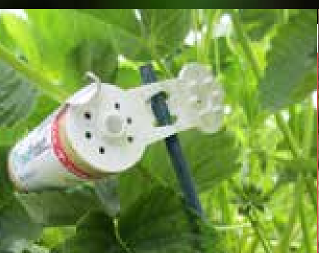
A grower guide

Soft Fruit

Biocontrol in soft fruit

Written by Robert Irving and Jude Bennison (ADAS)
and Roger Umpelby (Fruit entomologist)





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Introduction

This guide is written to provide soft fruit growers with an easy reference to get the most out of their biocontrol use within an Integrated Crop Management System. It provides information on the biology of pests and their biocontrol agents to help maximise the success of biocontrol.

Biocontrol has become a commercial reality on many farms and great success has been achieved from a range of biocontrol agents. Their use typically increases on the farm each year once the advantages are seen. In some cases biocontrol is now the preferred option, e.g. nematodes for vine weevil control, especially in substrates, or *Phytoseiulus persimilis* for larger canopy raspberry crops where spray coverage is difficult.

There are various biocontrol options; this guide concentrates on the major pests and their control. These are proven successes. It includes information for improving the overall strategy and also specific biocontrol agent activity on a crop and pest basis. There is additional information on biocontrols that are less widely used at present and suggestions for further reading.

This wealth of agents for both existing and new uses, and an emerging range of new agents in development, offer greater opportunities for the future.

Biocontrol is not a cheap or easy option; it is used because it gives the best results in specific cases. For most effective results, a careful and committed combination of crop hygiene, integration with pesticides and crop inspection is needed.

To date, greatest results have been achieved with everbearer strawberries (Figure 1) and primocane raspberries.

1. **Some of the best results have been achieved by introducing predators to everbearer strawberries**

It should also be noted that many HDC funded and other scientific projects aim to develop novel control techniques for pests and diseases, to reduce the reliance upon conventional crop protection products. However, it is unlikely that the industry will be able to rely completely on biocontrol measures in the near future. The guide therefore provides information on how to integrate biological control with conventional pesticides to form integrated pest management (IPM) programmes.

Making use of this guide

This is a comprehensive guide and as such does not need to be read from cover to cover all at once. It is divided into six sections which can be read individually. The sections are:

Commercial production of biocontrol agents - Many are not fully aware of the processes involved in producing biocontrol agents in a form that is ready for introduction or application to a crop. This section provides background information which will help to explain how and why the predators are delivered in the way they are.

Most reliable performers in soft fruit - There are a wide range of biocontrol agents available, but not all have been proven to be useful in soft fruit crops. This section lists those agents which have had greatest success and can be relied upon in soft fruit production.

Biocontrol agents still to be proven for widespread use in soft fruit - This section explains why some agents are still not widely used in soft fruit and explains the regulations behind their approvals.

Strategies for biological control - This section provides detailed information on the correct principles and practices to follow if biological control is to be a success. It guides growers on how best to manage biocontrol agents and how to make them work successfully.

Major predators for pest control - The largest section of the guide, this provides in-depth information on how to use predators to control some of the key pests in soft fruit crops including two-spotted spider mite, western flower thrips, tarsonemid mite, vine weevil, aphids, whitefly and caterpillars.

Native predators for pest control - This section offers in-depth guidance on the vast array of naturally occurring predatory and parasitic invertebrates found on soft fruit farms and how best to manage the farm to enhance their numbers for biocontrol purposes.

Some useful supplementary information is also included in the appendices at the back of the guide including guideline application rates for the commonly used predators, lists of biocontrol agents which are still to be proven on soft fruit crops and information on the harmful effects posed by approved insecticides to the commonly used predators in soft fruit crops.

This guide provides practical knowledge and information; it does not offer advice or direct recommendations. Growers should always consult a BASIS-qualified advisor with good knowledge and experience of Integrated Pest Management (IPM) before taking decisions on use of biocontrol agents in conjunction with pesticides.

Commercial production of biocontrol agents

The majority of agents used are insects, mites and nematodes. These are all living organisms that must be healthy and active when used in a crop. There are a few bacterial and fungal formulations, such as *Bacillus subtilis* (Serenade), *Bacillus thuringiensis* (DiPel DF) and *Metarhizium anisopliae* (Met52). Before using biocontrol agents, it helps to have an understanding of how they are produced.

Unlike chemical crop protection products that are produced in large batches at agrochemical factories and can be back stored for months at a time, insects, mites and nematodes are living creatures and must be reared or produced in response to anticipated demand. They must then be sold and distributed to farms immediately (Figure 2). As predatory mites and insects prey on invertebrates in crops, they cannot be stored for long as they may die of hunger and some have cannibalistic tendencies.

Bacterial, fungal and nematode products have a longer shelf life than predators and parasitoids. Some need to be stored in a fridge and their 'use by' date will be clearly marked on the pack.

Large volumes of predators cannot be reared overnight in response to demand from lots of growers. The process takes time and can be associated with separate production of a living food supply, for example *Phytoseiulus persimilis*, the predatory mite for control of two-spotted spider mites. For *Phytoseiulus,* two-spotted spider mites and their host plants must be reared, usually under protection, where the pests and predators can be contained. The two-spotted spider mite population must reach a suitable level to allow the predator to have sufficient pest numbers to feed on and increase to a population large enough to allow the predator to be harvested in high numbers for packaging into the chosen delivery container.

Other predators such as *Neoseiulus cucumeris* (formerly *Amblyseius cucumeris*) are reared in bran formulations with another species of mite as a food supply, so don't require a glasshouse crop for production.

Make sure to order at least a week ahead of introduction. Pest levels should be estimated at that point rather than using the lower levels found at the time of inspection. Having an eye on the weather forecast for the intervening week will help.

It is not always possible for growers to order some biocontrol agents and take delivery of the required number exactly when they need them. If possible, it is best to plan the biocontrol programme and order well in advance.

2. Biocontrol agents must be sold and distributed immediately after being packaged

Most reliable performers in soft fruit

Biocontrol uses a diverse range of living organisms (referred to as 'agents' in this guide). They are mostly insects, mites and nematodes, although some mention is made of fungi and bacteria. They are mostly used to control invertebrate pests in crops.

There is a wide range of agents to choose from, but they all need fairly precise requirements for success. Those agents currently relied upon most heavily in soft fruit have been extensively used for decades in other crops such as glasshouse-grown cucumber, tomato, sweet pepper and ornamentals. They are well understood and are known to work well in field scale soft fruit production. In most cases the biocontrol agents work better under protection than outdoors.

Table 1 lists (for a range of common pests and diseases) the most reliable and most commonly used biocontrol agents in soft fruit. These are now used successfully on farms and should be the first choice when employing biocontrol.

There can be a wealth of alternative biocontrol agents available, but at present, they are not widely used due to their price or unknown efficacy in soft fruit. Some are supporting agents which can be used mid-season or to supplement existing biocontrol agents (e.g. to widen the mode of action). Supporting agents commonly (but not always) attack a different stage of the pest's life cycle than the primary agent.

Other novel agents that may have performed well in other crops are showing potential for use in soft fruit. Their performance should be monitored on other crops or in trials before being considered for commercial use in soft fruit.

Table 1. Principal biological control agents for soft fruit

Pest	Frontline agent	Supporting agent	Promising in trials - not widely used on fruit at present
Two-spotted spider mite (TSSM)	*Phytoseiulus persimilis, Neoseiulus californicus**	*Amblyseius andersoni*	*Beauveria bassiana* has shown promise in trials on tunnel grown strawberry, where timed carefully
Tarsonemid mite	*Neoseiulus cucumeris*		
Western flower thrips (WFT)	*Neoseiulus cucumeris, Orius laevigatus*	*Amblyseius swirskii*, Hypoaspis miles, Hypoaspis aculeifer*	*Metarhizium anisopliae*
Vine weevil larvae	*Steinernema kraussei, Steinernema carpocapsae, Heterorhabditis megidis, Heterorhabditis bacteriophora*		*Metarhizium anisopliae*
Aphids	Straight or mixes of: *Aphidius colemani, Aphidius ervi, Aphelinus abdominalis, Aphidius matricariae, Ephedrus cerasicola, Praon volucre*	*Aphidoletes aphidimyza*	
Caterpillar (Lepidoptera only)	*Bacillus thuringiensis*		
Whitefly	*Encarsia formosa*		*Beauveria bassiana*
Botrytis	*Bacillus subtilis*		

** These are classed as non-native species and may only be used in permanently enclosed crops i.e. in glasshouses, under licence from DEFRA. Restrictions apply concerning the types of crop and areas of crop on which it may be released. Consult your supplier for the latest information.*

Biocontrol agents still to be proven for widespread use in soft fruit

Biocontrol companies are constantly producing new agents, or established agents with new uses. This offers a stream of new possibilities for soft fruit production. These are being tested in trials (some HDC-funded). Although some biocontrol agents are not widely used on fruit at present, circumstances can develop rapidly in the light of a change of formulation, price or publishing of new trials evidence.

Typical agents that are still to be proven for widespread use in soft fruit are listed in Appendix 2.

Biological control agents are not free from regulations. They are split into two major regulatory groups:

- Macrobiologicals: these are insects, mites and nematodes, such as the predatory mite, *Phytoseiulus persimilis* and the nematode *Steinernema krausseii*. They do not need approval for use. However, those that are not native or established in the UK (e.g. *Amblyseius swirskii*) need a Defra licence for release, which restricts release to fully protected (glasshouse) crops only.
- Microbiologicals: these are fungi and bacteria, such as the fungi *Metarhizium anisopliae* (Met52), *Beauveria bassiana* (Naturalis-L) and the bacteria *Bacillus subtilis* (Serenade) and *Bacillus thuringiensis* (Dipel DF). These are classed as biopesticides and they need approval for use as specific formulations and application methods on named crops.

Strategies for biological control

This guide assumes that biological control is used alongside carefully chosen pesticides, selected for their minimal impact on the biocontrol agents chosen. This is a strategy commonly referred to as Integrated Pest Management (IPM). Much greater detail is found later in the guide.

Good pest control relies upon taking action that can greatly improve success:

- Plan, receive and apply biocontrol with great care.
- Regular crop checking through the growing season.
- Timely and careful introduction of biocontrol.
- Good choice of crop protection products to reduce their influence on biocontrol agents.
- Using traps for enhanced warning of certain pest activity.
- Creation of good crop records, sometimes referring to the previous season.
- Maintain cleanliness, avoiding weeds and old crop debris.

The following sections (overleaf) outline the actions necessary for a successful strategy.

Evaluation and planning

Planning your IPM programme makes biocontrol much cheaper and more effective.

It is easy to choose the correct biocontrol agent for the relevant pest, but less easy to choose the correct application rates and timings. It is difficult to accurately describe high, medium or low levels of pests, as the assessment varies enormously between individuals' perception. Keeping good crop records (pest level, time of application, operator, biocontrol amount and spray history) will build on success.

The end of the season is an excellent time to evaluate and manage crops for biocontrol in the following season. Pests frequently overwinter from previous cropping. Vine weevil, aphids, western flower thrips, tarsonemid mite and two-spotted spider mite are good examples. They can arrive on plant material as well, though propagators generally provide a good level of control.

A cheap end of season pesticide application will lower pest numbers ahead of the following spring. Clean crops, with a lower pesticide presence in early spring, allows more reliable and more cost-effective biocontrol.

The population level and time that a pest is discovered can influence the need for control. For example, a modest two-spotted spider mite population found towards the end of a crop in its final year can remain untreated. If seen at the same level several months earlier, treatment may have been necessary.

Start checking again (Figure 3) early in the year, e.g. February and March, for pests that are easily seen, such as two-spotted spider mite and aphids. If it is still too cool to use biocontrol agents, use appropriate pesticides that are safe to, or have short persistence against biocontrol agents. This reduces the pest population as early as possible, to enable later introduction of biocontrol agents for a thorough clean up.

3. Monitoring for insect pests should start early in the year

Don't wait too long into the season. Insects and mites can tolerate slightly sub optimum temperatures in the crop for part of the day. Many are mobile and adept at temporarily seeking shelter deeper in the canopy. Such conditions normally allow the predator to survive, but not thrive. In contrast, when temperatures are optimum for predators, they can feed and (very importantly) breed, to effectively beat the pest. Regular input of predatory adults in sub optimum temperatures can still maintain pest control but without the predator breeding. This would be a comparatively expensive option.

For some crops, biocontrol can provide extraordinarily good value compared to the use of chemical pesticides. For example a large raspberry canopy can be devoid of two-spotted spider mite for several years after just one season of biocontrol. This can be very satisfying and the reason why farms tend to increase their use of biocontrol. Not all procedures are as durable. Control may be incomplete for a number of reasons. Insufficient numbers may have been released or develop in the crop, temperatures may be sub-optimal or the pest can migrate into the crop after earlier biological control. Good records will be an enormous help for improvement.

Biocontrol introductions should always be made in good time. Early use is much more cost effective than trying to gain back lost ground later. This guide explains the biology of the agents. It is important to have realistic expectations of their strengths and weaknesses.

A good understanding of the pest life cycle and reproduction rates helps planning. There are several excellent HDC Factsheets to help (see Further information section).

Application rates

Bacillus thuringiensis (DiPel DF) and entomopathogenic fungi have definite recommended application rates, as they are applied as sprays, similar to chemical pesticides.

In contrast, with predators and parasitoids, it is difficult to be exact on the rates of introduction. Many factors are involved in the decision. Biocontrol suppliers and consultants can help with suggested release rates, and there is useful guidance to be found on biocontrol supplier websites or in product literature. Often, a choice of release rates is given, according to whether the biocontrol agent is used preventively or curatively, and whether the pest is present in 'low' or 'high' density. This can be difficult to judge, as pest numbers vary enormously within the same crop or between crops throughout the season. The matter of timeliness also needs to be addressed. For instance, is a speedy resolution needed or not?

Application rates are often provided on a 'per square metre of crop area' basis and do not include paths. This is not as clear cut as it appears. For instance, 1 m^2 of raspberries has a different leaf area to its equivalent in strawberries.

There is an inescapable ambiguity attached to any application rate. It is always best resolved by making weekly assessments of the crop and monitoring numbers of both pests and predators or parasitised pests. Never introduce a biocontrol agent and assume that the pest problem will be resolved without further management.

Initial application rates should be a combination of the recommended rate and previous experience. Further releases (if any) are adjusted according to weekly monitoring and estimation of pest and biocontrol agent numbers - and patience! Great confidence is soon achieved when following the predator development on a weekly basis. Keep good notes for future reference in the following year. Digital photos can also be a great help.

Suggested rates are listed in Appendix1.

Biocontrol interactions

Introducing more than one agent to a crop can be advantageous in certain situations. A second agent can usefully attack a different part of the pest's life cycle. However, it is worth noting that in a few cases it can attack another predator, which could potentially be counter productive. However, in practice, most biological control agents happily co-exist in a crop.

For example *Orius sp*. might eat young predatory mites within a strawberry flower. However, *Orius* are usually more interested in eating thrips and pollen, and they have been used together with *Neoseiulus cucumeris* (formerly *Amblyseius cucumeris*) for successful thrips control in sweet peppers for many years with no problems for the predatory mites. *Metarhizium* is thought to have little if any effect on predatory mites, but when incorporated in the substrate or soil, it may reduce the survival of soil-dwelling beetle predators such as *Atheta*.

Good reception and prompt application

Biocontrol agents are delivered as fresh living organisms in most cases. They have been reared with a high level of sophistication, which needs to be continued on the crops. Take note of the instructions for storage on arrival and where possible, introduce to the crops immediately. There may be instructions regarding their latest time of application. This is typically several days after receipt, but the quicker they are in the crop, the better.

Some agents can be quickly in need of a meal. Loose products are sometimes without a food source and need quick application. For example, *Phytoseiulus persimilis* can arrive in a state of hunger after a journey of several days. It feeds almost exclusively on two-spotted spider mite, which is not supplied in the bottle. However, it will become cannibalistic if very hungry. Prompt application and good placement in the crop canopy is essential.

Sachet-based products (Figure 4) such as *Neoseiulus cucumeris* (formerly *Amblyseius cucumeris*) have an extra mite species added to the sachet to maintain a food source and allow for controlled release. For example *N.cucumeris* will emerge continuously for over six weeks, depending on temperature and humidity. Placement in the crop canopy is therefore not so urgent using such a mechanism, but prompt application will avoid wasting predators emerging in the delivery box.

4. Neoseiulus cucumeris introduced to a strawberry crop through a sachet

Care on arrival

The ideal procedure is to have staff available to introduce the delivery on the same day of arrival. This greatly reduces storage risks and ensures the biocontrol agents have prolonged capability to search for their prey.

Mishandling either in transit or when they arrive can lead to both injury and stress for them. For example, parasitoids such as *Aphidius* species are very susceptible to over-heating and death in the release tubes, particularly if any adults have emerged from the 'mummies' during transit. All parasitoid products should be released into the crop as soon as possible after arrival.

Unpack and spread out large volumes to improve their ventilation. Choose a dark or shaded holding area to avoid direct sunlight.

It is important that the containers are checked on receipt, handled and stored correctly (Figure 5). Sometimes packaging is damaged or exposed to incorrect temperatures. Use a hand lens to check that the contents are alive. Be careful when examining formulations with a carrier (e.g. bran). Some predators (e.g. *Neoseiulus spp*.) are extremely quick at hiding themselves from view. Regularly disturb the bran whilst checking to keep the mites moving. Thinly spreading the bran on white paper will help. This is the time to phone the supplier if you suspect a problem or need advice before application.

5 . Containers should be checked on receipt

Each delivery to a farm will come with some form of identification, such as a batch number. Take note of these details and any instructions received. There should also be a 'use by' date on the container.

After taking delivery of biocontrol agents, there are a series of guidelines for each agent that should be followed very carefully to maintain their good health and wellbeing. These are summarised in Table 2. It is essential that these guidelines are adhered to very carefully. Failure to do so can lead to death of the biocontrol agents or at very least, reduced activity. This will probably allow pest numbers to develop further and unnecessarily increase the cost of subsequent treatments.

Storage temperatures and duration vary slightly between suppliers. Table 2 uses information from various suppliers.

Table 2. Basic care on arrival

*Neoseiulus californicus**	Delivered loose or as sachet formulation of adults, nymphs, eggs and carrier. Store at 8-10°C. Available as loose or sachet products. Keep the loose product tubes horizontal and cool until ready to use. Handle sachets at the top (hook) end to avoid crushing predators inside. Use within 1-2 days of receipt. Store in the dark (or out of direct sunlight).
Neoseiulus cucumeris	Delivered loose or as sachet formulation of adults, nymphs, eggs and carrier. Store at 10-18°C, depending on product. Store loose product tubes horizontally. Use within 1-2 days of receipt. Store in the dark (or out of direct sunlight).
*Amblyseius swirskii**	Available as loose or sachet products. Store at 10-15°C. Use within 1-2 days of receipt. Store in the dark (or out of direct sunlight) in a well ventilated store to avoid suffocation.
Aphelinus abdominalis, Aphidius colemani & Aphidius ervi as single or mixed species. Also available with *Aphidius matricariae, Ephedrus cerasicola and Praon volucre* as a mix of 6 species.	Delivered as parasitised aphid 'mummies' in plastic or cardboard tubes. Store individual species at 8-10°C. Use within 1-2 days of receipt. Store in the dark (or out of direct sunlight). Store the mix of 6 species in cardboard tubes at 3-4°C in the dark, for up to one week.
Atheta coriaria	Delivered as a loose formulation of adults, larvae, eggs and carrier. Transport and store in darkness at 10-15°C. Use within 1-2 days of receipt. Store in the dark (or out of direct sunlight) in a well ventilated store to avoid suffocation.
Bacillus subtilis	Delivered as liquid suspension of spores. Store at room temperature and avoid freezing. Higher temperatures will reduce its life. The suspension will last for two years.
Bacillus thuringiensis	Delivered as a water dispersible granule. Store at room temperature in a dry place out of sunlight. Avoid freezing.
Beauveria bassiana	Delivered as liquid suspension of spores. Preferably store part-used bottles at 4-7°C to retain maximum spore viability. Shelf life of 1 year at 20°C if unopened. Avoid freezing.
Encarsia formosa	Delivered as delicate pupae or parasitised whitefly scales attached to paper/ card. Use within 1-2 days of receipt. Store in a cool place (8-10°C). Keep out of direct sunlight.
Heterorhabditis bacteriophora *Heterorhabditis megidis* *Steinernema kraussei*	Delivered as infective juveniles in gel carrier. Store in a refrigerator at 2-5°C. Do not freeze. Note the expiry date. Ensure good air circulation around each pack.
Hypoaspis miles/aculeifer	Delivered as loose formulation of adults, nymphs, eggs and carrier. Store at 10-18°C. Use within 1-2 days. Keep out of direct sunlight. Store bottles or tubs horizontally.
Metarhizium anisopliae	Delivered as spore covered rice grains. Ideally store at 4-5°C. Guaranteed shelf life of one year at 20°C for a sealed pack. Use entire pack contents immediately. Avoid freezing.
Orius laevigatus	Delivered as loose formulation of adults and nymphs. Store at 8-15°C. Use within 1-2 days of receipt. Keep out of direct sunlight.
Phytoseiulus persimilis	Delivered as loose formulation of adults, eggs and carrier. Keep containers horizontal. DO NOT expose to direct sunlight. Keep in darkness at 8-10°C. Use within 1-2 days, preferably 1 day.

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Care at application

Having cared for biocontrol agents on arrival and during any necessary storage period, further care and attention to detail is needed during the process of introduction or application to the crop.

Staff employed to introduce predators are a critical part of pest control, so choose them carefully (Figure 6). Help them feel really involved in the outcome.

- Spend some time training them.
- Let them inspect the product with a lens (there are many good cheap plastic ones available) to see that these are delicate organisms that need their help to be spread evenly across the crop.
- Explain what is being achieved with careful application (e.g. closely locating the treatment to prey really improves performance).
- Frequently tap and roll the product tubes gently, if advised.
- You may like to identify the rows with each person, as some farms do for planting. This can improve their interest and ability to compare results.

6. Staff employed to introduce predators should be chosen very carefully

Care guidelines for each agent and helpful information on favourable conditions for their development are summarised in Table 3.

Table 3. Basic care at application

*Neoseiulus californicus**	Available in sachets and loose. Gently turn the loose product bottle before use. Sprinkle material on leaves. Temperature range 8-35°C and can tolerate lower humidity better than *Phytoseiulus persimilis.* This predator will overwinter.
Neoseiulus cucumeris	Available in sachets and loose. Gently turn the loose product bottle before use. Sprinkle material on leaves. Needs a relative humidity >75% and ideally temperature above 20°C for part of the day but can be released into tunnels from mid-late March at mean temperatures of 13°C.
*Amblyseius swirskii**	Available in sachets and loose. Gently turn the loose product bottle before use. Sprinkle material on leaves. Starts to develop when day temperature regularly exceeds 20-22°C.
Aphelinus abdominalis, Aphidius colemani & Aphidius ervi as single or mixed species*.* Also available with *Aphidius matricariae, Ephedrus cerasicola and Praon volucre* as a mix of 6 species*.*	For the single species or mix of 3 species in plastic tubes, add carrier to release boxes or to sheltered spaces beneath the crop (away from irrigation drippers). For the mix of 6 species in cardboard tubes, place the tubes horizontally in a sheltered area away from irrigation drippers and open the lid to expose the drop of honey and allow the adults out when emerged from mummies. Works best at 10-30°C.
Atheta	To mix the contents, gently rotate the tube several times before opening. Shake contents gently onto compost surface. Effective at a wide temperature range of 12-35°C.
Bacillus subtilis	Applied with conventional spray equipment to achieve good crop coverage, using a minimum of 400 l/ha water.
Bacillus thuringiensis	Applied with conventional spray equipment to achieve good crop coverage. Avoid high light intensity, rainfall or overhead irrigation within six hours of application and temperatures outside the range of 10-20°C.
Beauveria bassiana	Temperature range 10-37°C. The optimal conditions are between 20-30°C, relative humidity range 50-100% but ideally >80%. Do not tank mix with other products. Check label for fungicide compatibility.
Encarsia formosa	Use at temperatures >18°C during the day. Carefully handle the cards to avoid crushing the parasitised scales. Place in a shaded part of the crop canopy.
Heterorhabditis bacteriophora	Soil or compost must be well watered to aid migration. Works best at 11-33°C. These temperatures and substrate moisture must continue for at least two weeks after application. Use the entire pack in one go. Carefully read product instructions concerning application by drip line.

Heterorhabditis megidis	Soil or compost must be well watered to aid migration. Works best at 12-26°C. These temperatures and substrate moisture must continue for at least two weeks after application. Use the entire pack in one go. Carefully read product instructions concerning application by drip line.
Hypoaspis miles	Soil or compost must be moist and 15-30°C. Rotate the tube several times before opening. Gently roll the tube. Shake slowly to dispense the product onto the surface of the growing medium.
Metarhizium anisopliae	Soil or compost must be 5-40°C - it works best at 15-30°C. It will survive freezing to -18°C but is inactive below freezing. Expect useful activity to last about one year. Extreme over-watering reduces activity. Spores survive drought but will be inactive.
Orius laevigatus	Turn and shake bottle gently before use. Sprinkle over crop or into application boxes. Temperature range 15-30°C.
Phytoseiulus persimilis	Performs best at minimum 20°C and relative humidity >75% for part of the day. Tap the container before opening. It drops the adults from the upper side of the container where they concentrate. Gently roll the vial/ bottle horizontally to distribute them evenly throughout pack. Place product over the leaves or application boxes. Maintain gentle shaking and rotating for a uniform distribution. Vigorous shaking will damage or even kill the mites.
Steinernema kraussei	Soil or compost must be well watered to aid migration. Temperature range 5-30°C. Nematode activity usually lasts for one month. Use the entire pack in one go. Carefully read product instructions concerning application by drip line.

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Distribution of biocontrol

Many biocontrol agents need repeated applications. For example, preventive releases of aphid parasitoids will need to be repeated each week or fortnight, so that there are always parasitoid adults present to find aphids to attack as soon as aphids infest the crop. Similarly, repeated applications of predatory mites for thrips control will ensure that enough are present when thrips first infest the crop, and enough are maintained to keep control of the pest. Repeat applications also help to ensure a more even distribution and allow for variability of temperature, humidity, insecticide effects and pest development.

Repeat applications can also overcome the problems created by inclement breeding conditions, when predators just feed but don't breed. This can be especially appropriate for predatory mites.

Good even distribution within the canopy is very important for raspberries. Raspberries have an enormous crop canopy, which should be taken into consideration when releasing some predators. For example, try to locate *Phytoseiulus persimilis* near the two-spotted spider mite colonies. Expect the newly introduced predators to be hard to find for the next couple of weeks until they build in number. These tiny mites are introduced into a very large area of canopy and are soon lost once they leave the clearly visible carrier behind. Consider the areas relating to one *Phytoseiulus persimilis* mite:

- A single raspberry cane at the end of the season, which is 2 metres tall, has a leaf area of more than $0.6m^2$.
- A single 60-day Elsanta plant at the end of the season has a leaf area of more than $0.3m^2$.
- One *Phytoseiulus persimilis* predatory mite occupies about 0.0000004 m^2. This is 0.00007% and 0.00014% of the respected areas above.

It is therefore very difficult to detect these predatory mites soon after introduction.

Using a reference point ensures you that they are present and working in a crop. Mark a reference point in the plantation and introduce a higher number of predators at that point. This point can then be checked first as populations are likely to be higher in that area.

You will find the predator or its eggs in most colonies of spider mites when *Phytoseiulus* is well established.

Further details on application and distribution of the major biocontrol agents are found in the section entitled 'Major predators for pest control'.

Crop monitoring

Numbers of pests and biocontrol agents can change quickly in the growing season. Any new orders for biocontrol agents should be made promptly after a crop inspection. The total volume ordered should account for any further increase in pest populations that may occur between the time of ordering and delivery, which can take up to a week. This can be significant in the heat of summer when pest levels are increasing rapidly.

Tremendous confidence to interpret events is rapidly gained if the crops are checked regularly, ideally at weekly intervals when temperatures rise. Decisions about doubtful situations, for example whether or not the predator numbers are adequate, can be postponed to the next assessment if checks are frequent. The more frequent the assessments, the fewer the surprises.

Using the same person to assess each time maintains consistency of the IPM strategy, which at times can need fine judgement either to adjust the programme or to delay for a second opinion in the near future.

Sticky traps, sex pheromone traps and lures are being continually developed which can assist with pest evaluation.

Sticky traps attract certain pests from the immediate surrounding crop and reduce the need for, but do not replace crop inspections. Sticky traps are only useful for monitoring flying pests such as thrips or whiteflies. They should be used in conjunction with some kind of crop inspection system to monitor for other pest species such as spider mites and aphids.

7. Blue sticky trap with lure for catching common green capsid.

There are no precise recommendations for the number of sticky traps that should be used in a given area. As a general rule, one trap per 100m^2 should be adequate; this should give an idea of pest populations. Yellow traps attract most insects but are best for monitoring adult whiteflies, whereas blue traps are best for monitoring western flower thrips.

Sticky traps should be placed just above the crop. This distance ensures that flying pests will still be attracted to the traps whilst minimising the number of biological control agents and plant / peat debris caught on them. Traps should be changed (and dated) on a regular basis, usually fortnightly, as over time they collect peat debris, plant material, non-pest insects etc., making interpretation difficult.

Traps using sex pheromone or attractants that are used for monitoring moths, capsids (Figure 7), weevils and midges, use a chemical lure specific to certain species and can attract pests across a large area.

In practice, a combination of monitoring methods is usually employed.

It is important that the information collected during the monitoring process is recorded in a way that allows prompt interpretation and action. Information to collect includes:

- Pest numbers on traps to allow populations to be monitored and appropriate control measures implemented.
- Pest and disease reports, detailing pest threshold numbers and the necessary action points.
- Numbers of biological control agents, or percentage parasitism of pests.

Once created, the records should be stored so that they can be referred to from year to year, to help plan future management strategies. Monitoring is the only real way to achieve accurate pest recording. Other parameters should also be taken into consideration when trying to forecast pest populations. These include:

- Prevailing weather conditions, e.g. increasing risk of pest damage in hot, dry spells.
- Time of the year and the life cycle of the pest, e.g. vine weevil.
- Harvesting periods of adjacent crops (harvesting sometimes leads to pest influxes).
- Condition of bought in plant material.

Compatibility of chemical pesticides in IPM

There is a vast amount of information on pesticide safety to biocontrol agents provided by the biocontrol companies. It is not as daunting as it looks. It is easier to start planning from the end of harvest in the previous year. End of season pesticide use is commonly less restrictive than early season, when biocontrol agents are present in low numbers and most vulnerable to set back.

HDC-funded research has demonstrated that difficult spring-occurring pests such as aphids and caterpillars can be greatly reduced in number with late autumn-applied insecticides, leaving a low pest pressure for spring.

Before introducing predators, check that the plant propagators have not used a long persistence pesticide.

Many years of research by scientists through the direction of the International Organization for Biological Control (IOBC) has provided a portfolio of safety information on the use of chemical pesticides in conjunction with biocontrol agents. The information allows growers to consider the potential side effects of active ingredients to most commercially available biocontrol agents.

Several biocontrol suppliers have excellent websites providing this and their own data in useful tables, offering guidance on the options (see Further information section). These tables give good guidance, directing users towards the least damaging crop protection products. The tables use the following IOBC categories for the degree of harmfulness of pesticides to biocontrol agents:

- Safe: kills<25%
- Slightly harmful: kills 25-50%
- Moderately harmful: kills 50-75%
- Harmful: kills >75%

Information on persistence (in days or weeks) of the harmful effect on biocontrols is also given in Appendix 3 at the end of this guide.

It can be perfectly possible to treat crops (Figure 8 - overleaf) in advance of starting a biocontrol programme. In some cases, pest populations may be at such a high level, that it would be uneconomical to introduce the required number of biocontrol agents to gain satisfactory control. If this option is chosen, it is very important to check not only the potential harmfulness to the biocontrols to be used, but also the persistence against these biocontrols. Pesticides ‘safe’ or ‘slightly harmful’ and with short persistence are always the best ones to select, to avoid long-term side effects. Sometimes the options are limited after considering harvest intervals, maximum application limits or pest levels.

8. It can be necessary to use a crop protection product to reduce pest populations before introducing a biocontrol agent

There can be difficult decisions required when it is not clear whether use of a pesticide on its own, a biocontrol agent on its own or a combination of the two is best. In some cases, the only approved or most appropriate choice of pesticide may conflict with the use of a biocontrol agent, i.e. it is harmful to the biocontrol agents involved, when applied either before or after introduction.

Targeting a pesticide within the crop canopy can make it safer to the biocontrols. For example a light spray of a contact acting product to the outer crop canopy avoids penetration throughout the crop canopy. The use of spot-sprays to treat isolated patches of pests can reduce any harmful effects on biocontrol agents. For example, the lower zone of raspberries can be targeted with a spray to control adult vine weevil whilst biocontrol works higher in the canopy. These are practical solutions that need to be weighed up at the time.

Also consider that a rapidly expanding crop can soon provide young growth that is free from residues of earlier contact-acting pesticides and thus minimise risks to biocontrols working in the emerging growing points, flower buds and flowers. This can allow biocontrol agents to be used sooner than they might otherwise have been if the side effects information was strictly followed. However, this strategy is not appropriate for systemic pesticides that are taken up to the growing points after application.

A table of side effects caused by use of a range of pesticides is listed in Appendix 3 at the back of this guide.

Enhancing Natural Predators

Appreciate the presence of naturally occurring beneficials. They are free, can overwinter and are sometimes very pesticide tolerant. For example:

- Notable levels of beneficial predatory mites such as *Amblyseius sp*. can transfer year to year. Some farms even transfer plant debris between crops to facilitate this.
- Avoiding harmful pesticides such as methiocarb slug pellets allows survival of predatory rove beetles.

Further information is included later in the guide in the section on 'Native predators for pest control'.

Major predators for pest control

In this section of the guide, the optimum biocontrol strategies for the principal insect pests of soft fruit are described. Key facts are also included for the primary biocontrol agents used to control each pest. To allow farms to improve the management and success of biocontrol, it is essential that they have a good understanding and knowledge of each predator used.

The pests included are:

- Two-spotted spider mite
- Western flower thrips
- Tarsonemid mite
- Vine weevil
- Aphids
- Whitefly
- Caterpillars

Two-spotted spider mite

Two-spotted spider mite – key facts

Mites overwinter as hibernating females. They are known as the diapause stage. They are brick red in colour and are easily seen on the underside of the leaf. Female mites start to enter diapause in September, in response to shortening day length, reducing temperature and crop senescence. They seek out sheltered places to overwinter deep in the canopy and cropping structures. During this time they do not feed or lay eggs and cannot be controlled by acaricides.

On outdoor crops, they become active in March and begin to lay eggs (Figure 9), about 30-40 each, after which they die. They become active earlier under protection, but not usually earlier than February. Two-spotted spider mite eggs are perfectly round in shape, translucent and less than a millimetre in diameter. On hatching, they develop through a series of larval and nymph stages before turning into pale green egg laying adults (with two black spots on their backs – Figure 10) for the rest of summer.

9. Overwintering adult female two-spotted spider mites laying eggs on the underside of a strawberry leaf

10. Egg laying two-spotted spider mite adults

At around 15°C the life cycle is completed in about 35 days. At 25°C, the cycle speeds up, taking about 9 days. Each female produces between 50-100 eggs, depending on the host crop. Populations increase extremely rapidly as temperatures increase. Hot and dry conditions favour this pest. Low humidity actually contributes to an increase in spider mite numbers; the opposite applies to its primary predator *Phytoseiulus persimilis* that prefers warm, humid conditions (see later).

Summer adults start to turn into their diapause stage in mid September. Under tunnels, many eggs are seen through until October, although these will not overwinter.

Damage symptoms

Spider mites feed on the underside of the leaf, sucking sap from leaf cells. The damage is initially seen as small patches of pale or yellow spots (similar to a sprinkling of pepper) on the upper surface of the leaf. If left uncontrolled, the whole leaf becomes affected, turning yellow and dying. It also becomes covered in spider mite webbing (Figure 11). Webbing is first seen as patches within the crop. It spans the serrated edge of the leaf. There will be significant levels of mites both in the webbing and in the surrounding non-webbed crop.

11. Strawberry leaf and flower covered in two-spotted spider mite webbing

Phytoseiulus persimilis - key facts about the primary predator

Minimum temperature

- *Phytoseiulus* works best at temperatures above 15ºC. Below 15ºC predators will move sluggishly and eventually starve. Even a few bright warm days cannot correct the situation, as predators are too weak to take advantage.

Maximum temperature

- It works best when temperatures lie between 18-21°C but is ineffective above 30°C. It stops feeding at 35°C. At such sustained temperatures, predator death occurs due to a lack of movement leading to starvation.

Tolerance to humidity

Humidity suits it; egg laying and egg survival is severely reduced if there are dry conditions (<60% RH), especially at high temperatures.

Activity

- Best control of two-spotted spider mite is achieved from 15 – 25°C.
- The predator is capable of very rapid population growth. It eats all stages of two-spotted spider mite (eggs, nymphs and adults). It only eats spider mites and cannot feed on other prey or plant material. There must be a spider mite presence to maintain populations of this predator, which can ultimately clear up the spider mites (given time and appropriate starting numbers). When it has fed on all available spider mites, it becomes cannibalistic or alternatively migrates or starves.

12. ***Phytoseiulus persimilis* searching for two-spotted spider mite**

- *Phytoseiulus* is highly mobile within strawberries and raspberry canopies. It tends to move upwards if there is no prey about. It effectively searches out the pest (Figure 12) and lays translucent, pale pink, oval- shaped eggs amongst colonies of spider mites. Spider mite eggs are about half the size of *Phytoseiulus* eggs and are spherical and colourless.
- The predators are greatly helped with a meshed canopy so that they can find 'bridges' between food sources. This means that methods of distributing predators throughout the crop generally have an advantage over patch treatments. The more we help them to spread, the less time lost finding food.
- The female can lay up to five eggs per day, which roughly equates to its own body weight. Females can lay more than 50 eggs during a lifetime. About 80% of the predator population is female.
- Low humidity (<60% RH) reduces *Phytoseiulus* egg survival.
- At 20°C, egg to adult development is completed within 10 days. This development time is halved at 30°C.
- At 20°C, *Phytoseiulus* reproduces twice as quickly as two-spotted spider mite. In contrast, above 30°C, two-spotted spider mite will reproduce more quickly that *Phytoseiulus.*
- Care should be taken to integrate pesticides that are safe to both predators, or have minimal harmful effects (see Appendix 3).

Appetite

- Given long periods of optimum temperature and humidity, the adult predators will eat about five adult spider mites or twenty eggs and/or juvenile mites per day. All stages of the spider mite are eaten, including its eggs.

How and when to start assessing pest presence

Pest experience from the previous season provides a valuable indicator of where to spot trouble. There is a strong probability that the pest will appear early in the new season e.g. where two-spotted spider mite populations have been controlled poorly the previous autumn. This can happen even if the previous crop is removed and a new crop planted.

On both outdoor and tunnel crops, the easiest time to assess early season two-spotted spider mite populations is from February to March. They are easily spotted as red adult females on the underside of 'ground hugging' strawberry leaves (Figure 13) or, less easily, in the leaf trash at the base of raspberries. They can also be found hiding in cracks and crevices provided by pot-grown crops.

13. **Overwintered adult female two-spotted spider mites on underside of strawberry leaf**

Make the first assessment before there is much crop growth. This is a good policy to adopt in both outdoor and protected crops. Many red (diapause) mites tend to remain in situ and lay eggs on the lowest leaves of strawberries. However towards the end of March, a few will begin to ascend into fresh expanding growth.

Similarly in raspberries, spider mites can initially be found on the undersides of leaves close to ground level. Their presence is often apparent from symptoms of silver speckling on the upper surface of those leaves (Figure 14), especially for thin-leaved raspberries. The mites will be carried upwards as the primocanes (spawn) start to grow. Early spawn growth of 5-10cm in height is a very good place to find spider mite colonies. These can be significant in number as this is the first bit of green tissue to feed upon.

14. **Typical silver speckling on raspberry leaf as a result of two-spotted spider mite feeding**

Populations on crops under fleece, tunnels and other forms of protection rapidly develop and grow more rapidly than those on outdoor crops. The spider mite development matches crop growth, as both are temperature driven.

Rapid spring growth can deceive anyone who is assessing a crop for two-spotted spider mite. The early spider mite colonies become thinly spread across the quickly expanding leaves and shoots and they can easily be missed during April if the early assessments are not made. Check the oldest lowest leaves if in doubt. There will be remnant colonies still here, or masses of white exoskeletons (shedded mite skins).

These early inspections can also reveal the presence of overwintered predatory mites (Figure 15). Where acceptable control was achieved in the previous season and such overwintered predatory mites are found early, growers can derive great confidence that successful control will be achieved during the season ahead. Further information on overwintered predatory mites is available in the report of HDC project SF 115, (*The identification of overwintering predatory mites in raspberry and strawberry, and investigation of on-farm production*).

15. Early inspections can reveal the presence of overwintered predatory mites

This project demonstrated that the overwintering predatory mites *Amblyseius andersoni* and *Neoseiulus californicus* (formerly *Amblyseius californicus*) could be typically seen in very low numbers in March. Their presence is a very good omen as they support the activity of bought-in *Phytoseiulus.* Crops are commonly kept clean by the presence of these naturally occurring predators alone. Their numbers increase more rapidly from the end of April onwards, as their populations increase within the spider mite colonies. These predatory mites are highly mobile. They are an off-white colour and lay oval, colourless eggs, slightly smaller than those of *Phytoseiulus.*

Assessing damage during the season

Weekly crop inspection of the canopy using a x10 hand lens quickly builds experience. Anyone making such regular inspections will soon develop the expertise to judge the need for remedial action and to decide on the most appropriate additional control measures if needed.

On strawberry, fine white speckling is the first symptom to appear on fresh leaves (Figure 16). The pest should be spotted by lens way ahead of these symptoms appearing. Spider mite numbers can be quite high at this point (over 10 per leaf). The colony collects and develops on the underside of the leaf towards the leaf margin. If not controlled, fine threads of webbing soon appear at the very tips of the leaf margin.

16. The first symptom to appear on fresh strawberry leaves is a fine white speckling

In raspberry, the pest is best spotted in an early crop inspection using a hand lens. The greatest level of speckling is seen on the lowest leaves at first, particularly in the lowest 50cm of the crop (Figure 17). Raspberries are slightly different in that they have very thin leaves and are readily speckled by much lower numbers of spider mites. This damage is seen well in advance of webbing which allows an early decision to be made about control measures.

17. Lower leaves of raspberry crop displaying silver speckling

Sometimes two-spotted spider mite is found for the first time from May onwards. For some crops, this can be of little consequence. For instance, for a mainseason crop of strawberries with perhaps only six weeks to go until the end of harvest, the use of an acaricide may be sufficient to contain a spider mite infestation until the end of cropping. Populations of naturally occurring predators, which are tolerant of a wide range of insecticides, may also build up to adequate levels during this time.

Longer term crops of tunnel protected 60-day and everbearer strawberries, or summer fruiting and primocane raspberries, suffer a much greater exposure to two-spotted spider mite. The efficacy of acaricides may be reduced by the dense crop canopy, the need to observe harvest intervals and restrictions on the permitted number of applications. However, they can have a place in an IPM programme. For example, the early and efficient application of an appropriate acaricide may help to reduce spider mite numbers in advance of introducing *Phytoseiulus*. From mid-April onwards pest populations will develop rapidly and IPM-compatible methods to prevent this is a huge advantage for later biocontrol programmes. It commonly takes a week from ordering biocontrol agents until receiving them and a further two weeks before any predator effects are noticed. The use of an appropriate acaricide can therefore reduce pest populations enough to permit such a time delay, without incurring economical crop damage.

If introduced at the right time when pest numbers are still low and temperature and humidity are optimum, *Phytoseiulus* will quickly eradicate two-spotted spider mite and avoid pest damage symptoms within a month. It is normal to have a few ‘hot spots’ within an infested crop as the spider mites are never distributed completely evenly through a plantation and neither are the predators, which take time to migrate through the crop and establish.

The presence of easily seen webbing is never a good sign (Figure 18). By the time the webbing appears, the population of spider mites is likely to be very high. If such damage is representative of the whole plantation, *Phytoseiulus* should have been introduced much earlier. Eradicating such high pest populations can take very high numbers of *Phytoseiulus* per plant, but it is still possible and sensible for a long-lived crop.

18. The presence of webbing is never a good sign

Hot spot management

Localised patches of spider mite damage can be successfully contained with ‘hot spot application’ of predators. Be sure to avoid placing the predators solely in the centre of the hot spot. It will largely stay there and consume the pest around it. Instead, apply predators around the edges of the ‘hot spot’ to contain any pest migration and allow them to work inwards towards the centre. Some brands of *Phytoseiulus* are sold in smaller bottles of 2,000 mites per bottle, to enable a concentrated application over a small area. These are ideal for hot spot work.

Crop hygiene

Inspect plants on arrival from the propagator. Clean permanent structures and containers between crops with sterilants. Avoid weeds, particularly willowherb and willows; these are alternative hosts for two-spotted spider mite.

How to treat with *Phytoseiulus persimilis*

Biological control using *Phytoseiulus* is a numbers game. The predator needs to be in the right place (plenty of food) at the right time (optimum conditions) in the right density (as a general rule, one predator for every 50 spider mites to establish well within one week). In this event, predators breed well and then spread rapidly at the rate of a metre or so per week (Figure 19).

19. *Phytoseiulus persimilis* predators need to be in the right place at the right time

Be observant and do not expect too much from predators. This approach will encourage farms to look after their predators and help them wherever possible. If conditions are not optimum, the predators should be monitored intensively and more introduced if necessary.

Thought needs to be given to the numbers of pests and predators and the ratios present when monitoring a crop for populations of two-spotted spider mite and *Phytoseiulus.* As a guide, if the ratio of prey: predator adults exceeds 10:1 then corrective action should be considered. In other words, if there is on average less than one predator per 10 spider mites, then more *Phytoseiulus* should be introduced, or an IPM-friendly acaricide used. *Phytoseiulus* tends to win when there are at least several of its eggs on most leaves with spider mites, even with a very high pest level. A weekly crop check gives an important insight into the population level and distribution of the predator. If predator numbers are building, then assuming there are no environmental changes that are unfavourable to *Phytoseiulus*, it is very capable of beating the spider mite.

Managing biocontrol is full of variables and until experience is gained, it can feel similar to guessing the weather. Developing a biocontrol strategy and closely monitoring progress is very important.

Biocontrol strategies

Strawberries

60-day and everbearer crops benefit most from the durable properties of biocontrol of two-spotted spider mite.

Relatively low introductions can be made to new 60-day crops, which tend to be planted at times of the year when temperatures are favourable for *Phytoseiulus*. Their smaller canopy and lower pest load require fewer predators to clear them up, compared to a later second year crop infestation. If there is a risk of two-spotted spider mite on 60-day crops, it is sensible to apply one *Phytoseiulus* per plant a couple of weeks after planting, to ensure a good protection through the first and second season. This is especially true for crops in permanent tunnel or glasshouse structures; they have a longer and warmer season for pests to build than their temporary tunnel counterparts. Predation is improved with a continuous canopy of coalescing plants. Young plants can have gaps between them, so even distribution at application is most important.

Everbearers are often fleeced (Figure 20) then tunnelled for their entire growing season. This provides plenty of time for two-spotted spider mite levels to build. Consider introducing 1-2 *Phytoseiulus* per plant about a month after planting in mid to late April, when the canopy is larger, and following the use of an IPM-friendly acaricide spray to reduce numbers of spider mite.

20. A strawberry crop covered with fleece

Second year mainseason crops or everbearers can often carry populations of two-spotted spider mite over the winter. Such crops should be assessed from early March onwards. These crops have large canopies and to provide the numbers of *Phytoseiulus* necessary to gain control would be an expensive option. Such crops benefit from an acaricide spray to reduce two-spotted spider mite numbers ahead of *Phytoseiulus* use. There is a wide choice of actives. Choose one with short persistence against *Phytoseiulus* to ensure no harmful active is on the leaves.

Look out for naturally occurring beneficial mites, which will reliably overwinter and tolerate a wide range of insecticides. They do not control the pest population as rapidly as *Phytoseiulus*, but they are a valuable support to *Phytoseiulus.* Some growers prefer to let these natural predators do all the work as they are so well established on their farm.

The following is a checklist of guidelines to follow when implementing a biocontrol strategy for two-spotted spider mite in strawberry.

- *Phytoseiulus* needs spider mites to be present.
- Look at the underside of the oldest 'ground hugging' leaves on mainseason and everbearer crops. It is easy to find the red overwintered spider mites in early spring. They may also be seen in April to July on ex cold store 60-day crops within two weeks of planting. These will soon lay eggs and hatch as green adults.
- There are several acaricides that are safe to *Phytoseiulus* yet kill summer adults and or eggs of two-spotted spider mite. These are good 'clean up' options when there are high levels of the pest, unreliable temperatures for biocontrol and the canopy is still small enough to enable adequate coverage with pesticide.
- You will need 1-3 *Phytoseiulus* per mature strawberry plant; 2 per plant would be a high rate and is used for a serious threat. Halve these amounts for low levels when the pest is thinly spread and hard to find. A drastic situation is best resolved by fixing a budget and working within it. Hot spot applications are the sensible way to prioritise your costs across a crop.
- Start introducing two weeks after planting when temperatures are over 15°C from mid April to June.
- Check predator status weekly. They are initially hard to find for the first two weeks. Thereafter, they should easily be found amongst two-spotted spider mite colonies. If there are no predators and no pest it is likely the predators have moved on or died of starvation.
- The very first few threads of spider mite webbing should be regarded as a 'hot spot'. These should be ring fenced with extra predators so that they contain the problem and head inwards to the centre of the 'hot spot'. It may still be possible to rely on an acaricide option to help at this point.
- Don't give up control on badly affected crops and maintain protection of the 'clean' ones. The latter may have unnoticed levels of pest or may slowly pick up mites from contaminated clothes of pickers arriving from infested crops.
- You are beginning to win when *Phytoseiulus* are found (Figure 21). Even if you find just one adult on most two-spotted spider mite infested leaves a week later, there will be many more predator eggs and adults that you have not spotted.
- Control can be very rapid once this stage is reached. Although speckling and webbing never vanishes on older leaves, fresh growth is completely damage free and is a good indication that biocontrol is winning.

21. The presence of *Phytoseiulus* predators is a sign that the two-spotted spider mite population is coming under control

Raspberries

Two-spotted spider mite is now successfully controlled in very large areas of protected raspberries through the use of *Phytoseiulus*. Acaricides alone are never successful as it is impossible to achieve adequate coverage of the crop due to its dense canopy.

Look out for the naturally occurring beneficial mites (very probably *Amblyseius andersoni*) that will reliably overwinter and tolerate a wide range of insecticides. They do not consume the pest population as rapidly as *Phytoseiulus*, but they are a valuable support to *Phytoseiulus* and some farms prefer to let them do all the work as they are so well established.

The following is a checklist of guidelines to follow when implementing a biocontrol strategy for two-spotted spider mite in raspberry.

- *Phytoseiulus* needs spider mites to be present.
- Assess the levels of two-spotted spider mite at soil or pot surface level on early spawn emergence in late March (Figure 22).

22. Two-spotted spider mite is often found on early emerging spawn in late March

- Use of acaricide products can help to clear populations of spider mite during April when temperatures are too unreliable for use of *Phytoseiulus*, and the crop canopy is still small and open enough to enable adequate coverage.
- Control of spider mites with *Phytoseiulus* should start in late April and early May. It is best to make repeated introductions to even out distribution across this large canopy crop.
- Deciding on the numbers to introduce requires a mix of estimation, weekly monitoring and patience. If stools or pots of canes have significant populations of spider mite, 10-20 *Phytoseiulus* per pot or stool should be introduced. This equates to 3-4 predators per cane. Halve these amounts for low levels when the pest is thinly spread and hard to find. A drastic situation is best resolved by fixing a budget and working within it. Hot spot applications are the sensible way to prioritise your costs across a crop.
- Check predator status weekly. They are initially hard to find. Early applications should be introduced at mid to low cane height, where they are sheltered and the pests can be found ascending the canes.
- *Phytoseiulus* and carrier can run off the leaves onto the ground (Figure 23) during introduction, leading to a bad start when they are in urgent need of food. Avoid this by making landing saucers out of a detached upturned leaf (Figure 24). Some biocontrol companies sell small cardboard release boxes; they are normally used in tomato and cucumber crops.

23. Phytoseiulus predators can fall off leaves when introduced to a raspberry crop

24. Landing saucers can be made out of detached upturned leaves to prevent predators from falling to the ground during introduction

- Hotspots of spider mite should be ring fenced around the edge with extra *Phytoseiulus* so the mites are contained and the predators head inwards to the centre of the hotspot. This principle can also be used for vertical control to reduce numbers of spider mites from ascending towards the cropping zone (particularly on primocane fruiting raspberries). Hotspot management works particularly well for raspberries as they show speckled leaves even with very small numbers of pest, which allows early spotting.
- Don't give up control on badly affected crops and be sure to maintain protection of the 'clean' ones. The latter may have unnoticed levels of spider mites or may slowly pick up the pest from contaminated pickers moving from the badly affected crops.
- You are beginning to win the battle when *Phytoseiulus* is found. Even if you find just one adult on most two-spotted spider mite infested leaves, a week later, there will be many more predator eggs and adults.
- Control can be very rapid once this stage is reached. Although speckling and webbing never vanishes on older leaves, fresh growth is completely damage free and is a good sign that biocontrol is winning.

The predatory mite *Amblyseius andersoni* is often found in raspberry and blackberry crops in the spring and provides useful preventive treatment. It is winter hardy and tolerates typical spray regimes used in cane fruit. It will survive by eating other non-pest mites in the absence of two-spotted spider mite. Although *Phytoseiulus persimilis* gives the most rapid clean up, *Amblyseius andersoni* can provide good supplementary control. Look for native mites at the leaf bases of cane fruit.

In some cases *Amblyseius andersoni* has been bought by growers and introduced into raspberry crops both in loose and sachet form.

- Research in HDC project SF 81 showed that under laboratory conditions, *Amblyseius andersoni* is capable of consuming more raspberry leaf and bud mites than either *Neoseiulus cucumeris* or *Typhlodromus pyri*. Unfortunately, when assessed in commercial raspberry plantations, they did not achieve the same level of success.

Western flower thrips

Western flower thrips – key facts

Several species of thrips can be found in soft fruit crops, but not all species cause serious damage. Western flower thrips (WFT) is the most damaging species, which will be dealt with here.

Western flower thrips was first confirmed in the UK in 1986, originally on imported protected ornamentals and young protected vegetable crops. In the past decade, it has become more widespread in soft fruit crops including those grown outdoors. Those long season crops that overwinter and are protected by tunnels are particularly affected. Everbearer strawberries have been badly affected in recent years. It is also a serious threat to mainseason strawberry varieties in permanent tunnels and glasshouses.

Western flower thrips overwinters in soft fruit crops. It becomes active in early spring and feeds in the centre of strawberry and raspberry flowers, consuming pollen and is normally first spotted there.

Adults are usually first seen in March and begin to lay eggs in April (Figure 25). The complete life cycle lasts 2-3 weeks at temperatures of 20-30°C. There are many generations each year as the pest breeds continuously under suitable conditions. Other than strawberries and raspberries, it is attracted to flowers of other plants and can successfully survive on nearby flowering weeds, such as dandelion and groundsel.

25. Adult western flower thrips

Amblyseius cucumeris has a well proven record of successful control in glasshouse strawberries. It has been renamed *Neoseiulus cucumeris* and is referred to as this throughout this guide. In field based crops, more variable temperatures and poorer hygiene have resulted in less reliable control, although successes have already been noted. Significant efforts are being made to develop novel biocontrol measures in a Horticulture LINK project HL 1107 (HDC Project SF 120).

Damage symptoms

Damage is first seen in May on tunnelled field grown crops, but can continue to appear throughout mid and late summer. First symptoms appear as characteristic brown marking on the flower petals (Figure 26). It is the receptacle (the yellow parts) of the flower that is the preferred feeding site, and therefore significant damage may have occurred to an individual flower before the petals become marked. When WFT numbers are high, damage occurs rapidly and the whole flower may gain a brown, unsightly appearance. Feeding continues on the surface of green and white developing fruits, which develop brown markings around the seeds and have a bronzed, unsightly appearance.

26. Damage to strawberry flower petals caused by western flower thrips feeding

Other thrips species have been suspected of similar damage, and current research aims to confirm this, both in the Netherlands and the UK. The Horticultural Fellowship project CP 89 will include work to confirm damage caused to everbearer strawberry by other thrips species.

Neoseiulus cucumeris - key facts about the primary predator

Minimum temperature

- N. cucumeris will develop at 8-30°C.

Maximum temperature

- Temperatures of 35°C and above are lethal to the eggs and young mites. However, it works well through the summer months under tunnels, as the mites will move quickly to cooler locations in the canopy if needed.

Tolerance to humidity

- Humidity should be above 70% RH. The eggs die at lower humidity. It is well suited to controlled release sachets, which contain prey mites of a different species, helping to support the colony for up to six weeks. Larger canopy crops have sufficient humidity (e.g. around leaf hairs, flower parts and crown centres), within them to support loose applications.

Activity

- *N. cucumeris* (Figure 27) will not eliminate thrips from a crop, but can contain the thrips population and fruit damage very significantly if applied well.

27. ***Neoseiulus cucumeris*** **adult**

- It is hard to find with the naked eye after it has been applied or introduced to a crop, so ensure even application and maintain accurate records. It tends to inhabit the same parts of a plant as its food source, (i.e. pollen and thrips larvae). It may be found in the flower centre and between the sepals and petals. It will not generally be found on the leaf surface, though may be found sheltering deep in the hairs at the base of leaf veins.
- These locations are perfect for thrips control as they are where the relevant stages of the pest are found.
- *N. cucumeris* only eats the first stage larvae of thrips. These early thrips stages are difficult to see even with a hand lens, as they are small (1mm long) and clear or white. Control manifests itself in a reduction in numbers of adult thrips (WFT and others) and relies on the presence of an almost unseen level of predators.
- *N. cucumeris* will also consume two-spotted spider mite eggs, though it should not be considered as a reliable predator of this pest.
- Bulk quantities can be applied by hand or various mechanised devices such as tractor mounted applicators or a blower operated applicator (Figures 28a and 28b), available from biocontrol suppliers.

28a. ***Neoseiulus cucumeris*** **application by tractor**

28b. Koppert air blower used to distribute bulk quantities of predators

Appetite

- *N. cucumeris* offers preventive control of thrips and should not be relied upon as a curative measure.
- Sachet formulations provide a food source for the predator in the absence of flowers. This is a convenient way to maintain a population in the early part of the season (March to April) when flower numbers are sparse. Loose applications are more useful when thrips are seen and sufficient flowers are open to provide a plentiful supply of pollen. *N. cucumeris* can feed on pollen as well as pests.
- *Orius laevigatus* (Figure 29) can be used as a supplementary treatment; they eat all larval stages of thrips as well as adults. Horticulture LINK project HL 1107 (HDC project SF 120) is investigating the benefit of using this predator to supplement control of WFT by *N. cucumeris* on everbearer strawberry.

29. ***Orius laevigatus*** **feeding on a midge larva**

- Care should be taken to integrate pesticides that are safe to both predators, or have minimal harmful effects (see Appendix 3).

How and when to start assessing pest presence

Significant new information has come to light about monitoring for western flower thrips in strawberry through Horticulture LINK Project HL 01107 (HDC Project SF 120).

The first strawberry flowers in tunnel crops are seen in March. They attract adult thrips, which soon lay eggs. The thrips concentrate in the yellow stamens and anthers as they feed on the pollen.

When monitoring for thrips in strawberry, the selection of flower age and position affects population estimates. For monitoring thrips adults, select flowers of medium age (all petals present, pollen shed) from the top of the plant, as young (petals fresh, pollen not shed) or senescent (petals dropping) flowers will result in an underestimation. For monitoring thrips larvae, select senescent flowers (petals dropping).

Look in the flower centres. The yellow parts (carpel) host the thrips, although the adults are commonly crossing over the petals, into and around the sepals.

Low levels of adults can be missed as they weave deeply amongst the stamens. There are various ways of exposing the adult presence using a x10 lens:

- Tap the flower sharply onto a hand or preferably a piece of paper on a clipboard or in a notebook and watch adults and larger instars run for cover. This is the best way to count numbers of thrips per flower. Tap a minimum of 20 flowers to get a good idea of mean numbers per flower, as numbers can vary considerably between flowers.
- Gently blowing into the flower centre forces the adults out onto the petal.
- Peel the petals and sepals back and look straight into the side of the carpel.

Bronzing damage to strawberry fruit (Figure 30) increases with increasing numbers of adult thrips per flower. In the Horticulture LINK project, initial results indicated that significant damage which might result in downgrading of fruit corresponded to an average of 4-8 adult thrips per flower. This result was on one everbearer variety, in one season only, and further work is planned in the project to confirm the ‘threshold’ number of thrips adults leading to fruit damage that downgrades fruit or renders it unmarketable.

30. Bronzing damage to strawberry caused by adult western flower thrips feeding

Blue sticky traps are very effective at catching thrips (Figure 31), each catching several hundred thrips per week at times in Spanish tunnels in the UK. In strawberry, the best position for traps is to mount them onto a post (a cheap bamboo cane is sufficient, held in place with a rubber band) with the bottom of the trap (landscape orientation) about 10cm above the top of the crop (one hand width), orientated to face south so that it catches more light. Traps are less useful than checking flowers, when deciding if action is needed to improve thrips control.

31. Blue sticky traps can be effective at catching thrips

Assessing damage during the season

The adults of western flower thrips are the first sign of trouble. You may suspect it is this pest where spinosad (Tracer) has failed to gain control in the past. A microscopic examination is the only way to make a clear identification of thrips species. Early signs of damage are seen as brown rasping at the back of the calyx on the inside the flower. Adult thrips will be easily found at this stage. Green berries of all sizes will be bronzed, remaining so until ripe. Low levels of damage only affect parts of a berry, though these rapidly become completely affected. Berry bronzing can be seen in April under tunnels as green berries develop.

Crop hygiene

Western flower thrips overwintering is still subject to further investigation. It can overwinter reliably in everbearer strawberry fields. HDC trials have shown that adults emerged in March and April from planting holes, second year overwintered plants and plant debris and straw in the alleyways. Its exact overwintering behaviour is still to be confirmed. Removal of the previous crop before replanting does seem to greatly reduce WFT presence in spring.

How to treat with *Neoseiulus cucumeris*

Field scale control of this pest using biocontrol agents is still under development in Horticulture LINK Project HL 1107 (HDC Project SF 120). Early results indicated that *N. cucumeris* emerged in reasonable numbers from sachets when placed in the crop when mean temperatures in the crop were above 13°C (this was mid-March in the year of the experiment). Further work showed that early releases of *N. cucumeris* from sachets followed by more of either sachets or loose product after 6 weeks can reduce numbers of western flower thrips in the crop, but numbers of the pest may increase later in the season.

Similar on farm commercial success using *N. cucumeris* has been gained through introduction of sachets (Figure 32 - overleaf) from mid March onwards in tunnel everbearer crops which are starting to flower, followed by fortnightly applications of loose product from mid April to mid September. The normal rate at present for prevention of thrips is 10-50 mites per plant per application. The most effective strategy for using the predator is currently being further refined in Horticulture LINK project HL 1107.

32. Sachets used to release *Neoseiulus cucumeris*

Supplementary support with the predatory mite *Hypoaspis miles* for control of thrips larvae when they fall to the ground to pupate, and of pupae, may help further. Introduction of *Orius laevigatus* in combination with *N. cucumeris* can provide control of all life stages of thrips in the warmer months from late May and June onwards (this predator needs a minimum of 15°C for egg-laying). This has been successful on some commercial sites, and the benefits of using *Orius* to support *N. cucumeris* are being studied in Horticulture LINK project HL 1107. The biocontrol costs using this programme are high, but are still significantly less expensive than the loss in revenue incurred by WFT damage to the crop, which can be >40% of lost tonnage for everbearers.

It should be noted that insecticides commonly used for capsid control in commercial plantations such as the pyrethroid lambda-cyhalothrin (Hallmark) and the organophosphate chlorpyrifos (Equity), are very harmful to, and persistent against, *N. cucumeris* and *Orius laevigatus*. Horticulture LINK Project HL 0184 (HDC Project PC/SF 276) led to the commercial development of capsid traps which contain lures using the female sex pheromone of common green capsid and European tarnished plant bug. These traps are commercially available and enhance the early detection of these pests, which could allow for more timely application of insecticides. Reducing weeds within the crop will also help to reduce the capsid threat.

Further reading

Further information on western flower thrips and other thrips species is provided in:

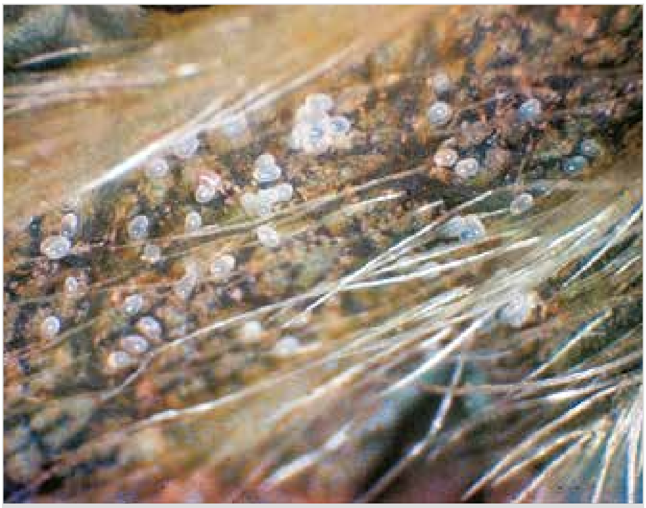
- HDC Factsheet 05/03 (*Integrated control of thrips on strawberries*) by Jerry Cross of East Malling Research
- HDC Factsheet 14/09 (*Thrips control on protected ornamental crops*) by Jude Bennison of ADAS

Tarsonemid mite

Tarsonemid mite – key facts

Tarsonemid mite can arrive on a farm via infested stock. Although it doesn't walk long distances, it can crawl from one plant to another where the foliage touches. It can also be carried on the runner plants developing at the tips of stolons, which elongate and grow away from the crowns of infested mother plants. In addition to being introduced on infested planting material, they may also be spread by other means such as insects, wind, trays, punnets, equipment and on clothing.

The pest is extremely small, so good light and a x15 lens is needed to see the mites (Figure 33). They are translucent and 0.2-0.25 mm in length. This is about three times smaller than a two-spotted spider mite. Adults overwinter and start laying eggs in spring. The pest presence is most frequently first noticed when small patches of emerging leaves become twisted, from May onwards, as populations of the mites increase. Their patchy distribution and minute size makes them very hard to spot any earlier than this.



33. Tarsonemid mite adults and eggs

Small numbers of adult female mites overwinter in the crowns of strawberry plants, between the bases of the petioles. In early spring, the females invade the youngest leaves and lay eggs, mainly on the upper surface of the main vein. Females lay up to 50 eggs. Each generation from egg to adult takes about 28, 24, 12 and 9 days at 12.5ºC, 15ºC, 20ºC and 25ºC respectively, the rate of development increasing markedly with temperature.

Damage symptoms

Once infested, emerging leaves and also flower trusses in everbearers become heavily distorted (Figure 34), leading to significant yield reductions in everbearers in the current season and loss of crop the following season in mainseason varieties. These central growing points are impossible to reach adequately using an acaricide spray. Late season flowers may fail and produce small hard brown berries.The pest then retreats deep into the plant crown through late autumn in order to overwinter.

34. Distorted strawberry leaves caused by tarsonemid mite feeding

Neoseiulus cucumeris **- key facts about the primary predator**

- As with thrips control, *N. cucumeris* offers preventive control of tarsonemid mite and should not be relied upon as a curative measure.
- Refer to *Neoseiulus cucumeris* key facts covered earlier in the western flower thrips section.

How and when to start assessing pest presence

Tarsonemid mite is first seen in May after it has emerged in sufficient numbers from the crown. Although it may be present, until numbers have increased and significant feeding damage has occurred, leaf damage is not obvious. As a tiny mite, it is often only found by accident whilst looking for other pests. The adults appear first on the base of the youngest leaves. Pick out a young furled leaf and examine close to the veins, especially the leaf base, for the presence of damage or mites using a x15 hand lens. They are buried in the hairs of the leaf and are best spotted in bright sunlight as they reflect light off their translucent bodies.

Affected leaves eventually have a darker area at their base, which becomes olive green to brown and tough to touch. It is likely that surrounding less developed patches in the crop will steadily become apparent. Start crop wide control as soon as these symptoms are found.

Assessing damage during the season

Severely infested plants have heavily restricted central crown growth and emerging leaves. Flower trusses in everbearers also become stunted. Flower stunting becomes apparent from July onwards. Severely affected plants will be almost impossible to save. However, the pest activity can be significantly suppressed in the surrounding plants.

Crop hygiene

Tarsonemid mite cannot fly. The rate of spread is slow, but 'spread' should not be confused with neighbouring sparse populations that develop at different rates across a field. It does not automatically follow that the new clean plants will be re-infested on re-planted sites that suffered from tarsonemid. The new plants will remain clean when good control has been achieved using *N. cucumeris.*

How to treat with *Neoseiulus cucumeris*

Everbearer crops are particularly susceptible to this pest. It is best to assume that almost all everbearer strawberry crops need protective treatments using *N. cucumeris* in mid May when the temperatures are reliable and the crop leaves are starting to touch each other to help the predators spread between plants.

Most crops are completely free of tarsonemid mite, but this protective treatment is cheap and effective for what can be a very expensive and difficult pest later in the season.

It is worth applying the predators to first year mainseason crops as soon as symptoms are seen if they are to be kept for another year.

N. cucumeris can be introduced in sachets (Figure 35) shortly before flowering at a rate of 5,000 sachets per hectare as a preventive measure. The sachets last for 6-8 weeks. They are only suitable for use in protected crops where they are protected from rain. Use of sachets is not advised for curative control of tarsonemid mite, as the release rate of the predators from the sachets is too slow.

35. Sachets used to release *Neoseiulus cucumeris*

N. cucumeris as a loose product (Figure 36) can be used to control established infestations of tarsonemid mite providing the extent and severity of infestation is limited.

36. *Neoseiulus cucumeris* released as a loose product

Pest Level	loose predator rate/m^2
Lightly infested areas	50
Heavily infested areas	200-400
None infested areas	20

A series of applications at the above rates until the problem is under control and the predatory mites have established is desirable.

Where infestations are severe, it may be necessary to reduce numbers of tarsonemid mites with an acaricide spray before introducing the *N. cucumeris*. These sprays need to be high volume and penetrating to the crown centre. A delay will be needed before introduction of predators to allow any harmful effects of the acaricide to decline before introduction.

Further reading

Further information on tarsonemid mite in strawberry is provided in HDC Factsheet 15/03 (*Tarsonemid mite on strawberry*) by Jerry Cross of East Malling Research.

Vine weevil

Vine weevil - key facts

Adult vine weevils (Figure 37) feed on leaves of soft fruit crops and cause little economic damage. The larvae (Figure 38) do the most damage as they feed on the roots of all soft fruit crops, reducing root volume, which brings about weak growth and plant stunting. Severe feeding damage to the roots can lead to complete root removal and plant death. In strawberries, the larvae tunnel into the crowns and cause extensive crop death (Figure 41). Vine weevil larvae thrive in both soil and container-grown crops. Container-grown raspberries and blueberries are more vulnerable to damage than their soil counterparts as their root systems are more confined.

37. Adults vine weevil

38. Vine weevil larvae

Larvae pupate in the spring and early summer with adults appearing from May and June. All adult vine weevils are females, which feed for 4-6 weeks before laying eggs. Each adult female is capable of laying 200-400 eggs in a season. Eggs start to hatch into larvae from late July under tunnels and from August outdoors, when root feeding begins.

Larvae feed on roots through late summer and autumn, then more slowly into the winter months and spring. Damage starts to appear in late autumn and again the following spring.

The classical vine weevil life cycle stages have become less defined with extended tunnel use, plastic covered beds and occasional mild winters. These sheltered cropping systems need closer vigilance.

Damage symptoms

Adult damage first appears from April to June. The adults are nocturnal, hiding at ground (or compost) level by day and climbing into the crop canopy on warm still evenings when they feed on leaf margins, producing a characteristic notching around the edges of leaves (Figure 39). This occurs throughout the summer months.

39. Notching on strawberry leaf caused by adult vine weevil feeding

As larvae start to hatch, they start to feed on roots from July until winter. In strawberry, visual damage is often not apparent until November, when early autumn red and orange leaf colour develops, signalling plant stress. In the following spring, affected plants remain weak and stunted and fail to develop like healthy plants. As temperatures increase, affected plants become stressed and the whole plant wilts and dies. It is worth noting that re-planted beds in spring can be badly attacked from overwintered larvae from the previous crop.

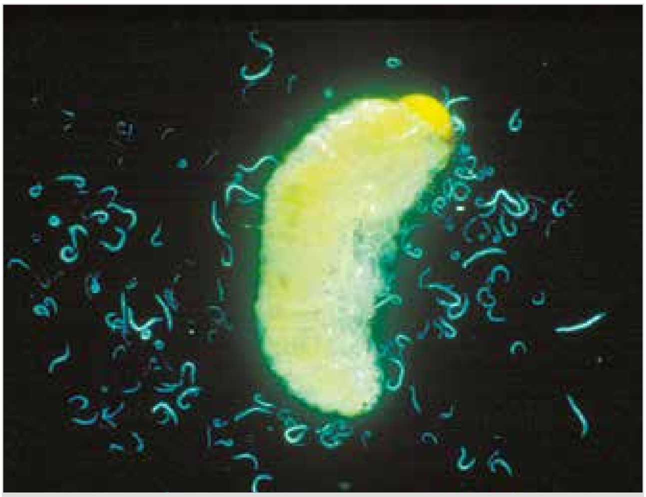
Damage is often less noticeable until the spring for soil grown cane and bush fruit. Substrate raspberries and blueberries are more easily damaged as they have confined root systems. Floricanes often fail to break bud. Some canes break bud as usual, but laterals remain stunted and then wilt and die. Primocanes on affected plants (or stools) either fail to emerge, or else start to grow but fail to develop to any significant height.

Predatory nematodes - key facts about the primary predators

Species

- Several species of nematodes are successfully used for controlling vine weevil larvae, including *Steinernema kraussei, Heterorhabditis megidis and Heterorhabditis bacteriophora.*

The nematodes are applied to the soil or compost as a drench, in suspension in water. They enter the larvae through body openings or by penetrating the weevil larval cuticle. Once inside, symbiotic bacteria are released which multiply rapidly, killing larvae within 48 hours (Figure 40). They are all highly effective if their use is well planned. They are best applied as drenches using trickle, spaghetti or hand lance applications. They have also been applied by tractor sprayer and irrigated in for traditional soil grown crops.



40. Vine weevil larva killed by predatory nematodes

41. Vine weevil larvae feeding on crown tissue of strawberry

Minimum temperature

- *Heterohabtis bacteriophora* and its bacteria is 11°C or 14°C, depending on supplier
- *Heterohabtis megidis* and its bacteria is 12°C
- *Steinernema kraussei* and its bacteria is 5°C.

Maximum temperature

- Heterohabtis bacteriophora and its bacteria is 30°C or 33°C, depending on supplier
- Heterohabtis megidis and its bacteria is 26°C
- Steinernema kraussei and its bacteria is 30°C

Activity

- All products need good volumes of water that need to be placed in the root zone. The nematodes migrate most easily through wet light soil or compost; plenty of moisture around the root zone is essential.
- Nematodes move less well through dry and heavy soils. Soil applications need excellent location of the drench in the root zone to work at their best. The nematodes need a continuous film of moisture to migrate to the vine weevil larvae and pupae.
- Once a larva is infected, the nematodes breed and then infect other larvae.
- Products claim up to four weeks protection under guideline conditions for one application. Appreciate that falling temperatures in autumn will impair this figure.

How and when to start assessing pest presence

In strawberries, some plant stunting and death occur in the autumn, but mostly spring will indicate root and crown damage. In raspberries and other cane fruits, poor bud break, stunted lateral growth and a lack of primocane or weak primocane growth will signal vine weevil larval activity. Dig strawberry plants or canes out of the soil or substrate and examine the crowns or roots for evidence of damage. In strawberries, a lack of roots and/or presence of tunnels in the crown will be found (Figure 41). Also look for signs of red/orange frass, which is left from the larvae feeding. In cane fruit, a lack of roots and tunnels in the larger roots may be evident.

Look for the larvae or pupae themselves, which will be found in the root zone in spring. They are sometimes found within the tunnels they have burrowed in the crown of strawberries or larger roots of cane fruit. It is possible for damage to occur before nematodes have been applied to a crop, so such damage may be apparent, even where vine weevil larvae have since been controlled.

Assessing damage during the cropping season

From late May onwards in tunnel crops, look for the characteristic notching around the leaf margins (about 4mm across) on the lowest leaves of raspberries (Figure 42) and fresh upper leaves of strawberries (Figure 39). It is worth checking for adult vine weevil activity in suspected areas. Vine weevil adults are nocturnal, so check by using a torch light (it should be too dark to read) on a warm still night to verify its presence and assess population levels. The leaves must be almost motionless for the adults to climb into the crop canopy. The adults will not climb shaking foliage due to wind or rain. This is a defence mechanism against foraging predators.

42. Leaf notching around margin of raspberry leaf caused by adult vine weevil

Where adults are found, it is certain that eggs will be laid around the plant roots, so regular checking for larvae should be made in the soil or compost around the root zone from late July onwards. It is essential to start treating with nematodes as soon as possible after egg hatch to prevent significant root feeding from taking place. If control is delayed too long, vine weevil larvae can start to burrow into strawberry crown tissue, causing significant irreversible damage. Also, depending on the nematode product used, night time soil temperatures can start dropping below the nematodes' optimum temperature from late September onwards, particularly in outdoor crops.

Crop hygiene

Vine weevil movement is fairly predictable on farms. It will migrate from infested areas to adjacent plants or crops. It cannot fly so tends to work in from the edges.

Adult vine weevils are readily carried by pickers who can transport them on their clothes, shoes, punnets or picking trays, sledges etc. This can lead to unexpected areas of damage appearing in remote or isolated parts of a previously clean plantation.

Aim to control populations in older crops, before the younger neighbouring plantations become infested.

How to treat with insect-pathogenic nematodes

Although most growers try to control adult vine weevils in the summer months using insecticide sprays, complete control is rarely gained and some degree of egg laying takes place. There are currently no recommended biocontrol agents available for controlling adult vine weevil, so biocontrol of the larvae is essential if the pest is to be controlled effectively.

Nematode drenches are very effective, if targeted in August and early September when optimum soil and compost temperatures prevail. The correct temperature is all important if good control is to be achieved. At least a month of the minimum temperature provides an acceptable period of time for nematodes to gain effective control. Complete control is unlikely with a single treatment as some larvae will be protected inside the crown and roots, or located outside the treatment area. For best results start treating with nematodes early to provide as big a window of control as possible. Do not wait until late September unless you are using the comparatively cold tolerant species *Steinernema kraussei.*

The product labels (Figure 43) give very important and clear guidance regarding application methods including the constant agitation of the solution to prevent nematodes settling out, removal of inline filters to prevent nematodes clogging them and assessing irrigation line flow times in order to reach the entire crop. It is important to locate the drench as close to the root zone as possible. Soil beds must be well wetted up beforehand to increase the potential for nematode migration. The small root zones of container or bag grown crops, and their comparatively damp root zone are perfect for nematodes.

43. Product label of predatory nematodes offering clear guidance on application

Autumn applied drenches of chlorpyrifos to soil grown crops (up to November according to label directions) are temperature insensitive and can complement the use of earlier applied nematodes if required.

Spring re-planted soil beds cannot be treated with chlorpyrifos, but are very effectively protected with a planting hole drench of colder tolerant *Steinernema kraussei* in March to April. A 100% plant survival rate is commonly possible for soil and compost re-plants.

Further reading

Further information on vine weevil in soft fruit is provided in HDC Factsheet 01/03 (*Vine weevil control in soft fruit crops*) by Scott Raffle, formerly of ADAS UK Ltd.

Aphids

Aphids – key facts

A large number of aphid species infest soft fruit crops. The most commonly found in strawberry include strawberry aphid (*Chaetosiphon fragaefolii* - Figure 44), shallot aphid (*Myzus ascalonicus*), melon and cotton aphid (*Aphis gossypii*), potato aphid (*Macrosiphum euphorbiae*) and glasshouse and potato aphid (*Aulacorthum solani*).

44. Strawberry aphid

Most commonly found in cane fruit are the large raspberry aphid (*Amphorophora idaei* – Figure 45), small raspberry aphid (*Aphis idaei*), potato aphid (*Macrosiphum euphorbiae*), peach-potato aphid (*Myzus persicae*), the melon and cotton aphid (*Aphis gossypii*) and two species confined to blackberry, the blackberry-cereal aphid (*Sitobium fragariae*) and the rubus aphid (*Amphorophora rubi*).

45. Large raspberry aphids

The life cycles of all of these aphids differ, but it is outside the scope of this guide to provide full details of each. Further information can be found in two HDC Factsheets (see Further information section at the back of this guide).

Good end of season hygiene using aphicides delivers a significant reduction of spring aphid levels.

Damage symptoms

It is important to know that the different aphid species cause varying amounts of damage to strawberry and cane fruit crops.

All species debilitate the plant by sucking sap and excreting honeydew that contaminates the foliage, flowers and fruits. Sooty moulds grow on the honeydew which gives rise to blackening. In addition, fruits and/or the calyx may be contaminated by aphids themselves, their dead bodies or their cast skins.

The strawberry aphid does not cause any leaf distortion in strawberry, but it is an important virus vector in strawberry and is capable of transmitting strawberry crinkle virus, strawberry mottle virus, strawberry vein banding virus and strawberry mild yellow edge disease.

The melon and cotton aphid (Figure 46) infests strawberry foliage and flowers forming dense colonies in patches that produce copious secretions of honeydew, which rapidly become blackened by sooty mould. It also acts as a vector of strawberry mottle virus.

46. Melon and cotton aphids

The potato aphid (Figure 47) is very common, especially in spring. Heavy infestations can weaken the young plants and flower trusses, causing distorted trusses and berries.

47. Potato aphid

The shallot aphid causes serious feeding damage to strawberry plants. It feeds during winter and early spring, mainly in the growing points and young leaves, causing strong plant distortion symptoms. Infested plants become severely stunted when growth commences in spring, the petioles being shortened and the leaves curled and twisted. Blossom trusses on infested plants are similarly affected. Cropping is much reduced and the fruits are small and of poor quality.

In cane fruit, the large raspberry aphid acts as a vector for black raspberry necrosis virus, rubus yellow net virus, raspberry leaf mottle virus and raspberry leaf spot virus.

The small raspberry aphid, if present in large numbers, can cause extensive leaf curling on primocanes (Figure 48) and developing fruiting laterals. Ants may be found associated with colonies of any aphid species, but they are particularly common on this species, feeding on the copious honeydew the aphids produce and defending the colony from attack by predators and parasitoids. The small raspberry aphid also transmits raspberry vein chlorosis virus.

48. Leaf curling damage on raspberry caused by the small raspberry aphid

Potato aphid can also give rise to serious leaf and fruit contamination by honeydew and sooty mould on raspberry, but is not considered to be a virus vector.

On raspberry, the melon and cotton aphid is increasingly found on protected crops. Although this species is a very efficient virus vector in many crops, its status as a virus vector on cane fruit is not well documented.

Parasitoids and predators – key facts about the primary biocontrol agents

- Both parasitic wasps (parasitoids) and predatory midges have been successfully used to control aphids in commercial soft fruit crops under protection, although they can be a more expensive option than a traditional aphicide.

Parasitoids

- Aphid parasitoids should be the first line of defence. They are very specific to certain aphid species, so until recently, correct aphid identification (or ideally, knowing which aphid species to expect, to allow preventive parasitoid releases) has been essential before deciding which parasitoid to choose. However, a mix of six parasitoid species is now available for use in soft fruit crops (Table 4 - overleaf). This extends the range of aphid species attacked, and as it is designed to be used preventively, it can be used without the need for aphid identification.

- Parasitoids lay their eggs inside the aphid's body, which turns into a parasitised mummy (Figure 49). Adult parasitoids emerge from the mummified aphid and search for living aphids in which to lay further eggs.
- Most parasitoid species (except for *Aphelinus abdominalis*) are very mobile. Release points every 200m^2 should be sufficient for good distribution as the adult parasitoids will fly to find aphids.

49. Parasitised aphid mummy

Table 4. Guide to aphids controlled by parasitoids (single: available as single species, mix: available in mix of 6 species)

Aphid species	Parasitoids					
	***Aphidius colemani* (single & mix)**	***Aphidius ervi* (single & mix)**	***Aphidius matricariae* (single & mix)**	***Aphelinus abdominalis* (single & mix)**	***Ephedrus cerasicola* (mix)**	***Praon volucre* (mix)**
Peach-potato aphid (*Myzus persicae*)	Yes		Yes	Yes	Yes	Yes
Shallot aphid (*Myzus ascalonicus*)			Yes		Yes	Yes
Melon and cotton aphid (*Aphis gossypii*)	Yes		Yes		Yes	Yes
Small raspberry aphid (*Aphis idaei*)	Yes		Yes			
Glasshouse and potato aphid (*Aulacorthum solani*)		Yes	Yes	Yes	Yes	Yes
Potato aphid (*Macrosiphum euphorbiae*)		Yes		Yes		Yes
Strawberry aphid (*Chaetosiphon fragaefolii*)					Yes	Yes
Large raspberry aphid (*Amphorophora idaei*)		Yes				Yes

Predators

- The aphid predatory midge *Aphidoletes aphidimyza* is the principal predator used in soft fruit and can be used to supplement the control achieved by parasitoids. It feeds on all aphid species.
- It only establishes where aphid colonies are present so should not be used as a preventive measure. Adult midges are mainly active at night. Females search for aphid colonies in which to lay their eggs. The number of eggs laid depends on the density of the infestation.
- The midge larva that hatches is bright orange and immediately attacks the aphids (Figure 50). The larvae inject a poison into an aphid to paralyse it, making it easier for the larva to consume. When many aphids are available, the midge larvae kill more aphids than they can consume, making the midge an effective and reliable predator.
- Temperature has a marked effect on the activity of *Aphidoletes aphidimyza*. A minimum dusk and night temperature of approximately 15ºC is required, which limits the use of *Aphidoletes* until about mid-May at the earliest under polythene tunnels. The midge needs high humidity conditions for adult survival.
- *Aphidoletes aphidimyza* needs 15 hours of daylight per day to allow it to complete its development, which also limits its use to between May and September.

50. *Aphidoletes aphidimyza* larvae feeding on aphids

Assessing crops for aphid presence and damage

Check all plantations weekly or at least fortnightly from the resumption of growth in strawberries and from bud burst in cane fruit.

Strawberry

In strawberry, monitoring should take place throughout the growing season and should continue through the winter, when shallot aphid becomes active. Examine the whole area of crop, looking for patches of stunted growth or abnormal colouring. Any such patches should be closely examined and the cause diagnosed. Although aphids could be the cause of such damage, other pests or diseases may be implicated.

Examine the undersides of the youngest emerging leaves and the undersides of the older leaves. Shallot aphid may occur singly or in small numbers between the folds of very young, unfurling leaves, which are usually characteristically distorted (Figure 51). Melon and cotton aphid may occur in the flowers. Leaves, flowers and fruits, including stalks, should be examined for other tell tale signs of aphid infestation such as glistening or stickiness of honeydew or the presence of cast skins. Blackening by sooty mould usually indicates the infestation has been present for some time.

51. Strawberry leaves distorted by shallot aphid feeding

Cane fruit

In cane fruit, monitoring should continue from bud burst until early autumn, looking initially in the unfolding leaves in the tips of fruiting canes and primocanes and later under all the foliar canopy when the aphids should be on the underside of fully and expanding foliage.

Damage thresholds

To date, for the majority of aphid species in strawberry and cane fruit, no economic damage thresholds have been developed. Simple thresholds that do not take into account time of season, growth stage, crop age, growing conditions and crop value are likely to be misleading.

There are exceptions however for the more damaging species. In strawberry, only very low populations (<5% plants infested) of damaging aphid species such as strawberry aphid or melon and cotton aphid can be tolerated early in the season. When low levels of these species are found, more frequent (twice weekly) and careful monitoring should be applied. There is a zero tolerance for shallot aphid, due to the damage it causes.

In raspberry, for the large raspberry aphid, the current suggested threshold for control in non-A_{10} resistant raspberry varieties is one aphid per young or mature leaf on fruiting canes or primocanes. A similar approach could be taken with the small raspberry aphid. For potato and peach-potato aphid, an estimation of the insect's population and its potential to cause crop contamination should be used to determine whether or not specific control measures are needed.

Crop hygiene

Aphids are ubiquitous pests so it is impossible to eradicate them from soft fruit plantations. However recent research in Defra Horticulture LINK projects to develop novel pest control technologies and ways of minimising pesticide residues in strawberry and raspberry (Projects HL 0191 – SF 94 and HL0175 – SF 74), has demonstrated that by completely eradicating aphids from strawberry and raspberry crops in the autumn, a significant reduction in pest populations will occur the following spring. Where this is achieved post harvest using aphicides, more reliance on biocontrol agents can be made the following spring when aphid numbers are low.

How to treat with parasitoids and predators

Specific parasitoids are supplied as parasitised mummies in a carrier (e.g. buckwheat), for gentle application to the crop canopy or release boxes (available from the biocontrol suppliers). The mixture of six species are supplied in cardboard tubes that need to be opened to allow the adults to emerge and feed on the drop of honey inside the cap, then placed horizontally in a sheltered position in the crop canopy to avoid direct sunlight and water (Figure 52).

52 . Parasitoid mix being released through a cardboard tube

For preventive treatment, introduce single species parasitoids at a rate of 0.25 per m^2 per week, as soon as the crop begins to grow in late March. Parasitised 'mummies' should be visible on the plants within two weeks of starting introductions. For curative treatment of low populations, introduce 0.5-1.0 per m^2 per week. The mix of six parasitoid species is recommended to be released preventively, at the rate of one tube every 200m^2, on three occasions.

The predator *Aphidoletes aphidimyza* is supplied as cocoons within a carrier, in bottles or pots. The bottle or pot should be opened and left in a shaded area where aphids are present. The adult midges will emerge from the cocoons in the carrier and fly off to find the aphids. Look for the orange midge larvae in aphid colonies one week after introduction.

For curative treatment of low populations of aphids, introduce *Aphidoletes* at a rate of 0.5-1.0 per m^2 per week. For curative treatment of higher populations, introduce at 1-2 per m^2 per week. For treatment of aphid hot spots, introduce at 5-10 per m^2 per week for the first introduction.

Whitefly

Whitefly – key facts

The principal whitefly species that affects soft fruit crops is the glasshouse whitefly (*Trialeurodes vaporariorum*). It feeds on plant sap, causing the plants to lose vigour. The waste product, honeydew, builds up on the leaves and allows sooty mould to grow, which is very disfiguring.

There are four stages in the life cycle of whitefly; eggs, nymphs/scales, pupae and adults (Figure 53).

53. Adult whitefly

Eggs are laid by the female whitefly on the undersides of leaves. They are an elongated oval shape and stuck onto the leaf. Eggs are normally laid on the youngest leaves towards the shoot tips. Glasshouse whitefly often lays them in a semi-circle in the case of heavy infestations, but otherwise eggs are scattered randomly. The eggs are white when first laid and turn black just before hatching into 'crawlers' or first stage nymphs.

The crawlers move around the underside of the leaf before they settle and attach themselves with their mouthparts. From this phase onwards they remain immobile, feeding on plant sap, and pass through four nymphal stages before reaching the pupal stage. Scales of glasshouse whitefly are translucent when young and pale cream in colour when older.

Older scales and pupae are found more often on lower leaves. The adult emerges from the pupa through a T-shaped slit in the upper surface. A hand lens is essential to check whether the adult has emerged otherwise the remains of pupae can be mistaken for living whitefly scales. This can lead to false conclusions about the effectiveness of control measures. Pupae are creamy white in colour, oval in shape and when viewed from the side, have a 'mattress' effect in that the depth can be seen.

Adults are 1mm long and appear pure white in colour. The adults have a 'lazy' flight compared to leafhoppers and tend to only fly when disturbed. They mainly occur on the leaves and very young shoots. Whitefly populations are generally low in the winter, but increase rapidly through the summer before decreasing again in late autumn.

Whiteflies require temperatures of 5-30ºC to develop with an optimum of 20-25ºC, when the time from egg to adult is around 32 days. Optimum humidity is 75-80% RH, so is almost exclusively a pest of protected crops.

Damage symptoms

No leaf or shoot distortion is caused by whitefly feeding, but both adults and larvae produce copious amounts of honeydew. When whitefly populations are high, the honeydew contaminates both leaves and fruit reducing crop vigour and making fruit unmarketable. On the foliage the honeydew eventually becomes infected with the sooty mould fungus and turns black (Figure 54).

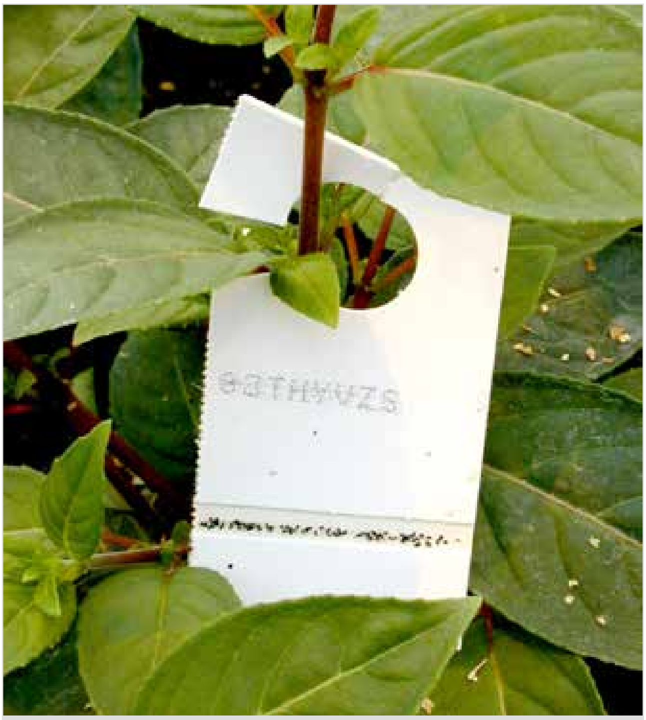
54. Sooty mould growth on honeydew

Encarsia formosa – key facts about the primary parasitoid

- The main biocontrol agent used for whitefly control is the tiny parasitic wasp *Encarsia formosa.*
- It needs higher temperatures than the whitefly i.e. a few hours above 18°C each day.
- The adult wasp lays eggs in the whitefly scales. The whitefly scale is killed and the parasitised scale turns black before the new wasp emerges (Figure 55).

55. Black (parasitised) and white whitefly scales

- The parasitoid is sold as parasitised (black) scales. The black scales contain *Encarsia* pupae from which very small adult wasps hatch and actively fly in search of unparasitised whitefly scales to lay eggs in.
- The *Encarsia* scales are available either loose in dispenser tubes or more commonly, stuck to cards which can be hung on the plant (Figure 56).



56. *Encarsia* scales stuck to card hanging from plant

- In the spring, *Encarsia* is quite slow acting and is best used preventively in crops prone to whitefly attack.
- Releases must be made preventively every week, and continuing at low whitefly population densities, as high numbers of whitefly scales on a leaf produce honeydew deposits that make parasitoid movement difficult.
- Pesticide options ahead of *Encarsia* introduction are very limited and should be considered carefully. Spiromesifen (Oberon) has an EAMU for use on protected strawberry grown in substrate or NFT. Thiacloprid (Calypso) has EAMUs for use on protected strawberry and raspberry. See Appendix 5 for effects on biocontrols.

Assessing crops for whitefly presence and damage

The best way of monitoring for whitefly is by checking the plants. This also allows checking for black parasitised scales and estimating the percentage parasitism. Whitefly adults, eggs and young scales will usually be in the tops of the plants and the older and parasitised scales will be further down the plant on lower leaves. Whitefly can also be monitored on yellow sticky traps, but this only gives an indication of the numbers of adults present, and does not enable parasitism by *Encarsia* to be monitored. The traps should be hung just above the crop canopy or near the top of cane fruit crops and secured to reduce movement. The optimum density is about one trap per 50-100 m^2 of floor space. It is better to have fewer traps that are inspected regularly than many traps that are never looked at.

Traps should be dated, assessed weekly and changed at least every three weeks. Trap catches should be recorded to plot the changes in the pest population.

Crop hygiene

Whiteflies are most commonly found in soft fruit crops under glass that has previously been used for producing salad or ornamental crops. They can also be brought in on planting material; particularly stock that has been propagated under glass. It can be very difficult to spot whitefly in the early stages after planting as they very often occur at very low levels.

Once present in a crop, localised infestations or ‘hot spots’ may develop in favourable areas, such as close to heating pipes in glasshouses. These may not be detected early by yellow sticky trap monitoring, so regular crop monitoring is essential.

How to treat with *Encarsia formosa*

Introduce *Encarsia* every week from the start of crop growth in the spring, at a rate of one black scale per m^2 (preventive rate). Temperatures should be 18°C for a few hours each day as this is a warm weather biocontrol agent.

Where a whitefly infestation becomes well established, the rate of Encarsia will need to be increased, in severe infestations perhaps to 10 per m^2.

Caterpillars

Caterpillars – key facts

A number of different moth caterpillars attack soft fruit crops. Many species can be tolerated at low levels as they only cause slight feeding damage and do not spread viruses. Examples of these include foliage feeding tortrix (Figure 57 - overleaf) and noctuid moths (e.g. cabbage moth) and the bramble shoot moth (*Epiblema uddmanniana*). The larvae of the small raspberry sawfly (*Priophorus morio*) also fall into this category. In certain seasons however, numbers of these moth caterpillars and small raspberry sawfly larvae can reach high levels, particularly in ‘hot-spots’ in plantations, so careful monitoring is required.

57. Tortrix caterpillar

Of greater concern in cane fruit crops are the raspberry moth (*Lampronia rubiella*) and the double dart moth (*Graphiphora augur*) which overwinter as larvae before climbing the canes and feeding on developing buds in the spring, which can lead to very significant damage.

Damage symptoms

Tortrix caterpillars tend to have two generations per year and cause most damage between April and September. On strawberry, they web young leaves and flower trusses together for protection while they feed. Some species will also feed on developing fruit. On cane fruit, they also bind leaves tightly together forming a protective canopy. They also attack young leaves in shoot tips, often killing the terminal bud, causing stem branching.

Noctuid moth caterpillars are much larger than tortrix caterpillars and may have one or two generations each year with most damage occurring between June and October. Noctuid caterpillars do not web leaves together but eat large holes in leaves and sometimes damage the crown or fruit.

The caterpillar of the bramble shoot moth is known as the webber, and can cause serious attacks to blackberry in spring. Infested flower buds are hollowed out. The leaves in the shoot tips of primocanes are webbed together and then killed, causing a growth check and distorted canes. These canes become weaker and have a reduced cropping potential the following year.

Larvae of the small raspberry sawfly feed on raspberry foliage, producing elongated holes in leaves, which although obvious, is rarely of economic importance unless numbers are high. The larvae can potentially be a crop contaminant.

Larvae of the raspberry moth hibernate in the soil or compost near the plant roots. In spring the larvae crawl up the cane (Figure 58) and bore into a bud or young shoot to continue feeding. Where the pest is present in high numbers, complete bud removal can occur across a whole plantation.

58. Larvae of raspberry moth climbing up raspberry floricane

Larvae of the double dart moth also overwinter on the ground and emerge in spring to climb the floricane and devour developing buds. With the correct weather conditions, a small number of caterpillars can cause severe damage and serious crop loss.

***Bacillus thuringiensis* – key facts about this bacterial biopesticide**

- *Bacillus thuringiensis* (Bt) is a bacterial biopesticide stomach poison, which is toxic to most caterpillars.
- The product is applied as a foliar spray in water and the bacteria are eaten by caterpillars on the leaf surface.
- Bt is most effective against the young stages. Eggs and adults are not controlled.
- Of the caterpillars listed above, it will control most with the exception of sawfly larvae.
- Bt is not rain fast so the bacteria will be washed off the leaf by rain or overhead watering. It should not be applied if rain is expected within six hours after treatment.

Assessing crops for caterpillar presence and damage

Crops should be assessed from the resumption of growth in strawberries and from bud break in cane fruit. Pheromone traps can be used to detect the presence of some tortrix moths, including summer fruit tortrix, fruit tree tortrix and carnation tortrix moth. Pheromone trap catches may also be used to establish a threshold, above which spraying for control is necessary.

However, in most cases farms rely on checking the foliage of their crops every 7 or 10 days throughout the growing season for the presence of these pests. Existing and potential damage to the crop as well as the risk of crop contamination at harvest will determine whether or not a spray is required.

In the case of raspberry moth and double dart moth larvae, raspberry canes should be examined very carefully both at the base of canes and in the developing buds. Look for presence of the larvae climbing up the canes from ground or pot level and also closely examine the buds and developing leaves. As the raspberry moth larva (borer) burrows into buds, it is worth randomly sampling buds destructively to identify if the larva is present in the buds. This is particularly important in plantations with a history of these pests.

Crop hygiene

Moth caterpillars are ubiquitous pests and there is little that farms can do to eliminate them from plantations. Populations can tend to build up over a period of years if they are left uncontrolled, so good monitoring from year to year is essential to determine if control measures will be required.

How to treat with *Bacillus thuringiensis*

Apply a spray of *Bacillus thuringiensis* at the first signs of damage. Ensure that good coverage of both sides of leaves is obtained, and at least six hours free from rain. Avoid strong sunlight and use between 10-20°C for the best effect. Caterpillars stop feeding and die one to three days later (Figure 59).

59. Caterpillars killed after ingesting *Bacillus thuringiensis*

Native predators and parasitoids for pest control

Introduction

Without exception all soft fruit pests have at least one naturally occurring predator or parasitoid. Normally there are several natural enemies for each pest.

In any natural ecosystem a balance develops between prey species and their enemies, but in crops this balance can be difficult to achieve. This is because many of the beneficials will need alternative food sources, which may not be present in or around the crop. However by positively managing the environment around, and to some extent within, the crop, beneficials can be encouraged.

There is plenty of evidence that naturally occurring beneficials can keep low pest populations at such a level that they do not develop to become economically significant. Conversely it is clear that established and rapidly growing pest populations will not be controlled by naturally-occurring beneficials before significant crop damage occurs.

Recognition of these beneficials and understanding their potential should be fundamental in any perennial crop production, soft fruit being a very good example. For this reason, monitoring naturally occurring predators and parasitoids should be included during routine crop walking.

Major predators and parasitoids

True bugs

Unlike many other insects, the larvae of true bugs resemble the adult, except for the lack of wings. The mouthparts of true bugs are adapted for sucking rather than chewing. Many bugs are plant feeders, but a number are carnivorous and are very useful predators.

Anthocorid bugs (Figures 60 and 61), assassin bugs and damsel bugs are the main predatory bug groups, with both nymphs and adults being predators. The largest group of true bugs is the capsids and, although most capsids are plant feeders, some, such as the black-kneed capsid (Figure 62 - overleaf), are voracious predators. Unfortunately, with the notable exception of the anthocorid bugs, distinguishing between pest bugs and predatory bugs in the field can be extremely difficult. Eggs of most bugs are laid in plant tissue or are very well concealed and are therefore unlikely to be found during normal crop monitoring.

60. Anthocorid adult feeding on aphid

61. Anthocorid juvenile feeding on aphid

62. Black-kneed capsid adult

The various predatory bugs feed on a wide range of invertebrates including aphids, scale insects, spider mites, thrips, other bugs, moth eggs and small caterpillars. Anthocorid bugs are normally entirely predatory, but when food is scarce they may probe ripe fruit causing minor damage.

Lacewings

Over 50 species of lacewings are present in the UK and all are predatory. Green lacewings are the commonest in crops and the adults are easily recognisable (Figure 63). Green lacewings overwinter as adults and shelter in hedgerows, dense evergreen vegetation, hollow trees and other cavities. Overwintering is quite common in outbuildings and in artificial refuges.

Their eggs (Figure 64) are laid on stalks that protect them from other predators; eggs are usually laid close to, or amongst, a colony of aphids. A single larva (Figure 65) can eat as many as 500 aphids before pupating in a spherical silken cocoon (Figure 66). As with many other general predators, larvae can be cannibalistic when other food is unavailable.

Lacewing adult and larvae feed mainly on aphids (Figure 67), but a range of other prey may be taken including spider mites, suckers, scale insects and leafhoppers. The adults of some lacewing species feed on nectar and only the larvae are predatory.

63. Green lacewing adult on strawberry flower

64. Lacewing egg on strawberry

65. Lacewing larva on strawberry flower

66. Lacewing cocoon

67. Lacewing larva eating aphid

Beetles

Ladybirds

These are probably the most easily recognised of our predators with 46 UK species. The majority of species are predatory (both as adult and as larva) but two species are plant feeders and three feed on fungi and pollen. Soft fruit is not attacked by plant-feeding ladybirds.

Aphids are the preferred food of the predatory species and in soft fruit the most common species are usually the seven-spot, the two-spot and the harlequin (Figures 68 and 69). The oval yellow/orange eggs are laid end-on, usually in groups, close to or amongst an aphid colony (Figure 70).

68. Ladybird adults (7, 2 and 16 spot)

69. Adult harlequin ladybird

70. Ladybird eggs

On hatching (Figure 71) the larva may eat its own eggshell and, if no food is available close by, will feed on un-hatched ladybird eggs. Larvae disperse readily and over relatively large distances, particularly when food is short; this is at least in part to avoid being eaten by one of their siblings (Figure 72). Larvae of the larger species, such as the seven-spot and the harlequin, can eat 700 aphids before pupating. The larvae are all distinctively marked, advertising to birds that, like the adults, they are unpalatable. Larvae often move off the plant to pupate, usually choosing a solid surface for pupation; pupae retain their warning colouration (Figure 73).

71. Young ladybird larva

72. Mature ladybird larva

73. Ladybird pupa

Adults overwinter, frequently in large groups, in similar situations to lacewings. Although aphids are their preferred food they are general predators and will feed on many other invertebrates including, scale insects, suckers, thrips, mites, insect eggs, small caterpillars and larvae of other invertebrates.

Ground and rove beetles

The adults of these beetles are generally fast running, shelter seeking and ground living (Figures 74, 75 and 76); their larvae are also ground living but usually not very active and are often overlooked (Figure 77). There are around 350 species of ground (or Carabid) beetles and most adults are predatory. One species, the strawberry seed beetle can be a pest; it is normally predatory, but as an omnivorous species, it will sometimes damage strawberry fruit when other food is scarce. There are nearly 1,000 species of rove (or Staphylinid) beetles in the UK and the adults of most are omnivorous predators.

74. **Ground beetle adult**

75. **Green tiger beetle adult**

76. **Adult rove beetle**

77. **Ground beetle larva**

Although both ground and rove beetle larvae are omnivorous, many are voracious predators of soil-living invertebrates, but being less active than the adults they may not be as important as beneficials.

These are general predators and usually have no favoured invertebrate food. Soil-living invertebrates are their main prey, but they also feed on insects, which normally feed in the plant canopy, but pupate in the soil. Both ground and rove beetles will climb up low growing plants at night to feed when aphids and foliage caterpillars become prey. Ground and rove beetles are the major predators of vine weevil eggs and larvae (Figure 78), and the larger species also feed on slug eggs and small slugs.

78. **Devil's coachhorse with vine weevil larva**

Other beetles

Although most beneficial beetles are included in the above groups, there are a few other smaller families, some of whose members are mainly predatory. Soldier beetles (Figure 79) and the cardinal beetles (Figure 80) are the best examples. Adult soldier beetles often hunt in flowers, but their larvae are voracious ground predators. It should be noted that one soldier beetle species adult is a pest of raspberries in parts of Scotland. Adult cardinal beetles are large brightly coloured general predators that are often present in soft fruit; their larvae are predators of wood-boring insects.

79. Soldier beetle adult

80. Cardinal beetle adult

Parasitic wasps

This group is arguably the most important and under-recognised group of beneficial invertebrates. Ichneumons, Brachonids and Chalcids are the 3 main groups and together contain well over 4,000 species, all of which parasitise other invertebrates. Adult wasps (Figures 81 and 82) have remarkable searching ability and, depending on the species, will lay one or more eggs in or on its host (Figures 83, 84 and 85). Each parasitic wasp species targets a limited range of prey; some being specific to individual species while others may target more than 50 different species. The larval stages of the host are normally attacked by most parasite species (Figures 86 and 87 - overleaf), but eggs, pupae and adults can also be targeted by other parasite species. The majority of soft fruit pests have at least one naturally occurring parasitic wasp enemy.

81. Adult parasitic ichneumon wasp

82. Parasitic brachonid wasp adult

83. *Aphidius* parasitic wasp laying egg in aphid

84. *Aphidius* pupa

85. *Praon* pupa

86. Caterpillar with parasite larvae

87. Caterpillar with parasite pupae

Hoverflies

Very recognisable adult insects which themselves are not predatory but usually feed on nectar or pollen, and are therefore attracted to flowering plants. Eggs are usually laid singly, always amongst their prey (Figure 88). Unlike some other general predators such as ladybirds and lacewings, hoverfly larvae (Figure 89) have limited mobility and searching behaviour. The larvae are voracious predators of aphids (Figure 90) and have been recorded as eating almost 1,000 aphids before pupating. Typical of fly larvae generally, feeding is rapid and the complete life cycle can take just 3 weeks, which is considerably quicker than other similar sized aphid predators. Hoverflies usually overwinter as larvae or pupae (Figure 91) on deciduous plants.

88. Hoverfly egg amongst aphids

89. Mature hoverfly larva

90. Young hoverfly larva feeding on aphid

91. Hoverfly adult and pupa

Hoverflies are primarily aphid predators, but they are known to feed on other sucking insects. They have also been recorded feeding on spider mites and small caterpillars, when their aphid prey runs out.

Other predatory flies

The adults of some large flies, such as robber flies (Figure 92), are predators of large flying invertebrates, but these have little effect on pest species. The most important predatory flies in soft fruit are those whose larvae are predatory, particularly the Cecidomyid flies (midges). The importance of these midges is confirmed by the commercial development of the widespread naturally occurring species *Feltiella acarisuga* for two-spotted spider mite control (Figure 93) and *Aphidoletes aphidomyza* for aphid control in the UK (Figures 94 and 95). These predatory larvae commonly appear naturally in moderate to heavy pest infestations and can rapidly reduce the pest population to insignificant levels. The larva injects a poison to paralyse its prey and can kill many more pests than it consumes.

92. Robber fly adult

93. *Feltiella acarisuga* larva feeding on two-spotted spider mite

94. *Aphidoletes* larvae in aphid colony

95. *Aphidoletes* larva feeding on aphid

Predatory mites

Predatory phytoseid mite species (Figure 96) are perhaps the most commonly introduced beneficials in soft fruit, but there are several naturally occurring species, which can be very important.

96. Typical Phytoseid mites

In HDC Project SF115, which looked at overwintering predatory mites in raspberry and strawberry crops, three main species were found in between 11 and 49% of crops sampled. The most common, *Neoseiulus californicus,* is currently not regarded as endemic but was found in many strawberry crops. *Amblyseius andersoni* was the most common naturally occurring predatory mite in raspberries. *Typhlodromus pyri,* a very common predator of spider and eriophiid mites in tree fruit, was found in 11% of samples.

These naturally occurring predatory phytoseid mites feed primarily on spider mites, but eriophiid mites such as blackcurrant gall mite and raspberry leaf and bud mite can also be prey. Both adult and juvenile mites are predatory, but identification to species is difficult and has to be undertaken in the laboratory.

Other predatory mites are less important, but are quite common general predators including anystid mites (Figure 97 - overleaf), *Anystis* spp., and the red velvet mite (Figure 98 - overleaf), *Allothrombium fuliginosum.*

97. Anystid mite feeding on aphid

98. Red velvet mite

Earwigs

Earwigs (Figure 99) are very underestimated predators in soft fruit and, although omnivorous, the adult and larvae are predatory with aphids, scale insects and small caterpillars being favoured prey. Earwigs are one of the few predators to feed on woolly aphids and woolly scale insects.

99. Female earwig

Other predators and parasites

Other general predators are frequently found in soft fruit crops, and some such as the social wasps and centipedes can be very useful at times. Social wasps feed their young almost exclusively on invertebrate prey, with caterpillars and aphids being favoured. Centipedes feed exclusively in or on the soil, and vine weevil eggs and their young larvae, slug eggs and various invertebrates pupating in the soil are all predated.

In addition to the parasitic wasps, a number of species of flies, particularly of the tachinid group (Figure 100), have larvae which parasitise caterpillars. Free-living nematodes which parasitise soil pests such as slugs and vine weevil are present in many soils. Identification of these beneficial species can only be done in specialist laboratories.

100. Tachinid fly adult

Table 5 lists the naturally occurring predators and parasitoids of the major pest groups of soft fruit crops.

Encouraging predators and parasitoids into crops

The fundamental principle of encouraging natural enemies into crops is to provide alternative habitats around and, as far as possible, within the cropping area. These alternative habitats will provide both shelter and alternative food supplies. Additionally, installing artificial refuges for the mobile natural enemies is extremely beneficial.

General farm management

- Undertake an environmental audit.
- Develop a whole farm environmental/conservation policy. Various professional organisations can assist with both the audit and the policy
- Investigate grant aid for conservation projects.

Table 5. Major predators and parasites of the main soft fruit pest groups

Pest group	Predators	Parasites
Aphids	Anthocorid and other bugs Earwigs Hoverfly larvae Ladybird larvae and adults Lacewing larvae and adults Midge larvae Social wasps	Parasitic wasps
Beetles (foliage)	Assassin and damsel bugs Earwigs Social wasps	Parasitic wasps
Capsids	Assassin and damsel bugs Earwigs Ground and rove beetles	
Caterpillars	Assassin and damsel bugs Earwigs Ground and rove beetles Social wasps	Parasitic flies Parasitic wasps
Leaf hoppers	Anthocorid bugs Lacewings	Parasitic wasps
Midges	Anthocorid bugs (on the foliage) Ground and rove beetles (in the soil) Predatory mites (in the soil)	
Mites	Anthocorid and other bugs Earwigs Hoverfly larvae Ladybird larvae Lacewing larvae Midge larvae Phytoseid mites Trombid mites	
Scale insects	Anthocorid bugs Earwigs Ladybird adults and larvae	Parasitic wasps
Slugs	Centipedes Ground and rove beetles	Nematodes
Thrips	Anthocorid bugs (on the foliage or in flowers) Ground and rove beetles (in the soil) Ladybird larvae (on the foliage) Predatory mites (in the soil)	
Vine weevil, other soil pests	Centipedes Ground and rove beetles	Nematodes

Management of plantations

- Biodiversity is usually greatest in what we may perceive to be untidy areas.
- Nettles provide one of the best habitats and food for many of our most effective predators and parasitoids.
- Field margins provide some of the best sources of biodiversity on farms and should be managed to maximise this effect. Grass margins and hedges are equally important for different types of wildlife.
- Never apply pesticides, including herbicides, to established field margins and other non-cropping areas.
- When planning new plantations, allow room for good sized margins and wide verges on roadways and cross alleys.
- Retain and properly maintain as many hedges and trees around the plantation as is practical.
- Hedges should include a wide range of plant species, and have a full dense structure from ground level to the canopy.
- Hedges should have herbaceous plants at the edge, through to mid-height, shrubs and to the full canopy with small trees.
- Do not mow close to hedges but allow grasses and herbaceous plants to form a mid-height tussocky buffer of at least one metre wide.
- This buffer should only be mown once a year, either before most plants flower, or after most have set seed.
- New alleyways and new margins should be sown with a mixture of annual and perennial flowering plants and durable grasses.
- Less frequent mowing of margins and alleyways will allow herbaceous plants to flower.
- Ideally only mow half of the plantation at once so there are always plants in flower.

Crop management

- Ensure that agrochemicals are only applied to the crop and are not allowed to drift onto margins and other non-cropping parts of the plantation.
- Fertilisers should be applied only to the rooting zones of the crop. Low fertility in non-cropped areas encourages a wider mix of plant species and therefore greater biodiversity.
- During routine crop monitoring, record the numbers of predators and parasites.

Further information

Glossary

Diapause – a hibernating stage when an insect or mite overwinters

Entomopathogenic (insect-pathogenic) – causing a bacterial or fungal infection in insects

Integrated Pest Management (IPM) – the integration of biological, cultural and chemical control methods to achieve sustainable pest control

Invertebrate – an animal without a backbone, e.g. insect, mite, nematode, slug

Larva – an immature insect that does not always resemble the adult stage (e.g. *Aphidoletes* larvae)

Lepidoptera – moths or butterflies and their caterpillars

Nymph – an immature insect or mite that resembles the adult stage but is usually smaller (e.g. predatory bugs such as *Orius*)

Parasitoid – a parasitic organism that kills another organism by developing inside or on the host insect's body (e.g. parasitic wasps that kill aphids)

Pupa – inactive stage of an insect that turns into the adult stage

Predator - an organism that attacks and eats its prey e.g. predatory mites

Selective pesticide – a pesticide that kills one or a few specific pests, with minimal risk to non-target insects or mites such as biocontrol agents, e.g. pymetrozine for aphid control

Thrips – thrips is both singular and plural, there is no such thing as a 'thrip'.

Useful HDC publications

- HDC Factsheet 01/03 – Vine weevil control in soft fruit crops
- HDC Factsheet 05/03 – Integrated control of thrips on strawberries
- HDC Factsheet 15/03 – Tarsonemid mite on strawberry
- HDC Factsheet 19/04 – European tarnished plant bug on strawberries and other soft fruits
- HDC Factsheet 08/05 – The biology and control of two-spotted spider mite in nursery stock
- HDC Factsheet 14/05 – Control of whiteflies on protected ornamental crops
- HDC Factsheet 26/05 – Aphids and their control on strawberry
- HDC Factsheet 01/07 – Sucking insect pests of cane fruit crops
- HDC Factsheet 14/09 – Thrips control on protected ornamental crops
- HDC Factsheet 07/11 – Beetle and weevil pests of cane fruit crops
- HDC Factsheet 10/12 – Midge, mite and caterpillar pests of cane fruit crops

Biocontrol suppliers

Agralan Ltd (Biobest products)
The Old Brickyard
Ashton Keynes
Swindon
Wiltshire SN6 6QR
Tel . (01285) 860015
www.agralan.co.uk

Becker Underwood UK
Unit 1 Harwood Industrial Estate
Harwood Road
Littlehampton
West Sussex BN17 7AU
Tel. (01903) 732323
www.beckerunderwood.co.uk

BCP Certis
Newbury House
Court Lodge Farm
Hinxhill
Ashford
Kent TN25 5NR
Tel. (01233) 667080
www.bcpcertis.com

Biowise
Hoyle Depot
Graffham
Petworth
West Sussex GU28 0LR
Tel. (01798) 867574
www.biowise-biocontrol.co.uk

Fargro Ltd
Toddington Lane
Littlehampton
West Sussex BN17 7PP
Tel. (01903) 721591
www.fargro.co.uk

Koppert UK Ltd
Unit 8
53 Hollands Road
Haverhill
Suffolk CB9 8PJ
Tel. (01440) 704488
www.koppert.co.uk

Syngenta Bioline
Telstar Nursery
Holland Road
Little Clacton
Clacton
Essex CO16 9QG
Tel. (01255) 863200
www.syngenta-bioline.co.uk

Biocontrol agents can also be obtained through most horticultural merchants.

Photographic credits

The HDC is indebted to all those individuals and organisations that provided images for use in this publication. A list of images and their source are listed below.

Figure	Image	Source
1	*Neoseiulus cucumeris* applied to everbearers for thrips and tarsonemid mite control	ADAS
2	Biocontrol agent containers in the field	ADAS
3	Crop inspection using a x10 hand lens	ADAS
4	*Neoseiulus cucumeris* sachet	ADAS
5	*Phytoseiulus persimilis* containers	ADAS
6	*Neoseiulus cucumeris* application by hand	ADAS
7	Common green capsid pheromone trap	East Malling Research
8	Pesticide spraying	ADAS
9	Overwintered adult female two-spotted spider mite laying eggs in spring on underside of leaf	ADAS
10	Two-spotted spider mite eggs and adults	ADAS
11	Two-spotted spider mite webbing	FLPA Images of Nature
12	*Phytoseiulus persimilis* amongst two-spotted spider mites on strawberry leaf	ADAS
13	Overwintering adult female two-spotted spider mites laying eggs in spring	ADAS
14	Two-spotted spider mite damage to raspberry leaf	ADAS
15	*Amblyseius andersoni* on raspberry leaf	ADAS
16	Two-spotted spider mite damage to leaf	Roger Umpelby
17	Two-spotted spider mite damage to lower leaf canopy in raspberry	ADAS
18	Two-spotted spider mite leaf webbing	ADAS
19	Biocontrol agent container left in the field	ADAS
20	Strawberry crop protected by fleece	ADAS
21	*Phytoseiulus persimilis* adult	ADAS
22	Emerging raspberry primocane spawn	ADAS
23	Bran run-off following application of predators to raspberry	ADAS
24	Up-turned leaf to contain bran following introduction of predators to raspberry	ADAS
25	Adult western flower thrips	Nigel Cattlin/FLPA Images of Nature
26	Western flower thrips damage to strawberry flower petals	ADAS
27	*Neoseiulus cucumeris*	Syngenta Bioline
28a	*Neoseiulus cucumeris* application by tractor	ADAS
28b	Koppert air blower for introducing predators	ADAS
29	*Orius* eating midge larva	Nigel Cattlin
30	Western flower thrips damaged strawberry	ADAS
31	Blue sticky trap in strawberry crop	ADAS
32	*Phytoseiulus persimilis*	ADAS
33	Tarsonemid mite eggs and adults	ADAS
34	Tarsonemid mite plant damage	Roger Umpelby
35	*Neoseiulus californicus* sachet	ADAS
36	*Neoseiulus cucumeris* applied to everbearer	ADAS
37	Adult vine weevil	James Hutton Institute
38	Vine weevil larvae	Defra
39	Adult vine weevil feeding on strawberry leaf	Roger Umpelby
40	Vine weevil larva parasitised by nematodes	Becker Underwood
41	Damage to strawberry crown caused by vine weevil larvae	ADAS
42	Damage to raspberry leaf by vine weevil larvae	Roger Umpelby
43	*Steinernema kraussei* packet	ADAS
44	Strawberry aphid	East Malling Research
45	Large raspberry aphid adults	James Hutton Institute
46	Melon-cotton aphid colony on plant stem	Roger Umpelby
47	Potato aphid colony	Roger Umpelby
48	Leaf curly on raspberry caused by small raspberry aphid feeding	James Hutton Institute
49	Mummified aphid parasitized by aphid	Roger Umpelby
50	*Aphidoletes aphidimyza* larvae feeding on aphids	ADAS
51	Twisted foliage caused by shallot aphid	East Malling Research
52	Aphid parasitoid mix release tube	ADAS
53	Adult whitefly	FLPA Images of Nature
54	Sooty mould on ivy leaf	Roger Umpelby
55	Black parasitized and white whitefly scales	ADAS
56	*Encarsia formosa* release card hanging in crop	ADAS
57	Tortrix caterpillar on raspberry leaf	Roger Umpelby
58	Raspberry moth larvae	James Hutton Institute
59	Caterpillars killed after ingesting *Bacillus thuringiensis*	Interfarm
60	Anthocord adult feeding	Defra
61	Anthocorid juvenile feeding on aphid	Roger Umpelby
62	Black-kneed capsid adult	Defra
63	Green lacewing adult on strawberry flower	Roger Umpelby
64	Lacewing egg on strawberry	Roger Umpelby
65	Lacewing larva on strawberry petal	Roger Umpelby
66	Lacewing cocoon	Roger Umpelby
67	Lacewing larva eating aphid	Defra
68	Ladybird adults (7, 2 and 16 spot ladybirds)	Roger Umpelby
69	Adult harlequin ladybird	Roger Umpelby
70	Ladybird eggs	Roger Umpelby
71	Young ladybird larva	Roger Umpelby
72	Mature ladybird larva	Roger Umpelby
73	Ladybird pupa	Roger Umpelby
74	Adult ground beetle	Roger Umpelby
75	Adult tiger beetle	Roger Umpelby
76	Adult rove beetle	Roger Umpelby
77	Ground beetle larva	Roger Umpelby
78	Devil's coachhorse with vine weevil larva	Roger Umpelby
79	Adult soldier beetle	Roger Umpelby
80	Adult cardinal beetle	Roger Umpelby
81	Adult parasitic ichneumon wasp	Roger Umpelby
82	Adult parasitic brachonid wasp	Roger Umpelby
83	*Aphidius* parasitic wasp laying egg in aphid	Roger Umpelby
84	*Aphidius* pupa	Roger Umpelby
85	Praon pupa	Roger Umpelby
86	Caterpillar with parasite larvae	Roger Umpelby
87	Caterpillar with parasite pupae	Roger Umpelby
88	Hoverfly egg with aphids	Roger Umpelby
89	Mature hoverfly larva	Roger Umpelby
90	Young hoverfly lava feeding on aphid	Roger Umpelby
91	Hoverfly adult and pupa	Roger Umpelby
92	Adult robber fly	Roger Umpelby
93	*Feltiella acarisuga* larva feeding on two-spotted spider mite	FLPA Images of Nature
94	*Aphidoletes* larvae in aphid colony	ADAS
95	*Aphidoletes* larva feeding on aphid	ADAS
96	Typical Phytoseid mites	ADAS
97	Anystid mite feeding on aphid	Fera
98	Red velvet mite	Roger Umpelby
99	Female earwig	Roger Umpelby
100	Adult tachinid fly	Roger Umpelby

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Harriet Duncalfe (H & H Duncalfe) acted as an industry co-ordinator for the production of the guide.

Appendices

Appendix 1 - Guideline application rates

Introduction rates vary considerably depending the level of pests, canopy size, duration of control required. These rates should only be used as a guide and specific professional advice should be sought before using biological control agents.

The only reliable method to assess the correct rate is to thoroughly check the crops at weekly intervals after application and adjust to circumstances.

The rates below are suitable for first year full season strawberries. They are mostly suitable as per metre run of bed or substrate (assume this approximately equals the /m² rate) or per plant where this applies. It is reasonable to increase rates to 2-3 times in the case of predatory mites to allow for the greater canopy size of cane fruit that they need to cover.

Biological control agent	Rates of use	Description
Amblyseius andersoni	1 sachet every 2 m of row or loose at 0.25-1 per strawberry plant, preventive	Active mites with food in slow release sachets, or loose
Aphelinus abdominalis	0.1 parasites/m²/week (preventive) 2.0 parasites /m²/wk (curative)	Parasitic wasps as mummies in bottle
Aphid parasitoid mix	Typically one tube per 200 m² Repeat up to three times for strawberries and raspberries	Parasitic wasps as mummies in bottle
Aphidius colemani	0.2 parasites/m²/week (preventive) 0.5/m²/week (curative)	Parasitic wasps as mummies in bottle
Aphidius ervi	0.2 parasites/m²/week (preventive) 0.5 parasites /m²/week (curative)	Parasitic wasps as mummies in bottle
Aphidoletes aphidimyza	1/m² (light, curative) 10/m² (heavy, curative)	Predatory midge as pupae in bottles in vermiculite or release tubs
Bacillus subtilis (Serenade)	10.0 l/ha	A bacterial formulation to be applied as a foliar spray
Bacillus thuringiensis (DiPel DF)	0.75g/litre high volume, up 1000 l water/ha	A bacterial formulation to be applied as a foliar spray
Beauveria bassiana (Naturalis)	Spray at 0.3% v/v, i.e. up to 3 litres in 1000 l water/ha	Insect pathogenic fungus
Encarsia formosa	1-2 scales per m² per week	Parasitic wasps as scales on a card
Heterorhabditis sp.	0.5-5.0 million nematodes/m² for soil (labels vary) 5,000 nematodes per litre compost	Insect pathogenic nematode for growing media drench
Hypoaspis miles	100 mites/m² preventive	Predatory mites in bottles of peat and vermiculite
Metarhizium anisopliae (Met52)	0.5 kg/m³ (1000 litres) substrate 122 kg/ha soil	Insect pathogenic fungus
Neoseiulus californicus	1 sachet every 2 m of row or loose at 0.25-1 per strawberry plant, preventive (solely for glasshouse use)	Active mites with food in slow release sachets, or loose
Neoseiulus cucumeris	1 sachet every 2 m of row or loose at: 50-400 mites per m² applied twice for tarsonemid 125-250 mites per m² fortnightly for thrips	Active mites with food in slow release sachets, or loose
Orius (*Orius laevigatus* is most commonly used)	0.25-1 bug per strawberry plant, repeat two weeks later	Predatory bugs as adults and/or nymphs in shaker bottles
Phasmarhabditis hermaphrodita (Nemaslug)	300,000 nematodes per m² compost, soil	Pathogenic nematode specific to slugs and snails
Phytoseiulus persimilis	0.25-4 mites per plant, up to 10 for hotspots	Predatory mites (adults and nymphs) in shaker bottle
Steinernema kraussei	1 million nematodes/m² 25,000 nematodes per strawberry plant	Insect pathogenic nematode for growing media drench

Appendix 2 - Biocontrol agents still to be proven for widespread use on soft fruit

Target pest	Potential biocontrol agents
Blackberry leaf midge	*Neoseiulus cucumeris, Macrocheles robustulus, Orius sp.*
Capsid	Presently no biocontrol agent
Caterpillar	*Trichogramma sp.*
Raspberry leaf and bud mite	*Amblyseius andersoni, Neoseiulus cucumeris*
Slugs	*Phasmarhabditis hermaphrodita*
Strawberry blossom weevil	Presently no biocontrol agent
Thrips	*Amblyseius montdorensis*[1], *Amblyseius swirskii*[1], *Atheta coriaria, Beauveria bassiana, Hypoaspis aculeifer, Hypoaspis miles, Metarhizium anisopliae*[2], *Verticillium lecanii*
Two-spotted spider mite	*Beauveria bassiana, Feltiella acarisuga* (formerly *Therodiplosis persicae*)
Vine weevil grubs	*Metarhizium anisopliae*[2]
Whitefly	*Amblyseius montdorensis*[1], *Amblyseius swirskii*[1], *Beauveria bassiana*

[1] Licensed for permanent glass only

[2] Presently available as a solid product for incorporation into the root zone. Progress is being made to license liquid formulations for use as drenches or sprays.

Appendix 3 - Harmful effects posed by approved insecticides to the most commonly used predators, parasitoids and bumble bees used for pollination in soft fruit

Active ingredient (Typical product)	*Phytoseiulus persimilis*	*Neoseiulus (Amblyseius) cucumeris*	*Orius laevigatus*	*Aphidius spp.*	Bees used for pollination
potassium bicarbonate (AgriKarb)	No information	Safe	No information	Safe to adults, no information on mummies	No action needed
abamectin (Dynamec)	Harmful (1-2 weeks)	Harmful (2 weeks)	Harmful to adults and nymphs (3-6 wks)	Harmful to adults (1 week) safe to mummies	Remove for 1.5-3 days
azoxystrobin (Amistar)	Safe	Safe	Safe to adults and nymphs	Safe to adults & mummies	Close and cover hives before application
Bacillus thuringiensis var *kurstaki* (Dipel DF)	Safe	Safe	Safe	Safe	Close and cover hives before application
Beauveria bassiana entomopathogenic fungus (Naturalis-L)	Safe	Safe	Safe	Safe	Close and cover hives before application
bifenazate (Floramite 240 SC)	Moderately harmful (1 week)	Safe	Safe to adults and nymphs	Safe to adults Moderately harmful to mummies (? weeks)	Close and cover hives before application
bupirimate (Nimrod)	Slightly harmful (4 days)	Safe	Slightly harmful to adults & nymphs at time of application	Safe to adults and mummies	Close and cover hives before application
chlorpyrifos (Equity)	Moderately harmful to adults & nymphs (up to 3 days)	Harmful to adults & nymphs (6-8 weeks)	Harmful to adults, slightly harmful to nymphs (up to 5 weeks)	Harmful to adults and mummies (? weeks)	Incompatible for at least 7 days
clofentezine (Apollo 50 SC)	Safe	Safe	Safe	Safe	Close and remove hives before spraying. Persistent for 24 hrs
cyprodonil/fludioxonil (Switch)	Slightly harmful (? days)	No information, but suspected to be slightly harmful	Harmful to adults and nymphs (? days)	No information	Close and cover hives before application
deltamethrin (Decis)	Harmful to adults & nymphs (> 8 weeks)	Harmful to adults & nymphs (> 8 weeks)	Harmful to adults & nymphs (> 8 weeks)	Harmful to adults & mummies (> 8 weeks)	Close and remove hives before spraying. Persistent for 2-3 days
etoxazole (Borneo, Clayton Java)	Harmful (4-8 weeks)	No information	No information	No information	Close and remove hives before spraying. Persistent for 3 days.
fenhexamid (Teldor)	Slightly harmful (? days)	No information	Slightly harmful to adults and nymphs	Safe to adults & mummies	Close and cover hives before application
fenpropimorph (Corbel)	Slightly harmful	No information	Safe to adults, slightly harmful to nymphs	No information	Close and cover hives before application
fenpyroximate (Sequel)	Harmful (2-4 weeks)	Harmful (? days)	Safe to adults, slightly harmful to nymphs	Harmful to adults (3 weeks) No information on mummies.	Close and remove hives before application. Persistence 1-2 days.
iprodione (Rovral WP)	Safe	Safe	Safe to adults and nymphs	Safe to adults & mummies	Close and cover hives before application

Active ingredient (Typical product)	*Phytoseiulus persimilis*	*Neoseiulus (Amblyseius) cucumeris*	*Orius laevigatus*	*Aphidius spp.*	Bees used for pollination
lambda cyhalothrin (Hallmark with Zeon Technology)	Harmful to adults & nymphs (> 8 weeks)	Harmful to adults & nymphs (> 8 weeks)	Harmful to adults & nymphs (> 8 weeks)	Harmful to adults & mummies (> 8 weeks)	Incompatible for 15 days
maltodextrin (Eradicoat/ Majestik)	Harmful until spray residues dry	Harmful until spray residues dry	Harmful until spray residues dry	Harmful to adults until spray residues dry	Close hives before application and open once spray residue dry
mepanipyrim (Frupica SC)	Slightly harmful (? days)	No information but is used by strawberry growers using IPM, with no apparent effect on *N. cucumeris*	Safe to adults and nymphs	No information	Close and cover hives before application
myclobutanil (Systhane 20 EW)	Safe	No information	Safe to adults and nymphs	No information	Close and cover hives before application
pirimicarb (Aphox)	Slightly harmful (3 days)	Moderately harmful (3 days). Safe to eggs.	Safe to adults, slightly harmful to nymphs (5 days)	Safe	Close and remove hives before application
pymetrozine (Chess/Plenum)	Slightly harmful to adults and nymphs, safe to eggs (? days)	Safe	Slightly harmful to adults and nymphs (up to 2 weeks)	Safe to mummies. Slightly harmful to adults	Close and cover hives before application
pyrethrins (Spruzit) (Pyrethrum 5 EC)	Harmful (1 day) Harmful (1 week)	Harmful (1 day) Harmful (1 week)	Harmful (1 week)	Safe to mummies, harmful to adults (1 day) Safe to mummies, harmful to adults (? Days)	Close and cover hive for 1 day Remove for 1.5 days
pyrimethanil (Scala)	Safe	Safe	Safe to adults and nymphs	No information	Close and cover hives before application
quinoxyfen (Fortress)	No information	No information (but use on strawberries has shown that *N. cucumeris* survives)	No information (but use on strawberries has shown that *Orius* survives)	No information	
spinosad (Tracer)	Slightly harmful (1 week)	Harmful (1-2 weeks)	Harmful (1-2 weeks)	Harmful to adults, moderately harmful to mummies	Close hives and remove for 1-2 days
spirodiclofen (Envidor)	Slightly harmful (2-3 weeks)	No information	Harmful to adults & nymphs (? weeks)	No information	Not compatible (7 days)
spiromesifen (Oberon)	Moderately harmful (4-12 weeks)	Slightly harmful	Safe	Safe to adults	Close and cover hives before application
sulphur (spray) (Kumulus DF)	Moderately harmful (? Days)	Slightly harmful (3 Days)	Safe to adults, slightly harmful to nymphs (? days)	Slightly harmful to adults & mummies (? days)	Close and remove hives before application (1-2 days)
tebufenpyrad (Masai)	Harmful for 1-2 wks	Harmful (? Days)	Moderately harmful to adults, harmful to nymphs (2-3 weeks)	Harmful to adults, safe to mummies (2 weeks)	Close and remove hives before application (0.5 days)
thiacloprid (Calypso)	Moderately harmful (2 weeks)	Moderately harmful (up to 2 weeks)	Harmful (2 weeks)	Moderately harmful to adults and mummies	Close and remove for 1-2 days

Safe: kills<25% **Slightly harmful:** kills 25-50% **Moderately harmful:** kills 50-75% **Harmful:** kills >75% (Persistence against bio controls given in brackets)

This data has been compiled from the following websites, and from the practical experience of BCP Certis:
http://www.biobest.be (Biobest also provide a helpful phone app) http://www.koppert.com (Koppert also have a simplified version for mobile phones)

HDC is a division of the Agriculture and Horticulture Development Board (AHDB).

AHDB Agriculture & Horticulture DEVELOPMENT BOARD

Horticultural Development Company

Stoneleigh Park
Kenilworth
Warwickshire
CV8 2TL

T: 024 7669 2051
E: hdc@hdc.ahdb.org.uk

www.hdc.org.uk