encarsia* which can lead to a breakdown in the control of the pest. The HDC funded project PC 275 did not provide consistent evidence to prove that this is the case.

Nonetheless, it is not unusual for growers to routinely increase the rate of release of *Encarsia* for 2–4 weeks following an application of sulphur.



18 Adult Encarsia laying eggs into whitefly scales



19 Two whitefly scales parasitised by Encarsia (black)

Financial benefits to organic tomato production:

- Project PC 240 developed cost-effective solutions to the most important pest problems in organic tomato production.
- Effective measures to control *Macrolophus* and mealybugs were successfully implemented in commercial crops during the first two years of the project and the immediate financial benefit in terms of reduced crop loss exceeded £0.6 million per annum. This will be sustained and increased each year as the technologies become more widely implemented.
- *Macrolophus* can now be employed as an effective biocontrol agent against whiteflies, spider mites and leafminers in the knowledge that populations can be culled before crop damage occurs. This has led to a fundamental change in the IPM strategy for organic tomato crops.
- Fine tuning leafminer strategies provided a 56% reduction in purchased products in the first year of implementation.
- The biocontrol recycling techniques yielded vast numbers of prime quality natural enemies, at very low cost, for redistribution elsewhere on site.
- The benefits of the new control measures against *Macrolophus* and mealybugs, combined with fine tuning biocontrol release strategies and the novel methods of harvesting/redistributing biocontrols, reduced expenditure on IPM products in organic tomato crops by over 50%. This brought the costs in line with conventional tomato production.
- These developments made a major contribution to the economic viability of organic tomato production in the UK and helped British suppliers satisfy the increasing demand from retailers for top quality organic products.
- The results are also having knock-on benefits for conventional tomato production.

Acknowledgements

The authors are grateful to colleagues at Wight Salad Group for their participation in trials, Dr John Fenlon for statistical guidance and Sophie Stewart for her work on *Dysdera* spiders.

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Additional information:

June 2010

Design and production: HDR Visual Communication