



Apple & Pear Australia Ltd.

INTEGRATED PEST MANAGEMENT FOR

AUSTRALIAN

APPLES & PEARS



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Prepared by Shane Hetherington

Edited by Ann Munroe

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Acknowledgments and contributors

Coordinating author

Shane Hetherington

The project team

Ms Penny Domeney, Department of Primary Industries, Parks, Water and Environment, Tasmania

Dr Mofakhar Hossain, Department of Primary Industries, Victoria

Ms Christine Horlock, Department of Employment, Economic Development and Innovation, Queensland Primary Industries and Fisheries

Mr Stuart Gray, Apple and Pear Australia Limited

Contributing authors and reviewers

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Stuart Learmonth, Department of Agriculture and Food, Western Australia

Paul James, South Australian Research and Development Institute

John Tracey, Industry & Investment NSW

Graham Thwaite, NSW Department of Primary Industries (retired)

Anne Mooney, Industry & Investment NSW

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Dedication

This manual is dedicated to my son Benjamin. Research and production were therapy during hard times... You taught me that tough guys sometimes wear nappies!

Dr Shane Hetherington
Industry Leader (Temperate Fruit)
Industry & Investment NSW

What is IPM?

Integrated pest management (IPM) is a philosophy of pest control founded on the principles of ecology. In practice, it involves using several control tactics based on a knowledge of the crop, pests and associated natural enemies to avoid crop loss and minimize harmful effects on the environment. Implementing IPM requires an understanding not only of insect and mite biology and ecology but also of the entire orchard system. This includes the plants and animals that comprise the orchard community, as well as consideration of contributions from the surrounding habitat. The orchard system also takes into account financial, physical and human aspects of orchard operations. More simply, IPM involves evaluating your pest problems and then applying the most appropriate solution.

IPM requires a more tolerant approach to pest control than traditional insecticide-based programs. Eliminating all insects and mites from the orchard is not the objective of IPM. Natural enemies are to be conserved as much as possible and some damage, especially to foliage, is tolerated. For example, pests that attack the foliage can usually be allowed to build to levels higher than those that attack the fruit.

There are both positive and negative impacts associated with the reduced insecticide use that usually accompanies the adoption of an IPM approach. Benefits of IPM include greater survival of natural enemies, slower development of resistance, less pest resurgence, fewer outbreaks of secondary pests, less negative impact on the environment, and greater worker safety. On the negative side, potential pests that are coincidentally controlled by insecticides used to control key pests may be released from all but natural controls. Natural controls will be effective for some. For others, however, the release from insecticidal control will result in population levels that are sometimes damaging. The transition to more intensive IPM programs in orchards will require knowledge and patience—knowledge of pest and natural enemy biology and patience to allow natural enemy build-up. Selective controls will have to be used for pests that are not maintained at acceptable levels by natural controls.

This information was taken from the Washington State University IPM online manual. I feel it encompasses the mind shift that needs to take place when entering into an IPM system. I feel it summarises quite well the feelings of where APAL see this manual taking growers. I am not sure whether this is too wordy for your liking, it is just a suggestion which I feel embraces the idea of IPM to me.

The complication is that, when choosing this option, you must consider its impact on the entire block.

All orchard blocks are home to a range of insects, mites and micro-organisms that attack and kill the pests that damage crops. These ‘beneficials’ attack pests and limit the amount of damage that they cause. Unfortunately, many beneficials are killed by common orchard pesticides. Broad-spectrum pesticides kill a wide range of organisms regardless of whether they are pests or beneficials. When too many beneficials are killed they can no longer reduce pest numbers, and unexpected outbreaks of pests or diseases occur on crops. Often these outbreaks do not involve the pest for which the spray was originally applied.

In the example (see page v), a broad spectrum pesticide applied for codling moth control reduces populations of this pest to low levels but results in an unexpected outbreak of two-spotted mites late in the season (see Option 1, page v). Because broad-spectrum insecticides kill a wide range of insects it is likely that predators of mites such as ladybird beetles, stethorus, hoverflies and lacewings will be killed in addition to the pest. IPM advocates management which reduces the likelihood of secondary problems such as this developing. An alternative management strategy more likely to fit within IPM would be to use mating disruption within the orchard (see Option 2, page v). Mating disruption specifically affects the pest species, leaving beneficial insect populations to develop normally. In this case, mating disruption will stop codling moth mating and reduce populations while leaving mite predators unaffected. As a consequence season-long control of both codling moth and two-spotted mite is more likely than under pesticide-only management.

Controlling Codling moth



Option 1

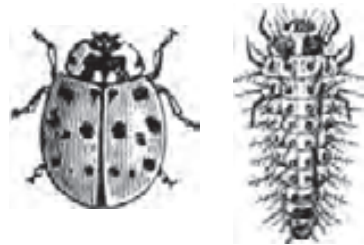
'Hard' pesticides e.g. Azinphos-methyl



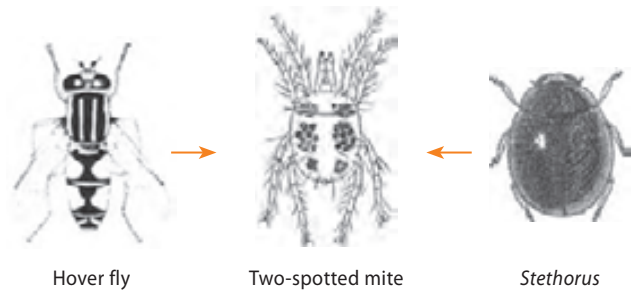
Two-spotted mite

Option 2

IPM e.g. Mating disruption



Ladybird beetle and larvae



Lacewing

Carbaryl is another orchard chemical that is often responsible for secondary outbreaks. In addition to being a broad-spectrum insecticide it is frequently used as a blossom thinner. Carbaryl is very toxic to bees, and carbaryl-contaminated pollen may remain toxic for up to 8 months when stored in the hive. Inappropriate use of carbaryl can severely reduce pollination and fruit set. Carbaryl is also toxic to the predatory mite *Typhlodromus occidentalis*, and its use early in the season for crop regulation and/or pest control can result in outbreaks of pest mites later in the season.

Often, fewer pesticides are used in a well-run IPM program. Although this isn't the overall objective of IPM, it is a natural consequence of considering the entire range of control options available. When an orchardist using IPM chooses a management option, it is because it is the most effective at controlling the pest without any bias toward or against chemical pesticides or other management options. IPM consists of several logical steps:

- *Prevention of pest infestation* is an important component of IPM. Many problems can be avoided by making your orchard an inhospitable place for pests and diseases. Some general strategies for doing this are outlined in this manual in the chapter entitled 'The plan' (see page 2). Specific prevention strategies for each pest are given throughout.
- *Monitoring pest presence and numbers.* Systematically inspecting your orchard to determine if pests are present and whether they are present in sufficient numbers to cause problems.
- *Appropriate action.* Where unacceptable damage is likely, early action is taken to reduce pest numbers, but consideration is given to the off-target impact of this management.
- *Monitoring and measurement of effectiveness.* Continue to monitor pest numbers and damage to your trees and crop after you've taken action. This is the only way that you'll know whether what you have done is effective.
- *Keeping good records.* The key to IPM success is to keep good records. Records should be sufficiently detailed to allow you to honestly evaluate whether you're choosing the best options.
- *Continual improvement.* Reject bad options, try new techniques, innovate and improve.

Making the decision to use IPM: personal choices

Australian pome fruit orchardists are understandably conservative. Bad and damaged fruit costs money, and margins are tight. Irrespective of economics, the level of damage that is considered acceptable varies between orchardists. Some want to produce 'perfect' fruit and are willing to pay to do this, whereas others will tolerate some damage. IPM involves making personal choices about what you think is acceptable and what level of risk you're willing to accept. There are no firm rules and regulations.

A well-run IPM program involves no reduction in pack-out. However, during the first few seasons inexperience means that mistakes will happen. The information in this manual provides a way of minimising that risk:

- *Start small.* Orchardists with limited experience should never convert an entire enterprise or a large, high-value block during the first seasons of transition. Start with a small, low-value block until you build up confidence.
- *Take it step by step.* Change one aspect of your pest management and evaluate the impact of the change over several seasons. At the end of each season modify the strategy until you're happy with the result. Gradually introduce changes to other management practices.

Some IPM terms defined

IPM comes with its own jargon. The terminology is quite simple and will help you to understand this manual. It's important that you understand the following four terms and how they are related.

1. Monitoring

Monitoring is a structured system for quantifying the likelihood of pests becoming a problem in the orchard. It involves both:

- carefully monitoring certain trees in the orchard, paying particular attention to trees prone to problems (i.e. hotspots)
- carefully monitoring the weather for conditions likely to favour pests.

2. Sample unit

This is the precise item that is monitored. For example:

- If two-spotted mite is being monitored, the sample unit is a leaf.
- If Phytophthora is being monitored, the sample unit is the crown or lower trunk.
- If black spot is being monitored, the sample units are the air temperature and leaf wetness.

3. Action threshold

This is the point in time when monitoring indicates that damage to the crop will be unacceptable unless the pest is managed. The action threshold can be the time at which:

- a certain number of pests are seen while monitoring
- a certain amount of damage is seen while monitoring
- the weather is so favourable to a pest that it is almost certain that damage will follow.

4. Appropriate action

When the action threshold has been reached appropriate action must be taken. Appropriate action must:

- be effective over a long period
- not cause secondary problems, or at least minimise them.

About this manual

This manual outlines an Australian apple and pear integrated pest management (IPM) strategy.

The development of this strategy has involved collaboration between Australian apple and pear growers, researchers and extension specialists. The objective was to create a strategy that gave practical pest management options instead of 'warm fuzzy' philosophy.

The information-gathering phase of the strategy involved interviews with apple and pear growers from eight production regions in six States. The objective was to identify the problems that were most important to industry. Orchardists were asked what their major pest and disease problems were. This series of interviews took place before the 2007–08 fruit season, at a time when many

of Australia's orchard regions were in the grip of a long-running drought. The interviewees were asked to take into account the possible reduction in pest problems due to the drought by recalling their problems from up to 10 years ago.

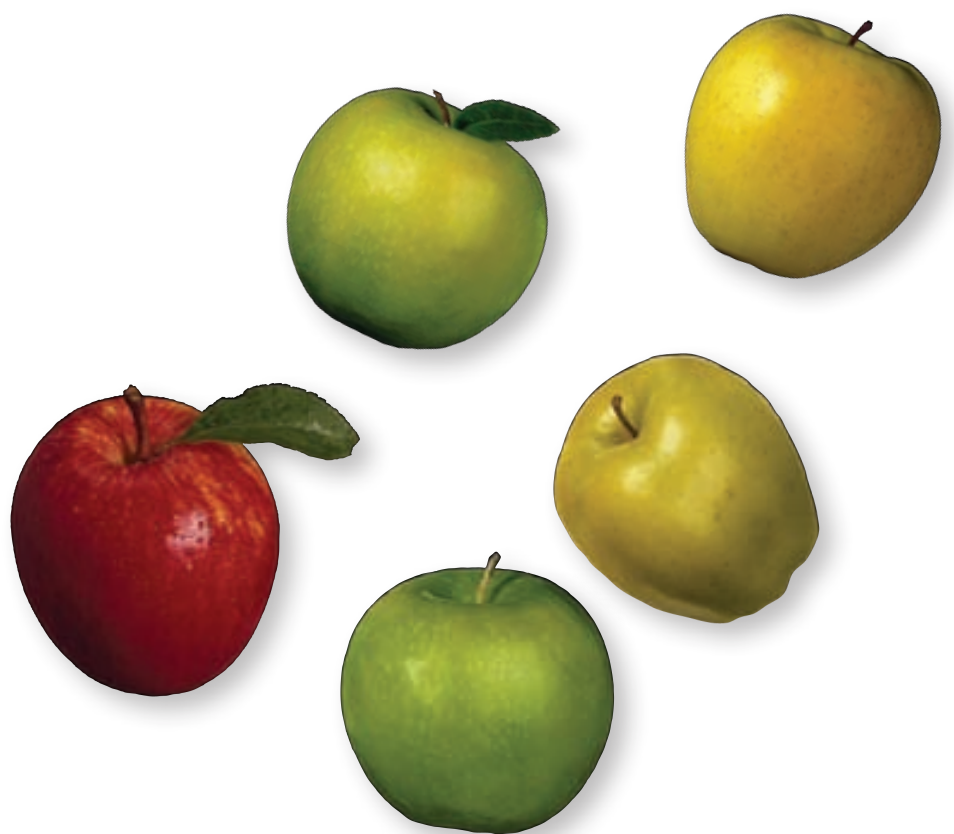
Australian pome fruit is grown in a range of climatic zones; naturally, the pest problems experienced by orchards in our regions are diverse. Writing a national manual was therefore challenging. The manual deals with this diversity by providing information on which regions have had problems with specific pests and diseases over the past 10 years. Where the information provided is region-specific, this is highlighted in the manual.

The manual provides a framework for setting up IPM in your orchard. Many orchardists will want to be personally responsible for monitoring and decision-making. Others may not have the confidence or time to do this. Consultants are available for this work in most regions. In any case, a successful IPM program will save money and improve your orchard and possibly even your personal health.

As we moved about the country asking questions, we realised that some of the issues being raised weren't quite what we expected. Bird damage was an issue that came up at almost all of the meetings. Initially we wanted to limit the manual to insect pests and diseases, but birds were such an issue that we included a section on bird control.

Many orchardists were interested in the life cycles of their pests and wanted this information included in the manual. This was difficult, because life cycles vary from region to region, usually in line with temperatures. Life cycles are also often complicated, and presenting a full life cycle would, at times, create confusion. The manual therefore presents simplified life cycles that contain enough information to help with pest control decisions but are not intended to cover all aspects of a pest's growth, development and reproduction.

Six steps to controlling diseases of apples and pears



The Plan

Step 1	Prepare and prevent (page 3). • Prepare the orchard • Prepare and calibrate machinery • Train and thin trees • Consider netting • Review your records and buy supplies • Preparing the packing shed
Step 2	Have a pest management plan for the season (page 14). • Choose your blocks • Know which pests are likely to cause problems • Keep records
Step 3	Monitor (page 16). • Monitor your trees and the weather • Know how much time it takes to monitor
Step 4	Take action only if you need to (page 19). • Know your thresholds • Check your spray coverage
Step 5	Evaluate the season (page 20). • Find out which pests caused trouble • Determine which types of management worked
Step 6	Plan for next season (page 21). • Work out what you have to do • Make sure all your preventive management strategies are in place • Plan for each pest and disease that has been a problem recently • Consider alternatives • Consider using IPM on more blocks

Step 1: Prepare and prevent

Before anything else, preparation is the key to success.

Alexander Graham Bell

An ounce of prevention is worth a pound of cure.

Benjamin Franklin

Prepare the orchard

Growers need to consider a many things when establishing a new block or setting up a block for the upcoming season. Many of the decisions they make will contribute to how hard they have to work and how much money is spent on pest control.

Setting up new blocks

1. Plan ahead (before removing old trees). Start planning before the old orchard is removed. This gives you time to:

- identify and correct any drainage problems and soil nutrition
- order the correct variety and rootstock combinations from nurseries
- order trellising and irrigation systems
- plan labour requirements
- plan cultural practices and equipment requirements such as ripping, discing, marking out, fertiliser incorporation and planting
- consider protective netting and OH&S issues
- consider future opportunities for orchard improvement.

The steps to take include:

- *Test soils for pH, soil nutrients, salinity and organic matter.* These tests identify whether you need to add nutrients or improve the soil. Subsoils should be tested for acidity and sodicity in areas prone to such problems. It is essential that these are known before there is any soil disturbance, so that correct measures can be applied at the right time and in the most appropriate way.
- *Check the site for apple replant syndrome, other soil borne problems, and nematodes.* Bioassay tests of soils show the extent of the effect the unamended soil will have on the growth of young trees. In some soils it may be necessary to test for specific soil-borne problems that will affect the soil treatments, for example, white root rot (*Rosellinia necatrix*) in Queensland, Phytophthora and Armillaria. Because nematodes can severely affect tree growth, a nematode test is highly recommended for light soils. Heavy metals (cadmium, arsenic, copper) may be an issue in some locations; obtain local advice and test if necessary.
- *Identify the lime, gypsum and/or dolomite requirements for the site.* It is extremely important that soil amendments (and phosphorous fertilisers) are incorporated into the root zone before planting, as they are highly mobile in the soil. Surface applications take several years to reach the root zone and to have a beneficial effect. Do not use dolomite in soils with high magnesium levels. Use calcium carbonate lime if acidity is an issue.
- *Accurately map the old area (or use an aerial photograph).* Using a map or photograph allows you to accurately determine where problems are (e.g. drainage, poor trees, different soil types, and prevailing winds). This allows time to plan for corrective measures such as installing drains or grassed waterways and planting windbreaks, or to make adjustments in irrigation systems. Accurately mapping old tree rows allows you to rearrange row positions and minimise the number of trees planted in an old tree row.
- *Select and order your varieties and rootstocks.* Selecting the right variety determines how much money you can make. Selecting the right rootstock determines the extent to which you can minimise production costs and maximise packouts and yield – and therefore maximise profits. When ordering trees, specify the type of trees you want for the training system you plan to use, for example whip, well-feathered trees (10 to 12 feathers) or double leader for Tatura trellis. With effective nutritional/soil adjustments and cultural practices, dwarfing rootstocks can be used to replant old orchards. It is not always necessary (or practical) to use vigorous rootstocks. Efficient and productive trees are preferred for today's orchard systems. Plan to plant what you want, not what you can get.

- *Budget accurately.* Budgeting helps you to plan effectively and make sure that you have everything you need. It also ensures that you don't get any unpleasant surprises.
- *Check local advice.* All production areas vary in their soil type, microclimate, soil problems and nutritional status. Obtain advice about any local issues you may need to consider.
- *Consider site rotation and possible cover crops.* Preparatory planning may show that it is inappropriate to replant the orchard. A change of crop or a longer-term approach to replanting may be necessary. Orchards are expensive to establish: don't waste money on a problem site by taking shortcuts.
- *Obtain the necessary permits* for vegetation removal, as well as planning permits and environmental impact statements, if you are removing native vegetation and constructing water storages or erecting protective structures.

2. Remove the old orchard or virgin bush and tree roots. The following steps need to be taken when removing old vegetation:

- *Remove trees when soil conditions enable easy removal of trees and roots.* It is important to remove as many roots as possible. Therefore, avoid dry periods or wet soils (erosion risks) when removing trees. The time and method of removal (bulldozing, front-end loader or stumping) will depend on the soil condition, the slope (safety and erosion), and the presence of permanent fixtures in the orchard.
- *Collect and dispose of as many roots as possible.* Old roots harbour harmful or dangerously high levels of soil organisms that can reduce new tree performance. Decaying roots can be toxic to young trees. Where practicable, remove all root pieces longer than 30 to 40 cm and/or larger than 4 to 5 cm in diameter. Use a disc to cut roots if they cannot be collected economically.
- *Wherever possible, do not burn old trees on the land to be replanted.* Heat generated by burning old trees affects the soil micro-organisms and nutrient availability under the heap. For orchard uniformity it is best to burn the trees away from the planting site. If trees have to be burned on site, several small heaps are better than one large one.
- *Take precautions to avoid erosion problems.* Tree removal can be one of the highest erosion-risk periods on steep slopes. Once the trees have been removed and heaped, use interceptor drains, add temporary contour grades, or roughly plough the block to minimise the speed with which water runs down the block. Establish a cover crop if land is to be left bare for any length of time, particularly in winter.

3. Prepare the site. Steps for preparing the site include:

- *Rip the site to improve soil aeration, drainage, and root removal and to reduce compaction problems.* Rip in late summer when the soil is dry and therefore shatters easily. Rip old orchards to break up hardpans and compacted areas, to improve aeration and root penetration, and to bring old roots to the surface. Remember to locate irrigation lines and controls and underground drainage. On steep sites, minimise the erosion risk by leaving the soil in a rough condition until you are ready to further prepare the site. In some situations erosion can be minimised by ripping only the proposed new rows, not the whole area. If you use this technique the new rows need to be marked out early in the process.
- *Roughly cultivate the site and remove any visible roots.* Each preparatory activity unearths old roots. The more roots that are removed (especially large roots), the better.
- *Mark out new rows, minimising planting in old tree rows.* The replanted block will usually have new training systems and different planting densities. Using your orchard plan (see 'Step 1: Prepare and prevent' p. 3), accurately mark out the new block. Minimise the number of rows in old row positions.
- *Even-out the site if required (and practicable).* Even-out any rough or shallow areas (especially along the planting row) to develop a uniform block. This is a high erosion risk activity, so take suitable precautions.
- *Apply and incorporate (to a depth of 15 cm or more) any fertiliser, lime gypsum, dolomite or organic matter (identified in step 1).* If problems are identified with subsoil acidity or sodicity, incorporate gypsum into the rip lines. Before final soil preparation, broadcast any fertilisers and soil amendments (e.g. lime, gypsum) and incorporate by cultivation. If significant quantities of trace elements and/or phosphorous are to be added, it is preferable to apply the soil amendments first, cultivate, and then apply the fertiliser separately.

- *Recultivate to prepare for planting or mounding.* If soil depth or drainage is an issue, the site can be mounded by moving topsoil from the centre of the row into raised mounds along the planting row. This increases the depth of the topsoil for tree roots and ensures that the root crown is above the watertable. The inter-row space also acts as a surface drain. Mounding is particularly valuable in replanted blocks that have previously had problems with root diseases such as *Phytophthora*, *Armillaria* or white root rot. On undulating sites ensure that the mounds do not impede the natural drainage from the site. Leave the drainage lines free so that grassed waterways can be installed to remove surface water. When mounds and grassed waterways are in place, the site is ready for the final cultivation to prepare the row for planting. This final cultivation should be done on the day of planting.
 - *Plant a cover crop.* When rows and mounds are defined, the inter-row area should be cultivated lightly and planted with a cover crop as soon as possible – preferably in autumn to stabilise the soil before winter and provide a firm surface during the winter/spring planting. When choosing a cover crop, pay attention to the pests that are likely to occur in the block, and plant appropriately. For example, Western flower thrips (p. 123) can build to large numbers in an inter-row containing white clover before they move into – and damage – the crop.
- 4. Plant wisely.** Use the following steps to ensure that your planting is well planned:
- *Store nursery trees correctly before planting.* Nursery trees (and especially their root systems) should never be allowed to dry out. Trees should be planted on arrival from the nursery. If this is not practicable, store them by:
 - » healing into moist sawdust, sand or well-prepared soil (good drainage is critical).
 - » placing them in a draught-free shed, bundled together and covered with moist hessian or tarpaulin. Moisten the cover several times a day. This is suitable only for short-term storage.
 - » putting them in cool storage. Place trees upright in a bin with the roots thoroughly covered with sawdust. Moisten tops daily and do not store with fruit. Only fully dormant trees are suitable for longer-term storage using this method.
 - *Plant early (June/July) where possible.* Weather conditions determine when soil can be prepared and therefore when trees can be planted. Early planting reduces stress on young trees and allows the roots to settle and recommence growth before shoot growth. Trees should be planted between June and mid-August.
 - *Late planting (September/October) affects first year performance.* In some cases planting after mid-August increases stress on young trees because they have to produce roots and shoots at the same time. Shoot growth is retarded, desiccation may be a problem, and tree losses can increase. However, some orchardists report that late-planted trees can perform as well as those planted early provided that they are well maintained and planted before wet weather.
 - *Don't put fertiliser in the planting hole.* Mono-ammonium phosphate (MAP) is often used as a planting hole amendment in replanted orchards. If it is placed incorrectly, young root systems can be burned and tree performance affected; trees can even die. If fertiliser requirements are correctly determined and the fertiliser is applied as outlined previously, there should be no need to use any fertiliser in the planting holes. Fertiliser containing nitrogen would be better on top, after planting.
 - *Plant quality, balanced trees with good root systems.* Ensure that the trees delivered are what you require for the training system. If there is considerable variation, discuss this with the nursery manager and consider regrading. Orchard uniformity is improved if similar-sized and -shaped trees are planted in the same row. If it is difficult to get uniform trees, grade for scion diameter and plant sequentially within the block and prune to the same structure. Good nursery trees should have a complete, evenly distributed root system with plenty of fibrous roots. Australian nursery trees are often large, with many fibrous roots removed. These trees must be looked after to ensure good establishment. A medium-sized tree with good fibrous roots should establish better in the first year than any tree that has had its roots severely pruned. Wherever possible, plant virus-tested trees.
 - *Don't plant diseased, damaged or desiccated trees.* Only healthy trees that are free of obvious diseases, including crown gall, should be planted. Damaged trees or roots should be graded out and treated/pruned. Avoid using desiccated trees. These trees can be rehydrated by placing in a running stream or bath of water for no more than 24 hours.

- *Planting depth and graft unions.* Planting depth is influenced by soil type, budding height and rootstock. Shallow soils should be mounded to give a satisfactory soil depth. Some dwarfing apple rootstocks are prone to burr knotting (especially M26), so graft unions should be as close to the soil as possible but high enough to minimise scion rooting (5 to 10 cm). Ensure that, irrespective of rootstock, all graft unions are at a consistent height above the soil. Using a consistent height increases the uniformity of tree growth in the orchard. Hand planting provides more consistency in planting depth than machine planting. Up to 2 weeks after planting, trees planted too low should be carefully raised.
- *Ensure trees are adequately watered-in at planting (by hand, rain or irrigation).* It is important to exclude air pockets from around the roots of newly planted trees. This improves soil-root contact, reducing moisture stress on the tree, and stimulates quicker growth. In dry conditions or soils, all trees should be watered-in at planting.
- *Minimise all stress to trees.* Attention to detail and careful handling at all stages of planting improve the chances of successful tree establishment. During planting, ensure trees are well protected from direct sunlight and wind, as desiccation at this stage will damage the tree. Don't plant into wet soils, as growth will be retarded.
- *Install an irrigation system.* Once planted, it is important not to allow the rapidly growing new trees to experience any moisture stress. Dwarfing apple rootstocks (especially M9, Ottawa 3 and M26) have small, fine root systems and are susceptible to moisture stress during establishment. It is therefore critical to have an irrigation system installed and operational at planting.
- *Install support systems, especially for dwarfing rootstocks.* Wind plays havoc with newly planted trees. Movement of tree tops will rock and break new roots. Provide support for trees soon after planting to minimise root damage.

5. Care for your trees. The following steps will help ensure that your trees remain healthy:

- *Use tender loving care.* The old strategy of treating young trees hard is totally inappropriate for new high density orchards. To ensure yields and quick returns on capital invested, do everything to maximise growth and minimise problems. The first two years of a newly planted orchard are the most critical. Poor establishment or tree performance in these years can negate the benefits of high-density plantings and substantially reduce the net profit of the orchard for its entire life.
- *Don't over fertilise – use little and often.* Proper application of fertiliser pre-planting negates the need for large applications of fertiliser to young trees. Young trees primarily require nitrogen for growth. This should be applied (to soil or fertigated) in small frequent doses during the first two seasons. Large doses of nitrogen fertiliser will encourage excessive soft foliage growth and encourage aphids and other sap-feeding pests. Once trees begin cropping the soil/trees should be tested and fertiliser applications adjusted according to test results.
- *Avoid moisture stress – irrigate carefully (light and frequent).* Problems with moisture stress cannot be overemphasised. Small trees have small root systems, so light frequent irrigations are required to avoid excessive soil wetting and drying. Investing in a moisture probe is advisable.
- *Keep young trees weed free.* Weeds compete for moisture and nutrients and must be removed. Be careful with herbicide applications.
- *Use tree guards where appropriate.* Tree guards reduce damage caused by rabbits, hares and wallabies, and they protect young green stems from herbicide. Don't bury tree guards, as this traps moisture around the tree stem and induces problems with Phytophthora. Pay careful attention to the type of tree guard used with M26 rootstock to avoid burr knotting.
- *Protect from the wind – support adequately.* See previous comments about tree support systems.
- *Keep trees pest and disease free.* Pay particular attention to pests that damage shoot development, such as light brown apple moth. Careful management of apple or pear scab on young trees is also very important.

- *Mulches may be used for moisture regulation and weed control.* Avoid disease; don't place mulch too close to tree trunks. Consider growing mulch in the inter-row and using a mower that throws it on to the tree line.
- *Grow the tree, then crop it – avoid the temptation to overcrop early.* The quickest way to slow down the growth of a tree (particularly on dwarfing rootstocks) is to crop it. A careful balance between crop load and yield is necessary to ensure adequate shoot growth in the first 2 or 3 years. Never overcrop a tree of any age.
- *Hand-remove flowers in the first season.* For most training systems it is highly advisable to hand-remove any fruit that sets in the first season after planting, as it can significantly affect tree canopy development. Avoid thinning chemicals as they suppress tree growth.
- *Don't neglect young trees.* Attention to detail helps to quickly establish (or re-establish) an orchard. Neglect affects the viability of the business. Measure the growth of representative trees across the block to pinpoint necessary management actions.

Preparing established blocks for a new season

Pest carryover. Pests need to survive through winter without fruit, leaves or succulent shoots for nutrition. Some migrate, but most pests never leave the orchard or its nearby surrounds. Knowing where these pests are, and destroying them, will reduce pest problems in the upcoming season.

Remove all fallen and hanging fruit and destroy it. Apply urea and/or mulch fallen leaves to hasten their breakdown.

Look for disease cankers and insect damage on limbs. This damage is easier to see and remove during dormancy.

Training, pruning, thinning and fertilisers.

Training systems that provide open canopies result in greater air flow and shorter drying times. Consequently, disease incidence tends to be lower. Open canopies allow light penetration for strong spur development and increased colour development. Increased light discourages woolly aphid (p. 134), a particularly difficult pest to control.

Training systems that minimise pruning and, subsequently, pruning cuts (disease entry points) result in fewer problems from diseases such as silver leaf.

Although benefits can be gained from opening up the canopy through pruning and training, orchardists need to be aware of the problems that may arise from sunburn in warmer regions. Sunburn can result in bark cracking and splitting and predispose the tree to fungal infections.

Pruning should:

- remove water shoots
- remove diseased tissue
- open the canopy to allow air movement and better spray distribution and increase light penetration.

General maintenance. Service all tractors and sprayers well before they're needed. For diseases such as black spot and powdery mildew you will need sufficient well-maintained equipment to spray the entire orchard within 3 or 4 days after rain. If your equipment is broken down and sitting in the shed you may be setting yourself up for a pest outbreak.

Prepare and calibrate machinery

Sprayers that are not properly prepared and calibrated are not likely to apply the correct volume of pesticides in the right location. If too little pesticide is applied, inadequate pest control is likely. If too much is applied, money is wasted and there is an increased likelihood of off-target damage (e.g. to beneficial insects) occurring.

The following extract from the I&I NSW *Spray Sense* information on pesticide issues (see 'More information: Six steps to controlling diseases of apples and pears' p. 200) will prove useful for preparing spray equipment for the coming season.

Hand-operated sprayers

Hand-operated sprayers, such as knapsack and mistblowers, which are designed to be carried and operated manually by one person, are widely used in agriculture. They are:

- suitable for treating small areas
- cheaper than tractor-mounted sprayers
- effective in restricted areas (e.g. slopes and close plantings).

Types of hand-operated sprayers. There two main types of hand-operated sprayers:

- *Knapsack sprayers.* These sprayers have a tank capacity of up to 20 L capacity. They are usually carried on the operator's back and have a pressurising system and a hand lance with a pressure gauge and one or more nozzles. The lance or wand usually has a simple on-off valve.

Three systems of pressurising the liquid are available:

1. Lever-operated sprayers use a regular pumping action to operate a piston or diaphragm pump within or near the spray tank to maintain operating pressure.
 2. Compression sprayers are filled to two-thirds capacity and the remaining air space is pressurised by a piston action air pump or gas cylinder. This constant pressure forces the spray out of the tank by replacing it with air. Compression sprayers should be equipped with a pressure gauge and a relief valve.
 3. Motorised knapsack sprayers use a small two-stroke engine instead of manual pumping to force the liquid to the nozzle. The pressure is adjustable by either changing the rpm of the engine (piston pump) or with a pressure regulating valve (diaphragm pump).
- *Mist blowers.* Mist blowers have a fan and a flexible discharge hose. The spray mixture is fed in to the air stream by gravity and fine droplets are formed by the shearing action of the high-velocity air stream (90 to 100 m/s). Mist blowers are ideal for applying pesticides in dense crops.

Nozzles. The nozzles used in knapsack sprayers are the same as those used on boom sprayers. Hollow-cone nozzles are used for insecticides and fungicides and flat-fan nozzles are used for herbicides.

Nozzles and nozzle tips are available in a wide range of materials. Ceramic nozzles are the most resistant to wear, followed by plastic and stainless steel. Brass nozzles wear quickly.

Pressure. Most hand-operated sprayers operate at low to moderate pressures (300 to 600 kPa). Droplet size and flow rates can be regulated by adjusting the pressure. The higher pressure, the smaller the droplets. The lower the pressure, the larger the droplets. Once the pressure and droplet size are determined it is important to maintain the same pressure. Pressure gauges on the hand lance make it easy to adjust and control the pressure.

With mist blowers, pressure is not important. However, air velocity and volume are critical because they decline markedly at low speeds, affecting droplet size and coverage. Spray at maximum rpm to maintain air velocity and air volume.

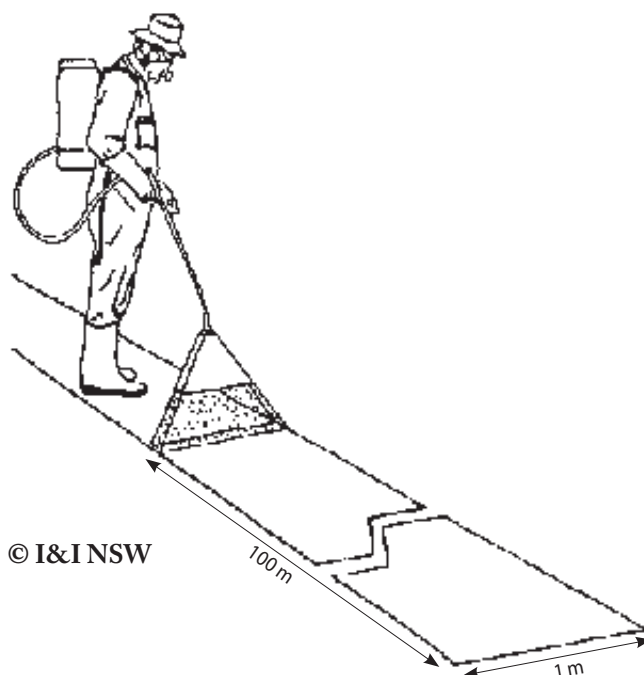
Calibration. All hand-operated sprayers need to be calibrated at the start of the season and kept in good operating condition. This will ensure that the correct rate of chemical is applied to the target plant.

Follow these steps to calibrate a knapsack sprayer

1. Measure the spray width of the nozzle(s) on a dry surface (in metres).
2. Spray a test area at the intended pressure and walking pace. Record the distance (in metres) covered in 1 minute.
3. Measure the nozzle output in litres over 1 minute in a measuring jug (L/min).

The spray volume can be calculated by the following formula:

$$\text{Application rate (L/ha)} = \frac{\text{Nozzle output (L/min)} \times 10\,000}{\text{Spray width (m)} \times \text{walking speed (m/min)}}$$



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For example:

Nozzle output in 1 minute = 5 L

Spray width = 1 m

Walking speed = 100 m/min

$$\begin{aligned}\text{Application rate (L/ha)} &= \frac{5 \times 10\,000}{1 \times 100} \\ &= \frac{50\,000}{100} = 500 \text{ L/ha}\end{aligned}$$

Mist blowers can be calibrated by the following method:

1. Fill the tank with water up to the defined mark.
2. Spray over a measured distance of 100 m.
3. Measure the volume of water (in litres) required to top up the tank to its previous mark.
4. Multiply the measured water (L) from step 3 by 100 to obtain the application rate L/ha.

How much to put in a tank. The following formula can be used to determine the amount of product needed for each tank.

$$\text{Product / tank (L or kg)} = \frac{\text{Recommended rate (L/ha)} \times \text{tank size (L)}}{\text{Application rate (L/ha)}}$$

For example:

Recommended product dosage: 5 L / ha

Application rate: 500 L / ha

Tank size: 20 L

$$\text{Product / tank (L or kg)} = \frac{5 \times 20}{500} = \frac{100}{500} = 0.2 \text{ L or } 200 \text{ mL}$$

In this example, 200 mL of the product is added to a 20-L knapsack sprayer to give the recommended rate of 5 L/ha.

Airblast sprayers

Airblast sprayers are designed to apply low to medium volumes of spray using small droplets between 30 and 350 µm in size. The droplets of the water and chemical are carried to the target plant in an air stream generated by the fan. The airblast sprayer displaces the air in the canopy of the target plant with the spray-laden air from the machine.

Most airblast sprayers have at least two fan speeds. Normally, the lower fan speed is used on smaller, less dense trees. As plant size and density increase, more air is needed, so the higher fan speed is used. Airblast sprayers can generate their own wind, so spraying can be undertaken under calm conditions. However, a slight breeze of 5 to 8 km/h may improve spray penetration.

The air stream that carries the droplets plays no part in their production. The size of the droplets is controlled by the nozzles used on the machine and the operating pressure.

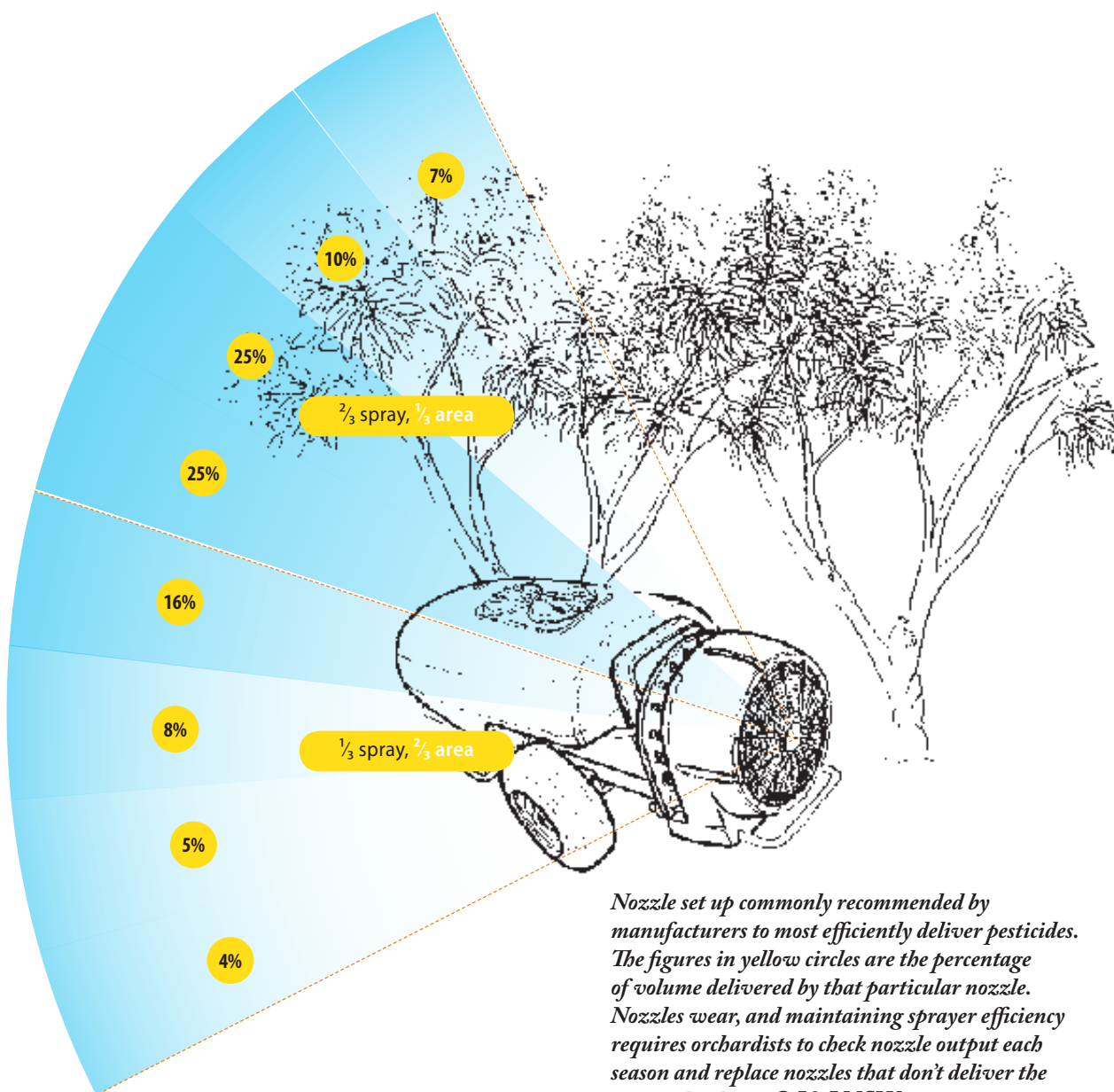
Other types of sprayers are also being used more frequently in apple and pear orchards. Tower or directed sprayers can offer benefits in terms of cost effectiveness, resistance and environmental issues.

Nozzles. Nozzles are the most important component of any spray machine. The type of nozzle commonly used on airblast sprayers is a hollow cone that produces small droplets. The nozzles are usually arranged so that nozzles producing larger droplets are at the top and those producing smaller droplets are at the bottom. This setup is designed to apply two-thirds of the spray volume to the top third of the target plant.

In most cases nozzle size and placement are specified by the manufacturer.



Airblast sprayer © I&I NSW



Nozzle set up commonly recommended by manufacturers to most efficiently deliver pesticides. The figures in yellow circles are the percentage of volume delivered by that particular nozzle. Nozzles wear, and maintaining sprayer efficiency requires orchardists to check nozzle output each season and replace nozzles that don't deliver the required volume. © I&INSW

Position the nozzles on your sprayer so that spray droplets cover the target plant from top to bottom. Nozzles directed into the air and on to the ground waste spray. Turn off nozzles that are not needed. Nozzles wear out quickly, so check them at the beginning of the season and continue to check them regularly. Usually they need replacing at least once a year.

Calibration. The aim of calibration is to ensure that a specified rate of chemical is applied to the target plant. To do this you need to measure the total spray output of the machine and the travel speed, and then calculate the application rate.

- **Calculating total sprayer output (L/min).** The aim here is to measure the total liquid sprayed from your machine in one minute. First, disengage the gearbox and set the pressure at the correct level for spraying and the PTO at 540 rpm. Leave on all the nozzles used for spraying, but turn the fan off.

1. Fill the spray tank with clean water.
2. Place a measuring jug under one nozzle. If you do not want to get wet, attach a piece of plastic hose to the nozzle and place the other end in the jug.
3. Run the sprayer for 1 minute at the correct pressure with all the nozzles operating.
4. Measure how much water is in the jug. Compare this with the output specified by the manufacturer, using the correct pressure. Nozzle output should not vary by more than 10%. If it does, the nozzle is worn and needs to be replaced.
5. Repeat steps 2 to 4 for all nozzles.
6. Add all the jug measurements to find the total sprayer output in litres per minute.

- *Calculating travel speed (km/h).* The normal speed for spraying is between 4 and 8 km/h. The slower you travel, the higher the application rate. A change in ground speed of 10% results in a 10% change in application rate. Adjust your travel speed so that the target plant is covered with spray but the spray is not running off the leaves. If you have large, dense trees you can reduce tractor speed to improve spray coverage and penetration.

1. Measure out a distance of 100 m on the ground and mark the start and finish positions with pegs.
2. Select the correct gear for spraying and increase the engine rpm to give 540 rpm at the PTO.
3. Measure how many seconds it takes to travel 100 m with the sprayer attached and half full.
4. Calculate your travel speed by inserting the time in seconds into the following formula:

$$\text{Travel speed (km/h)} = \frac{100 \text{ (m)} \times 3.6}{\text{Time (seconds)}}$$

- *Calculating spray application rate (L/ha).* First, measure your row width. If you are spraying both sides when travelling down every row, the row width is the distance between the two rows of trees. If you are spraying only one side when travelling down every row, the row width is the distance from the centre of the row to the tree line.

Calculate the application rate by using the following formula:

$$\text{Application rate (L/ha)} = \frac{600 \times \text{total sprayer output (L/min)}}{\text{Row width (m)} \times \text{travel speed (km/h)}}$$

Example: If your total sprayer output is 40 L/min, your speed is 5 km/h, and the row spacing is 5 m:

$$\text{Application rate (L/ha)} = \frac{600 \times 40}{5 \times 5} = \frac{24000}{25}$$

Benefits of calibration. By calibrating your machine you find out your spray application rate. This information is necessary whenever you use chemicals that have application rates specified in amounts per hectare. It will also allow you to work out how many spray tanks are needed for a particular job.

The spray application rate varies for different crops and different plant spacings, and with the age, height and density of crops. Therefore, you need to calibrate for each crop or block. In the long term it will save you time and money and result in a more effective and efficient spraying job.

Train and thin trees

One of the objectives of tree training should be to create an open canopy. More and more Australian orchards are being grown at high density. One of the few disadvantages of these growing systems is that they reduce air flow in the orchard and make it more difficult to achieved good spray penetration. Both of these factors make pest control more difficult, and good tree training has become even more critical. Many pests become established in the tops of trees because inadequate pruning and poor calibration of spray equipment have led to poor spray penetration high in the tree. It is important to check spray coverage regularly (see 'Check your spray coverage' p. 19).

Good advice on tree training can be found in a number of manuals or from your local commercial supplier, consultant or State government agronomist. In the context of pest and disease control it is important to keep the following in mind:

- Always make clean cuts with sharp, well-maintained pruning equipment.
- Consider painting large wounds to stop pests entering.
- Always prune trees with pests last.
- Carefully remove pest-infested prunings from the orchard and burn them.
- Consider the time of the year and the weather and what influence pruning will have on pest spread. For example, pruning in the middle of winter is not advisable in orchards with silver leaf infections.

Thorough fruit thinning will also help to reduce pest problems. Clusters of fruit are prone to pest infestation because:

- they provide sheltered feeding and nesting sites for insect pests
- humidity between fruit is higher, making clusters more prone to disease infection
- pesticides don't reach the space between fruit
- fruit-to-fruit contact leads to skin damage, making it easier for pests to infest and spread between fruit. Damage starts on one fruit and soon the entire cluster is worthless.



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Consider netting

Netting an orchard block is an expensive venture. Netting should be undertaken only when the resulting improvement in returns outweighs crop damage from birds, bats and hail. A complete analysis of the costs associated with netting can be found in *Managing Bird Damage to Fruit and Other Horticultural Crops* (Tracey and others 2007). For a complete reference to this publication see 'More information: Reducing the impacts of birds in horticulture' (p. 205).

Netting has a number of implications for pest management:

- Higher humidity under nets may increase the likelihood of disease problems.
- When using airblast spraying equipment a light breeze helps pesticide penetration. The still air under netting will influence spray coverage.

In practice, neither of these factors seems to cause significant problems, and disease control under nets is usually no more difficult than in adjacent uncovered blocks. However, care must be taken when spraying pesticides under nets before flowering. Dormant sprays of copper sometimes drift on to nets and dehydrate to form a residue. If the next rain is during blossom, or if blossom sprays wet the net, the copper can go back into solution, drip down, and damage the flowers. Similarly, care needs to be taken in the weeks leading up to harvest. Sprays applied to comply with withholding periods can dry on overhead netting, fall later and cause residue problems.

Temporary netting can also provide protection against birds and is much less expensive.

Nets draped over T-trellises are compatible with the trellising systems being promoted by *Future Orchards 2012*; these new systems are essential for support of dwarfing varieties. Because they involve establishment of some infrastructure they can be expanded as finances allow and developed into more conventional netting systems. Experience has shown that the systems allow good colour development and spray penetration and there is good air movement in the canopy of the trees.

Other temporary netting systems fully enclose the trees. Users of these systems say that spray penetration is adequate, as is colour development. Tree growth can be affected. If the tree has low vigour it will develop rounded, misshapen branches in the shape of the cover. Some growers believe that although this looks ugly it is actually beneficial in that the trees have even less vigour with the netting and therefore are easily and quickly pruned. Trees with high vigour are hardly affected and will maintain shape.

Both systems allow some protection from hail damage. Less hail damage occurs on the T-trellis system. With the enclosed netting system there will be hail damage to those fruit directly exposed to the outside of the netting. This would equate to less than 5% of fruit.

The main disadvantage of both systems is the labour required to lay out and retract netting. Growers using these systems consider this extra labour expenditure to be worthwhile.

Review your records and buy supplies

Reviewing your records from previous seasons will allow you to anticipate and prepare for the arrival of pests. Using records, you should be able to approximately judge the time at which pests will arrive. As seasons pass, this accumulated knowledge can be used to refine monitoring and pest management. Monitoring can be intensified when pests are likely to arrive and be less intensive when they are unlikely to be present. This will save time and money.

Well kept records will also tell you which management options have worked in the past allowing you to prepare early. For example, if the management option is pesticide application you will be able to make sure that the most appropriate pesticide is available at your local supplier when it's likely to be needed.

Prepare the packing shed

Good packing shed hygiene is essential. Poor hygiene can lead to serious problems with postharvest diseases such as *Penicillium* and *Mucor*. Before the start of the season:

- Clean and sanitize bins using a high pressure water cleaner using either hot (70 °C+) or an approved sanitizer (e.g. quaternary ammonium or hypochlorite). Alternatively exposing bins to intense sunlight can be used to sanitise bins provided bins are turned to expose all surfaces.



Fully enclosed temporary netting Michael Cunial, © I&I NSW

- *Check bins for damage.* Repair any loose boards or rough surfaces to make sure that they don't lead to cuts and other damage to the crop, that may provide entry for postharvest diseases.
- *Clean grading equipment and cold rooms.* Non-corrosive food grade sanitizers, steam or pressurised hot water can be used to clean grading lines. Coldstores should also be thoroughly cleaned before use.

At the start of each season, drenching systems for DPA, fungicide and calcium application should be fully tested. If using DPA for scald control, prepare a chart showing the amounts of DPA and fungicide required for each variety. Put in a place an easy system to measure top-up volumes to make sure that the DPA concentration is correct. Further information on DPA application can be found in 'Guidelines for postharvest drenching of apples and pears' at www.apal.org.au/information-fact-sheets.cfm?id=3213&t=/post-harvest-drenching-of-apples-and-pears/

Step 2: Have a pest management plan for the season

When a man does not know what harbor he is making for, no wind is the right wind.

Lucius Annaeus Seneca, Roman statesman

A pest management plan should be started at the beginning of each season. The plan is not set in stone. As the season progresses unexpected problems will occur and the pest management plan will need to be modified.

The plan is underpinned by a comprehensive and well-kept set of records from the current and previous seasons.

Choose your blocks

Start small! No-one likes to take risks. IPM usually involves a reduction in the number of pesticide sprays applied. A well-run IPM system will not result in more pests, but until you have gained some experience there is a risk. By reducing the number of pesticide sprays you run the risk of more pests and greater financial loss. Therefore, it is a good idea to introduce IPM gradually.

In the first season, use IPM on a low-value block. It would be best if this block is relatively large, but if a large block isn't available a small block will do.

Most IPM strategies work best on larger blocks or even across whole orchards and even regions. Using a small block to start means that you don't get the full benefit of IPM. As you gain confidence and IPM spreads across the whole orchard, pest and disease control become easier.

Know which pests are likely to cause problems

The most effective way to control pests is to anticipate which ones are likely to cause a problem and be ready to control them. Make a list of the pests that have been in your orchard over the last four seasons. As a general rule, if a pest hasn't been seen for four seasons it shouldn't be necessary to monitor for it. Pests that have caused financial losses should be given priority. If pests have been present but haven't caused losses, then include them on the list, but it may not be necessary to do anything about them in the coming season.

Pest lists will vary from orchard to orchard and probably from block to block; in some cases they will be linked to climatic conditions.

Find out all you can about the pests and diseases that attack your orchard:

- When can you expect them to occur?
- What do they look like (particularly early, before they've had a chance to do serious damage)?
- When is the most effective time to control them?

The pest fact sheets in the following chapters provide this information for most common pests of the Australian apple and pear industries.

You should also become familiar with the beneficial organisms that are likely to become more common in your orchard as you convert more and more blocks to IPM.

Keep records

Write it down. Written goals have a way of transforming wishes into wants; can't's into cans; dreams into plans; and plans into reality. Don't just think it —ink it!

Source Unknown

Compulsory records

All Australian States have legislation that requires anyone using pesticides for commercial or occupational purposes – such as on your produce or farm or in your business – to keep a record of each pesticide application. Many quality assurance schemes also specify pest management information that must be recorded.

Typically, these pesticide records need to be made within 24 hours of application, must be written in English, and must be kept for 3 years. A record must be made when:

- spraying crops, plants or produce
- spraying fallow land
- dipping produce
- baiting for pests.

The information recorded for each application includes:

- *details of who applied the pesticide:* their name, address and contact phone number. If a contractor or employee applied the pesticide, they need to also record the contact details of the employer.
- *the owner of the land sprayed.* This may be the owner, manager or lessee. Record their name, address and contact phone number.
- *date and time of application.* Record the date and both the start and finishing time of the application.
- *product details.* You need to record the full product name of the pesticide used.
- *crop or area treated.* Record the crop type or situation where the pesticide was used.
- *application equipment.* Specify the type of equipment used (e.g. backpack, mister or airblast sprayer).
- *the amount of product used.* You need to record how much pesticide was used (rate) and what area was covered. You can do this by specifying the total concentrate or the total spray mix and the area covered (in m² or ha).
- *where the pesticide was applied.* You need to record the property address and the name or number of the block sprayed.
- *the order of blocks sprayed.* If more than one block was treated at the same time you need to record the order in which the blocks were sprayed.

- *weather information.* You need to record wind speed and directions as well as any significant weather changes during applications. You can estimate the wind speed by using the Beaufort Wind Strength Scale. A portable weather meter (which can measure wind speed, temperature and humidity) will give more accurate readings.

An example of one type of pesticide record sheet is provided in Appendix 1: Pesticide application record sheet (p. 168). It includes all categories that you must record when applying agricultural pesticides.

These compulsory records are **not** adequate to manage pests using IPM. Recording and updating the following information will give you much more information for use in developing management strategies for pests and diseases.

Block plans

Numbering tree rows is time consuming to start with, but it's helpful over a number of years in terms of time saved in big blocks looking for particular trees (especially in trellised orchards). Block plans should be written in sufficient detail that individual trees, service points (e.g. tank filling points, chemical stores and dams) and other points of interest can be found quickly by someone who has no prior knowledge of the property.

Block plans are extremely useful for many things, but in the context of pest management they enable outbreaks to be recorded and monitored over time much more easily. For example, it is easier to find a small infestation of mites knowing the exact location of the tree rather than having only a rough idea of where it is in a block.

The indexing system (block and row names, numbers or letters) is at the discretion of individual growers, but it must be documented as a written record and kept in the shed or office.

Hand-held global positioning systems (GPS) can be used to determine orchard dimensions very accurately and are extremely useful in calculating pesticide application rates.

Monitoring records

Most growers keep a record of the pests that have affected their orchards during a season. Often this is kept in conjunction with compulsory spray records. A separate book should be devoted to the information, which will be collected as a result of systematic monitoring (see 'Step 3: Monitor' p. 16).

The information in this book should include:

- *Pest name.* For most orchard pests the common name (e.g. black spot, codling moth) will suffice. For other, less familiar, pests, accurate identification will be needed. Keep in mind that in some cases pests that appear similar are controlled in very different ways. Most State departments of agriculture provide pest identification services (see 'Appendix 2: Useful contacts' p. 169). Fees for this service usually apply.
- *Date and location first noticed.* This can be compared with records from previous and future seasons to determine whether pests are arriving earlier or later. In some cases pests that arrive very late may not have time to build their numbers to damaging levels and won't require management.
- *Location.* Record where the pest was first seen by using a reference from the block plan. Nothing is more frustrating than searching for a pest outbreak in a poorly mapped block. This information can also be used in your end-of-season review to decide whether monitoring trees should be changed. If pest outbreaks persistently occur in one area of the block, perhaps something can be done to improve management there.
- *Damage.* A record should be kept of the type and severity of damage. By combining this information with the record of when the pest arrived, growers should get an indication of how serious the damage is likely to be. This estimation can be even more accurate if you have a knowledge of the pest's life cycle and a weather forecast.

- *Beneficials.* A record of beneficial organisms will also help to decide whether management is needed in the current season. If numbers of beneficial organisms are high it may not be necessary to apply management, even if pests are present.

Management records

Fruit growing is a business. When making decisions on pest management it's important to have a complete set of financial records from previous seasons. Balance the financial inputs associated with pest management against the economic benefits. For example, were the costs of a particular pesticide (and the machinery running costs and labour needed to apply it) justified by the increase in money received for that crop?

Weather records

Many pests respond to the weather in a predictable way. It's particularly useful to record rainfall, temperature and humidity. Over a series of seasons an accurate picture of what pests are likely to become problems following a certain type of weather will become clear. This allows earlier, preventive management to be done before problems become serious.

Rejected-fruit records

Often problems – particularly diseases – don't become apparent until after harvest. Infections that occur in the orchard may not show up until fruit is harvested. Keep a record of the quantities of fruit rejected or downgraded in the shed, in storage or on the grading/packing line, together with the reasons for rejection.

Step 3: Monitor

Monitor your trees and the weather

The type of monitoring done will be determined by the types of pests that are likely to cause problems. For some pests, careful observation and detection can allow early, effective action to be taken. Systematic visual monitoring of the orchard block can save money and time later in the season.

In other cases even detection of the very earliest stages of the pest are too late to prevent significant damage. However, monitoring the weather that allows the pest to develop may give forewarning of its arrival.

Visual monitoring

In IPM a 'block' is a group of trees that are fairly uniform in terms of physical characteristics, variety and age. It is an area that is managed as a unit. This includes pest and disease management (e.g. spraying).

Most orchardists don't have the time to monitor every block in the entire orchard. Instead, indicator blocks can be used. Choose indicator blocks with care. The blocks chosen for monitoring should be those with a history of pest problems.

Within the indicator blocks, monitor the same trees during the entire season. Mark these trees with flagging tape or by painting their butts. Because trees within blocks are numbered according to the block plan you will be able to keep an accurate record of where in the block problems are occurring.

Choose trees:

- that have been pest 'hotspots' in past seasons
- in a pattern that makes you visit all parts of the block during monitoring. Even though the trees between the monitored trees aren't formally part of the IPM system, watch out for unusual pest activity as you walk through each time.

Step 1. Select trees to be monitored in the orchard block. Concentrate on trees which have had pest or disease problems in the past.

Step 2. Mark the trees clearly with flagging tape or bright acrylic paint. Randomly select and mark flowers, shoots or fruits to monitor on each of the chosen trees.



Surprisingly little equipment is needed visually inspect the indicator trees. Close examination of pests can generally be done with a hand lens. Professional consultants will need more equipment, including a binocular microscope for counting and identification of mites and thrips.

The table below gives an indication of the number of trees to monitor in orchard blocks of various sizes.

Determining how many trees to monitor in your orchard blocks

Area (ha)	Number of trees sampled	Time taken (minutes) to check block*
<1	10	20–30
1–3	15	30–45
3–4	20	40–60
4–6	25	50–75
>6	30	60–90

*Time taken for an experienced operator; allow more time when you first start.



Step 3. Every 7–14 days during the fruit development season, carefully monitor the marked flowers, shoots and fruit for early signs of pests. Record any pests seen.



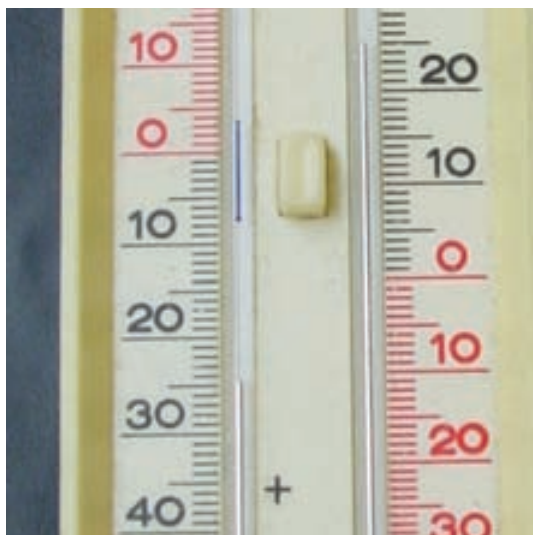
Monitoring the weather

Some pests quickly become damaging after weather that favours their development. Often, by the time these pests are seen, serious damage has been done to the crop. Fortunately these pests tend to respond to weather in a predictable way.

By carefully monitoring the weather, it is possible to apply management before these pests become a problem. Temperatures can be monitored by using a simple thermometer, but more information can be gained by using a maximum–minimum thermometer (these are available at most rural suppliers). It is important that thermometers are mounted in the orchard but not in direct sunlight.

Using a data-logger will give you better weather information. Small, relatively inexpensive units are available from a number of Australian suppliers. It is useful to buy loggers that measure temperature, humidity, rainfall and leaf wetness.

The ways in which a number of pests respond to weather have been studied and developed into mathematical models. These models have been programmed into predictive forecasting units that can be placed in the orchard and downloaded regularly to help with pest-management decisions.



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Know how much time it takes to monitor

Monitoring takes time. Allow sufficient time to do the job properly. Monitoring should never be deferred because of other commitments. When IPM fails it is almost always because monitoring loses priority at peak times. Be realistic – if you don't have time to do the job properly, hire a consultant or scout.

For a beginner, as a rough guide, the time needed will be:

- 15 to 20 minutes per hectare every 7 to 14 days at peak times

It will take several months for an inexperienced person to monitor confidently and accurately.

For an experienced person, the time needed will be:

- 10 to 15 minutes per hectare every 7 to 14 days at peak times.

If you are using a consultant to monitor your orchard and you don't think IPM is working, make sure they are spending at least this recommended length of time in your orchard.

Step 4: Take action only if you need to

You must take action now that will move you towards your goals. Develop a sense of urgency in your life.

Les Brown

Know your thresholds

An action threshold is the point in time at which monitoring indicates that the financial loss caused by a pest is unacceptable. At this point something must be done to control the pest. If a pest isn't costing you money or causing other problems, why waste time, money and effort controlling it?

But how do orchardists know when pest damage has reached this point?

- Very little research has been done on the relationship between damage and economic loss.
- The level of acceptable damage will vary from orchardist to orchardist and from market to market.
- The level of acceptable damage will vary from year to year, depending on the market.
- For some pests it's too late by the time you see the problem.

In some cases threshold damage levels have been published, and they have been included in this manual in each pest section. They should be regarded as a guide only. Orchardists are encouraged to try them and then modify them to suit their enterprises. Review whether they worked after two or three seasons and then revise them up or down.

Thresholds are important tools for avoiding either pest damage or unnecessary sprays, but in most cases orchardists will need to decide upon reasonable thresholds themselves. The key to deciding on a reasonable action threshold is to keep good records:

- What pests have been problems in the block over the last 2 to 5 years?
- How much damage have they done?
- What control measures were used and how much did they cost?
- Did the control measures work?

Check your spray coverage

There are many reasons why a pesticide application can fail to control a pest. Although it's tempting to look for complex reasons, often the solution is simply that the rig wasn't set up to provide good coverage. This is particularly the case when the trees are dense or tall, or when pests tend to shelter in rough bark or other cryptic parts of the tree. It's good practice to check coverage immediately after a pesticide has failed, so as to eliminate this possibility.

Spray cards

A spray card is a strip of water- or oil-sensitive paper. The cards are produced in a range of sizes. They were developed for use in the field for quick evaluation of spray coverage and droplet size.

- *Water-sensitive paper.* These strips are made of specially coated yellow paper that turns blue when exposed to water droplets. The paper will also change colour when exposed to high humidity or even sweat from your fingers and hands. When not in use, the paper strips must always be stored in the foil packet and kept dry.
- *Oil-sensitive paper.* These strips are made of a black card coated in a white oil-soluble wax. The waxy surface is dissolved when contacted by oil-based droplets, leaving permanent black marks on a white background. This paper is not sensitive to all oils.

Using spray cards. Spray cards are among several tools you can use to assess spray coverage. They allow you to see where the spray is going in your crop and what sort of spray coverage you are getting with your equipment.

The spray cards can be placed in the crop by using staples, pegs, or paper clips before any spray operation. Be sure to use brightly coloured pegs, as the water-sensitive cards turn blue when wet and can be difficult to see in green foliage. The cards should be collected as soon as they are dry.

The cards can also be used to give you an indication of droplet size and density. However, once the liquid hits the paper, the droplets expand and may appear slightly larger. For assessing droplet size and density, the cards were originally designed to be viewed under a microscope or hand lens; the droplets were counted and compared to pictures showing different densities per square centimetre.

Spray cards are good tools for evaluating both your spray equipment and your spraying operation. They can be used to check where your spray is going in the crop and whether it is getting inside the canopy and to the top and bottom of trees. This information is useful when calibrating your spray equipment, especially with regard to nozzle size, placement, direction and travel speed.

Limitations of spray cards. Spray cards have certain limitations:

- The cards don't work under very humid conditions, as the water-sensitive paper turns blue at about 80% relative humidity.
- Droplets smaller than 100 µm are not visible on the cards. Remember that there is often a large percentage of spray droplets smaller than 100 µm (100 µm = 0.1 mm). This is especially the case with spray equipment such as airblast sprayers and misters designed to produce droplets smaller than 100 µm.
- You need to wait until the plant's foliage is dry before placing cards in the crop. Wait until fog has lifted or dew has evaporated.

- Once the cards have been used, don't collect them from the crop until they are dry.
- Wear gloves when handling the cards so that they don't become stained from your perspiration.

Other spray assessment tools

The other main method of visually assessing spray coverage is by using ultra violet (UV) fluorescent dyes. The liquid dye is placed in the tank of your sprayer and a normal spray operation is undertaken. To see the UV droplets you need to use a UV light at night to view the area sprayed.

This method of assessment is far superior to using spray cards but is a lot more difficult to organise.

Where to buy spray cards

Spraying Systems Co. Pty Ltd is the only company in Australia supplying spray cards (phone 03 9318 0511). Contact your local agricultural supplier for more information.

Step 5: Evaluate the season

Find out which pests caused trouble

Keep accurate records of pest incidence in your orchard during the season. Keep your records for up to 10 years. The more historical information that you have, the better the decisions you're likely to make.

Losses caused by pests that generally affect leaves or branches (e.g. powdery mildew, two-spotted mite) are more difficult to assess than those affecting fruit. Keeping accurate records of the percentage of trees affected and comparing these with previous seasons' is the only way that management action can be evaluated.

Examine rejected fruit regularly in the orchard, after picking, and in the shed. Determine the major reason why the fruit wasn't packed. Some pests can be very obvious in the orchard but really don't cause major problems. More effort than is needed is sometimes put into controlling these problems than other, less obvious – and perhaps more damaging – pests.

Determine which types of management worked

After reviewing losses due to specific pests, think about how you tried to control that problem during the season. For example, for pesticides, estimate the total volume of pesticide applied for each pest (spray records will provide this information); the price of the pesticide; and the total cost of control, including application time (labour) and running and maintenance of equipment.

More accurate records allow for better decision-making, and the overall objective of IPM is to find the best management options.

Step 6: Plan for next season

When defeat comes, accept it as a signal that your plans are not sound, rebuild those plans, and set sail once more toward your coveted goal.

Napoleon Hill

For all of the blocks you have in your IPM program it is important to do a pest and disease management review at the end of each season.

The best way to improve your pest and disease management is to look at what you've done and then put more emphasis on the things that worked and find alternatives for those that didn't.

Work out what you have to do

A plan for next season should include each pest you think you may have to control. Answer this question:

Has the pest or disease caused a problem in my orchard during the previous four seasons?

1. *Yes.* Formal monitoring will be needed. Control may be needed, depending on the results of monitoring.
2. *No.* Only casual monitoring will be needed. Specific control measures will probably not be needed next season.

Make sure all your preventive management strategies are in place

If the pest or disease was a problem last season, start by doing some preventive management. Often prevention reduces the number and severity of problems encountered during the season. This manual contains suggested preventive management strategies for the most serious pests of the Australian pome fruit industry.

Plan for each pest and disease that has been a problem recently

Planning on the run usually doesn't work; plan well in advance.

The technique you use for monitoring should detect pests before they cause serious damage. Where serious damage did occur, why did monitoring fail? Was enough time allocated to it? Were the designated monitoring trees (see 'Step 3: Monitor' p. 16) the right ones? Are there more serious 'hotspots' in the block that would be better suited for monitoring?

Have you been happy with the management options for each pest and disease in the past? Look at your records and consider:

- Did it work?
- Was it cost-effective?

For pesticides:

- Did it cause secondary problems, such as mite outbreaks?
- Did it cause any other problems, such as health or disposal problems?
- What about residues?
- Have new, and potentially better, products come on to the market?
- Is there a danger of pesticide resistance developing?

Consider alternatives

Even if something is working well, there may be an even better alternative. If for any reason you're not happy with some aspect of pest management, change it. Be conservative to reduce risk: trial major changes to your pest management on small, low-value blocks before using them more generally.

This manual provides a number of pest and disease management options for each of the major pests of Australian pome fruit.

Consider using IPM on more blocks

Consider switching more blocks to IPM if:

- pest and disease losses in IPM blocks are no higher than those in other blocks, and/or
- pest and disease losses in IPM blocks are no higher than they were before conversion to IPM.

Mating disruption



Mating disruption



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Introduction

Many moths use chemical signalling systems to enable males and females to find one another, mate and produce a new generation. The chemicals used in this signalling are called pheromones. In Australian orchards, pest moths that produce pheromones include.

- codling moth
- lightbrown apple moth
- oriental fruit moth.

Commercially available products using artificially produced pheromones can be used to manage these pests in a number of ways. Pheromones are emitted by the female moths, and these powerful scents are able to draw males from great distances. The presence of male moths (even at low numbers, early in the season) can be monitored by placing point sources (lures) in orchards and using sticky traps to monitor the numbers of moths attracted. The techniques for monitoring using this method is outlined in this manual in the sections specific to the moths listed above.

Some orchardists will be able to make even better use of pheromones by using mating disruption to control their pest moths.

What is mating disruption?

Under normal circumstances a male moth is able to follow a single scent trail to locate a specific female moth. Mating disruption uses a grid of powerful dispensers to release massive quantities of pheromone into an orchard. In an orchard using mating disruption to manage pest moths there are so many strong scent trails that the male moth becomes confused and is unable to find a female. Imagine being in a room with a group of friends. You should be able to find a specific friend when they call you, even if other people are talking at a normal level. But now imagine what happens if everyone begins to shout your name ... you become overwhelmed, confused and have no idea who to go to.

These confused male moths have trouble finding a female moth with which to mate so that some females will go unpaired or mating will be delayed so that the number of fertile eggs laid will be very much reduced.

Advantages of mating disruption

- *Specificity.* Each of the pest moths produces a specific type of chemical signal or pheromone. This means that the mating disruption products that use these pheromones are effective only against the pest that they target (although note that products using more than one pheromone in a single package are likely to be available in future). For example, Isomate CTT® pheromone affects only codling moth, not lightbrown apple moth, oriental fruit moth or any other insect in the orchard. Mating disruption agents have no effect on biological control agents (e.g. predacious mites, hoverflies, Trichogramma) or bees.

- *Reduced pesticide use.* Conventional insecticidal control of these moths usually requires frequent applications to be made throughout the season. This is particularly the case for codling moth, where entire insect pest management programs are based on how codling moth is controlled. Mating disruption should allow for the number of insecticide applications to be reduced (see 'Emergence of secondary pests' p. 27) and provide savings not just in the cost of insecticides but also in the cost of application (diesel, spray rig maintenance and labour). Because biological control agents such as hoverflies are likely to become more active, fewer sprays should be required for other pests.
- *Fewer pesticides on fruit.* Mating disruption agents should allow you to use fewer sprays; this will lower the possibility of fruit being contaminated with insecticide residues.
- *Block shape and size.* Mating disruption should not be used in blocks or contiguous areas of trees that are under 2 ha. Mating disruption does not work well on long thin blocks; square blocks are preferable.
- *Likelihood of migration.* Mating disruption will not stop mated female moths from flying into a block and laying eggs. Blocks adjacent to areas in which moths are not controlled are not suitable for mating disruption. Encouraging neighbours to clean up and (preferably) implement mating disruption will improve outcomes.
- *Slope.* Mating disruption will work best in flat blocks. Pheromones drain away with air movement down slopes.
- *Wind and shelter.* The pheromone concentration is diluted on windy or exposed blocks. Hill sites are often windy and can be a particular problem.
- *Trees.* A uniform block with large trees is better than one with many small or missing trees.

Can mating disruption be used on my block?

Before deciding to use mating disruption to manage pest moths it is important to assess the suitability of your blocks. There are a number of factors to consider.

- *Pest numbers.* Mating disruption works best when pests are present in low numbers. If pests are present in very high numbers it is probably best to use insecticides and other measures to reduce the populations over a number of seasons before switching to mating disruption. It is also possible to augment mating disruption by applying insecticides, but at a reduced frequency.

Optimising the effectiveness of mating disruption

Where an orchard block is suitable for mating disruption (see section on this page) the key to optimising pest moth management is to know which products are available and how to get the most out of them (see table below).

A grid of mating disruption dispensers must be set up well before the emergence of the first moths in spring. Records of monitoring from previous seasons should be used to calculate this date, but be careful not to rely on information from an abnormally hot or cold year. Preferably, predict the emergence date by averaging emergence dates from a number of years and

Numbers of mating disruption dispensers for various pests

Pest	Product	Registered crop	No./ha
Codling moth	Isomate C® pheromone	Apples and pears	1000
	Isomate CTT® pheromone		500
	Disrupt CM®		500
Oriental fruit moth	Disrupt OFM®		270
Lightbrown apple moth	Isomate LBAM Plus® pheromone	Apples	500 – 600



Examples of mating disruption dispensers. Isomate C (left), Isomate CTT (centre) and Disrupt CM (right) © I&I NSW

then ensure that mating disruption is applied 1 month before this predicted date. The timing of application will vary between regions, and application times from other districts should not be used. If you are uncertain, contact your local horticultural consultant.

Dispensers will release effectively high concentrations of pheromones into the orchard for a period of 200 days under Australian conditions. Late season moth problems should not occur if good control has been observed throughout the season. However, where monitoring (see p. 27) has indicated that moth populations are not under control, a late-season insecticide application may be necessary.

When applying mating disruption dispensers the objective is to create a 'pheromone fog', which should be as uniform as possible across the block. Where there is a high risk of moth infestation the 'fog' should be thicker.

Tips for optimising dispenser use

- Draw up a good block plan. Before starting the job, sit down with the plan and decide on the placement of dispensers. In general, placement should be in grids, but remember to map out areas that are at increased risk of moth infestation and allow for extra dispensers in these areas. Ad-hoc placement without planning is likely to not achieve uniform pheromone saturation and will waste dispensers (and therefore money).
- For twist-tie-type dispensers, bend the dispenser around the tree and use one twist to loosely attach it. Tying the dispenser too tightly will lead to tree training and structural problems and also takes too long. At the end of the season – when the dispensers are exhausted – it is important to go back to the orchard and remove the dispensers before tree damage occurs. Winter is a good time for this job, because they are easier to see.
- Dispensers should be placed toward the top of a tree because the pheromone from a dispenser flows down a tree. In many cases moth courting and mating also predominantly takes place here. Place dispensers in the top 10% of a tree's height. Do not place a dispenser on a branch or twig that is likely to bend over and take the dispenser below the height required for adequate protection. You will probably need a ladder or cherry picker to place the dispensers; allow 2 to 4 hours per hectare.

- Double-tube dispensers can be applied from the ground using poles.
- Dispensers should be placed on the shady (southern) side of the tree, as this will reduce the rate of evaporation of the pheromone and prolong the dispenser's life.
- Most trees in the mating disruption grid will need only one dispenser. Where there is an increased likelihood of infestation, it may be necessary to place two dispensers in one tree. In these cases, place the dispensers individually on opposite sides of the tree.
- In high-density plantings it will not be necessary to place a dispenser in each tree. The number of dispensers required, and their grid pattern distribution, can be calculated from the number of dispensers required per hectare.
- Extra dispensers are likely to be needed on boundary trees, at the top of slopes, on the side of the orchard from which the prevailing wind blows, and along fence lines.

Is mating disruption working? Monitoring in mating disruption blocks

As with any form of pest management, it is important to monitor and determine whether what you have done has been successful. In conventional orchards that rely on insecticide applications, monitoring is done by using pheromone caps and sticky traps. This technique will not work where mating disruption is being used. The 'pheromone fog' associated with mating disruption masks the pheromone from standard monitoring dispensers. Standard monitoring traps used in a mating disruption orchard will therefore underestimate the number of moths present. The solution is to use a modified pheromone-based monitoring system and other non-pheromone-based methods of monitoring.

Use of 10× concentrate pheromone caps

When using 10× concentrated caps in traps, placement is important. Traps should be placed in the very tops of trees at a density of 1 trap every 2 ha, with a bias towards areas more prone to infestation.

Traps containing DA (pear ester) lures will also be useful for monitoring moth numbers in blocks using mating disruption. These lures use substances associated with ripe fruit (rather than sex pheromones) to attract moths and are therefore not confounded by the presence of a grid of mating disruption lures. They are used similarly to other monitoring lures and full instructions can be found on their packaging. Growers should be aware that the variety of the trees in the block in which they are placed may impact on their effectiveness.

It should be possible to place these traps containing these lures using a long piece of PVC pipe with a wire hook at one end. Check and clear the traps weekly and record the number and type of moths caught. Change the bases and caps as often as needed. If monitoring indicates a rise in the numbers of pest moths, an insecticidal spray may be needed.

Crop monitoring

The structured monitoring procedure outlined in this manual becomes even more important in orchards using mating disruption, and orchardists should be prepared to devote sufficient time to monitoring to discover any outbreaks as quickly as possible. This monitoring should look for the physical signs of infestation (damaged fruit or foliage, curled leaves and silken feeding nests) as well as the insects themselves.

Emergence of secondary pests

Where an orchard's size, condition and topography make it possible to use mating disruption to control pest moths, there is only one serious disadvantage. As with all pest management strategies that minimise the use of broad-spectrum insecticides, insect pests previously considered occasional or secondary become more serious. If mating disruption is used, other moth pests such as *helicoverpa* and loopers often become serious enough to warrant spraying. However, the damage caused by these secondary pests is seldom serious enough to consider a return to conventional management of codling moth, lightbrown apple moth and/or oriental fruit moth.

Pest and disease fact sheets



Alternaria leaf blotch and fruit spot

IPM quick facts

- *The identity of the Alternaria causing this disease is uncertain. The disease has slightly different characteristics from State to State and also overseas.*
- *Promotion of rapid breakdown of fallen leaves during dormancy will help to reduce the amount of disease inoculum that will infect trees in spring.*
- *For adequate control with fungicides, careful applications will need to be made over a number of seasons. Early application of trifloxystrobin before visible symptoms occur and late application of broad-spectrum fungicides are required.*



Christine Horlock, Biosecurity Queensland, a service of DEEDI

The pest and its impact

Alternaria leaf blotch of apples is widespread internationally. In countries other than Australia the fungus causing this disease is *Alternaria mali*. The situation is more complex in Australia, where – in addition to *A. mali* – a number of other species of *Alternaria* seem likely to cause leaf blotch and fruit spot symptoms. This has important implications:

- Australian species seem to cause symptoms that are subtly different from those from overseas.
- In some areas – notably the Granite Belt – fruit symptoms are more severe than in infections occurring overseas or in other parts of Australia. In the USA, fruit damage has been described as rather inconspicuous. In NSW the primary concern is premature leaf fall.
- For the above reasons, control of the disease may vary between regions.

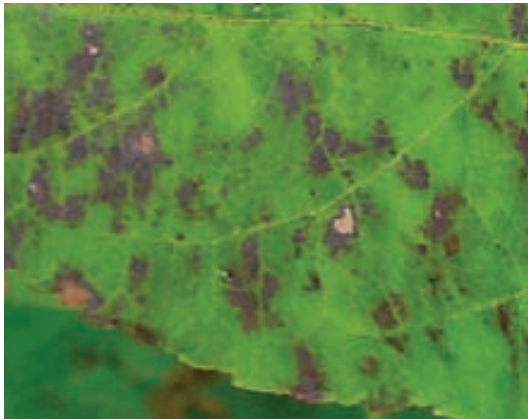
Life cycle

The exact identity of the Australian species of *Alternaria* responsible for leaf blotch and fruit symptoms is not clear. *Alternaria* species commonly survive through winter in leaf buds and on fallen leaves and rough bark. This disease is likely to be perpetuated through spores surviving in leaf litter, winter prunings, and dormant leaf and flower buds.

Through the early part of the fruit production season the pathogen stays relatively inactive, causing only small lesions and often not being observed at all. The disease develops explosively following heavy summer rainfall events and high humidity. Overseas, trees that have mite infestations are predisposed to rapid disease development. Circumstantially, in Australia, any underlying stress is likely to make the disease more severe. For example, Granny Smith is relatively resistant to the disease unless infected with apple mosaic virus.

Secondary spread of the disease occurs where spores (conidia) that develop on lesions are splashed by wind-blown rain. This dispersal is relatively rapid, and entire orchard blocks are quickly infected. Be extremely cautious when reading overseas literature on this pathogen. It is highly likely that Australian species of *Alternaria* cause a disease similar to that seen overseas, but it may be quite different and may respond to different management techniques.

Progression of leaf symptoms



1. Early purplish lesions © I&I NSW



2. Later light brown lesions Christine Horlock, Biosecurity Queensland, a service of DEEDI

Damage

Leaves. Lesions may not appear until well into summer but may precede fruit infection. They first appear as small, roundish purplish or blackish spots that gradually enlarge. Low levels of these types of lesions are present on the tree and may be found on most leaves.

A significant, summer rainfall event triggers disease development, and the number and size of the lesions explodes within days. The appearance of the lesions also changes. They become light brown with a distinctive purplish border and have an irregular shape. As they continue to grow they coalesce to form large necrotic areas. Leaves turn yellow and drop. Severe early defoliation is often seen as early as January in severely infected blocks.



3. Yellowing leaves Christine Horlock, Biosecurity Queensland, a service of DEEDI



*Defoliated trees in January after an *Alternaria* infection* © I&I NSW



Alternaria fruit spot symptoms commonly seen in New South Wales (left) and Queensland (right)
© I&I NSW; Christine Horlock, Biosecurity Queensland, a service of DEEDI

Fruit. Both the incidence and appearance of fruit symptoms vary. In Queensland, fruit damage is common and causes significant economic loss. Small, slightly sunken, light to medium brown spots appear on the lenticels of the fruit, often soon after rainfall, and usually no earlier than 6 to 8 weeks before harvest. Interestingly, fruit spots do not appear during storage, and preharvest *Alternaria* fruit spots do not appear to enlarge markedly during cold storage. However, once fruit is removed from cold storage existing spots can continue to grow in size, and new spots can develop, providing an excellent entry point for other secondary fruit rots.



Fruit symptoms are relatively rare in NSW. Where they are seen they are sometimes similar to those seen in Queensland, but more often they are less conspicuous, depressed, dark lesions that are centred on a lenticel and may have a red halo.

This disease should not be confused with *Alternaria* core rot, or mouldy core, a postharvest storage rot caused by *Alternaria alternata*.

Similar damage

A number of disorders cause foliar symptoms similar to those caused by *Alternaria*; they include bitter pit and *Elsinoë piri* infection.

Although individual lesions caused by *Elsinoë piri* appear similar to those caused by *Alternaria*, they are usually far more numerous; there may be hundreds on a single piece of fruit.



Alternaria fruit spot has symptoms similar to those caused by bitter pit (top) and Elsinoë piri (above)
© I&I NSW

Prevention and good orchard management

Removal or destruction of prunings

In blocks where *Alternaria* has been a problem it is important to make sure that all winter prunings are mulched and completely broken down, or are removed from the orchard and destroyed before the leaves begin to emerge in spring. This will reduce the amount of carryover inoculum infecting new growth.

Urea application

Management aimed at reducing overwintering black spot spore carryover will also be effective against *Alternaria*. Ground and foliar applications of urea well after harvest will help leaves to break down more quickly and completely. Fallen leaves and prunings should be swept into the inter-row so that routine mowing operations shred and mulch them, allowing them to break down more quickly.

Varieties

Most varieties are susceptible to this disease to some degree. The disease is particularly severe on Gala, Cripps Pink and Red Delicious. The disease is very rarely seen Granny Smith. However, trees of all varieties can become infected if they are stressed.

Tree health

Maintaining overall tree health is particularly important in reducing the damage caused by this disease. Although other maladies can exacerbate *Alternaria* leaf blotch and fruit spot, control of mites is particularly critical.

Monitoring

It is possible to get a reasonably accurate estimate of the severity of the *Alternaria* problem by closely examining the leaves from around October onwards. At this stage the disease is present as small purple lesions. This can be used to guide the extent to which late season

pesticides are applied (see 'Responsible use of pesticides' below). However, if monitoring suggests that the disease is likely to be severe, then fungicide applications are unlikely to have a great effect. In this case monitoring should be regarded as indicating that more careful management is required for next season.

Management

Responsible use of pesticides

Fungicide applications during two distinct periods of fruit development are required to manage *Alternaria* leaf blotch and fruit spot.

Early-season fungicide applications. A block of three fungicide applications at weekly intervals must be applied from petal fall. The disease may not be evident at this stage, but is present as small lesions or overwintering spores. Often growers react only when they see a disease, but in this case the benefits of spraying before symptoms are apparent will become evident a few months down the track. A number of fungicides will have an effect, but the greatest reduction in disease severity follows applications of trifloxystrobin.

Late-season fungicides: Early-season fungicides will usually only moderate the disease and will not provide adequate control without the additional application of late-season fungicides. Research conducted in Australia has shown that mancozeb and/or dithianon are good choices for this spray.

Problems may occur when significant rainfall occurs during the withholding periods of these pesticides. Apples cannot be harvested for 14 days following application of mancozeb and 21 days following application of dithianon. Applying both early and late season fungicides should reduce the threat of late-season outbreaks. Regardless, fruit damage tends to occur only when leaf damage has been severe for a long period of time; maintaining tree health until 2 to 3 weeks before harvest should result in reduced fruit damage.



Rows of Gala apple trees that have been treated with two different fungicide regimes. The near row ① received the grower's standard fungicide applications. Early-season trifloxystrobin and late-season mancozeb were applied to the far row ②. Note the difference in leaf fall.

© I&I NSW

It is very important to realise that this disease will not be eliminated from orchards with a single season of careful fungicide application. Growers should adopt an integrated approach to disease management and should apply fungicides for at least four seasons – regardless of disease severity – to gradually reduce the amount of disease inoculum. Monitor the outcome of repeated applications and slowly withdraw any extra sprays when control has been achieved.

Caution. Growers may be tempted to rely on fungicides that have provided control overseas. Australian research has shown that many of these are ineffective here. In particular, captan provides practically no protection against this disease.

Acknowledgments

Many of the images included in this chapter were obtained from Christine Horlock [Senior Plant Health Scientist, Biosecurity Queensland, a service of the Department of Employment, Economic Development and Innovation (DEEDI)] and have been reprinted here with her permission.

Apple dimpling bug

IPM quick facts

- The pest commonly called apple dimpling bug in Tasmania (*Niasstama punctaticollis*), is a different insect from the pest called apple dimpling bug on the mainland (*Campylomma liebknehti*). The two pests require different management, so be sure that the management you are using applies to the pest in your orchard.
- Avoid planting light-coloured varieties in blocks prone to apple dimpling bug.
- Monitor your fruit's health and apply pesticides early if necessary. In Tasmania, chlorpyrifos should be applied to orchard-side hedges that shelter dimpling bug.



Campylomma liebknehti: mainland Australia
© I&I NSW

The pests and their impact

Two species of Australian native insects are called apple dimpling bug. For both species, feeding activities during and shortly after flowering distort fruit growth. Affected fruit is severely downgraded and often unmarketable although damage is superficial. Despite the similarity in the damage that these two types of insects cause, it is important to note their differences as management designed for one species will be ineffective against the other.

Mainland Australia



Campylomma liebknehti © I&I NSW

The species of insect commonly known as the apple dimpling bug on mainland Australia is *Campylomma liebknehti*. Adult dimple bugs are greenish-brown and about 3 mm long. They have spiny legs and a generally triangular shape formed by their wing covers and dark bands at the base of the antennae. They have a distinctive sweet odour when squashed.

In Western Australia (where codling moth is absent), or other areas where codling moth damage is low, apple dimpling bug is often regarded as the most serious insect pest.

Although apple dimpling bug causes serious damage to apples, it commonly feeds on 62 species of plants, including Australian native and introduced tree species such as tagasaste (*Chamaecystis proliferus*), Chinese hawthorn (*Photinia robusta*), Geraldton wax and wattle (*Acacia* sp.). Wattle is an important host across mainland Australia, and large numbers of the bug can breed up on a single tree.

Tasmania

The species of insect commonly known as the apple dimpling bug in Tasmania is *Niastama punctaticollis*. This insect looks quite different from its mainland cousin.

A number of practical features set *Niastama punctaticollis* apart from *Campylomma liebknechti*. *Niastama punctaticollis* lives on only a very small number of plants apart from apples and it breeds exclusively on macrocarpa (*Cupressus macrocarpa*).

Adults lay their eggs in the macrocarpa from late September to November or early December. The eggs do not hatch until the following July. The hatched nymphs go through five developmental stages before becoming adult dimpling bugs.

Newly hatched nymphs are quite small (1.5 mm long) but get longer with each new developmental stage: mature nymphs are 5 mm long. The body of the nymph is pale green with red markings on the upper surface of the legs, and the eyes are bright red. Nymphs have no wings.

The adult bug is about 2 mm wide and 7 mm long. The green body contains red markings that are covered by the wings when the insect rests. The wings are dark chocolate brown with some green and red markings.

From late September until about the end of October adult bugs leave the macrocarpa and feed on nearby plants, including apple trees

Damage

The damage caused by both the Tasmanian and mainland types of apple dimpling bug is similar. The initial fruit development stages of apple are most vulnerable to damage from apple dimpling bug from bud-separation through until 1 week after petal fall. Most damage occurs in the 2 weeks between early pink and complete petal fall.

The insects feed by inserting their sucking mouthparts into the developing bud, piercing the ovary and sucking the sap. Scarring associated with this 'sting' site fails to expand and may become calloused. This failure to expand leads to distortion of the fruit as the surrounding healthy tissue grows normally. This gives affected the fruit its dimpled appearance.

Apple dimpling bug shows a marked preference for flowers in full bloom. Fruit damaged severely by apple dimpling bug may be shed, resulting in a reduction in yield. The greater the number of apple dimpling bugs, the greater damage to fruit.

Similar damage

It may be difficult to distinguish between low-level apple dimpling bug damage and damage caused by plague thrips (*Thrips imaginis*; see 'Thrips: Western flower thrips, Plague thrips' p. 123), green crinkle virus or nutritional problems such as boron deficiency.



Boron deficiency can be confused with apple dimpling bug damage © I&I NSW

Prevention and good orchard management

Varieties

Damage seems more serious on lighter skinned varieties such as Granny Smith and Golden Delicious. This may be a result of sting sites and the associated dimpling being more obvious. Nonetheless, it is logical that, for a given level of actual damage, darker skinned varieties are less likely to be downgraded. Do not plant light-skinned varieties in blocks prone to apple dimpling bug infestation.

Other hosts

Both types of apple dimpling bugs spend critical stages of their life-cycle on plants other than apples. In Tasmania, orchard damage is more likely where macrocarpa is close to the orchard. In mainland Australia, the most critical alternative hosts are wattle and tagasaste.

If these tree and hedge species can be eliminated from the orchard surrounds there will be fewer winged adults available to move into the apple orchard during flowering. This strategy is likely to be more successful in Tasmania, as *Niastama punctaticollis* (the Tasmanian dimpling bug) relies on a much smaller range of tree species than its mainland cousin.

Hand-thinning

Remove damaged fruit during hand-thinning.

Monitoring

The decision to manage apple dimpling bug should be made on the basis of the severity of the damage it has caused in previous seasons, and the numbers of insects detected through monitoring. Monitoring should commence in other host trees (e.g. acacia, tagasaste for mainland Australia and macrocarpa for Tasmania) before the apple trees begin to flower. This will give an indication of the likely infestation pressure as apples become susceptible. For Tasmania, there are no registered pesticides for application in-orchard. Where monitoring of macrocarpa adjacent to orchards indicates that there are large numbers of dimpling bugs, pesticides should be applied to the macrocarpa immediately.

Guidelines for monitoring in apple orchards

(adapted from information provided by the Department of Agriculture and Food, Western Australia)

- Start sampling apple trees at the pink bud stage and sample twice weekly until petal fall.
- Sample in the cool of the morning (before 9.00 am), as the bugs become too active for accurate identification and counting when it becomes warmer.
- Dimple bugs occur in greater numbers on the sunny side of the tree. Tap 20 flower clusters on the sunny side of each of five tagged monitoring trees (see 'Monitoring' image below) over a container. A white ice-cream tub is good, as the bugs will be easily seen.
- Record the number of dimpling bugs found and determine whether a spray is required according to thresholds (see 'Thresholds' p. 38).
- Do not stop sampling after a spray; re-invasion from the bush is likely. Sampling after spraying will also help you to determine the effectiveness of the spray.
- Poor sampling is likely to result in underestimation of dimple bug numbers; this may lead to increased levels of damage.
- Ants deter dimple bugs. If ants are found in the sampling container, move to another tree.
- Monitoring of alternative hosts is useful in both mainland Australia and Tasmania. For mainland Australia, wattle trees and tree lucerne should be carefully monitored.



Monitoring. Tapping wattle flowers so that apple dimpling bugs fall into an ice-cream container
© I&I NSW

Thresholds

Published thresholds for *Campylomma liebknehti* vary but are within the range of two to four apple dimpling bugs for every 100 apple flower clusters monitored. If apple dimpling bug numbers exceed this threshold and an insecticide is not applied, damage is likely.

Responsible use of pesticides

Mainland Australia

There is a critical period of approximately 3 weeks for protecting fruit. This period is from the pink bud stage to 1 week after petal fall.

Thiacloprid has recently been registered for application against apple dimpling bug. It is softer on bees and other beneficial organisms than any other insecticide registered for this purpose, and its use is preferred over other pesticide alternatives.

More complete information on bee safety and application of insecticides for management of dimpling bugs and other insects that infest when apples and pears are blossoming can be found on this page.

Tasmania

In Tasmania, pesticides are used to reduce the number of adult bugs before their arrival in the orchard. The optimum time to spray macrocarpa trees is the short period from mid-August to early September. A single application using drive-past equipment is usually adequate. For tall trees, where the spray does not reach more than halfway up, a further application about 3 weeks later is advisable. In this case the first spray should be applied early in the critical period so that the second application is not too late. Hedges should be sprayed from both sides. Chlorpyrifos, which is harmful to bees, is the only insecticide registered for this use. Hence care should be taken to avoid drift into the orchard, and the precautions listed should be taken to protect bees.

Reducing bee poisoning from pesticides

There are around 500 000 commercial bee hives in Australia that are being used for paid pollination and honey production. Additional pollination is carried out by feral European bees. Honey bees (*Apis mellifera*) are vital for

pollination of fruit trees. Killing honey bees reduces fruit set and yield. Where possible, avoid applying insecticides during the period when trees are in blossom, because all insecticides will have some negative effect on bees.

Most fungicides, herbicides, plant growth regulators and nutrients can be applied at bloom because they are not harmful to bees. The exceptions are mancozeb and triforine, which are moderately toxic to honey bees. However, control of some insect pests during blossom may be necessary. Insect pests that may require attention at this time include apple dimpling bug (*Campylomma liebknehti*), plague thrips, western flower thrips, and early fruit caterpillars such as *Helicoverpa* and loopers. The use of carbaryl to thin fruit can also have a serious impact on bees. It is important to consider bees during this time of the year and to use chemicals wisely.

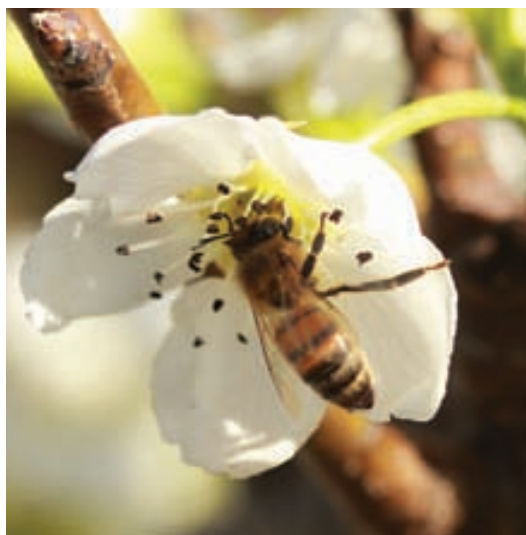
Symptoms of poisoning

Where bee poisoning has occurred there will often be a large number of dead bees in front of hives and a lack of foraging bees. Bees will generally become more aggressive after poisoning.

Bees may perform abnormal communication dances on the landing board at the hive entrance when poisoned, and their disorganised behaviour patterns are generally not recognised by guard bees.

Poisoning by organophosphates such as chlorpyrifos can cause bees to regurgitate their honey stomach contents.

Carbaryl is especially dangerous to bee hives. Bees poisoned with carbaryl slow down and may take several days to die. This slow death allows them to transport loads of contaminated pollen or nectar back to the hive, where they subsequently poison large numbers of bees within the colony (often including the queen).



Use the least toxic option and schedule sprays to avoid bee activity

In Australia, a large number of insecticides are registered for use against pests which may be a problem on blossoming apples and pears. The majority of these insecticides should not be used when trees are in blossom because:

- they are harmful to bees
- alternatives that are less likely to harm bees are available (see table below).

If it is necessary to apply an insecticide during blossom a number of factors should be considered:

- *Temperature.* If temperatures after application remain unusually low, insecticide residues will remain harmful to bees for a longer time than normal. Therefore, avoid applying insecticides on cold nights. Conversely, if evening or morning temperatures are unusually high, bees may prolong their foraging activities. Always check for bee activity in the orchard before spraying.
- *Drift.* Beware of insecticide drift from blocks being sprayed on to blocks containing later varieties that may still be in blossom.
- *Distance from the hive.* Bees typically forage at a maximum distance of 1.5 to 3 km from their hives. However, during periods of nectar shortage they can extend this range up to around 8 km. Be aware of where hives are placed in your orchard and your neighbour's orchard.

- *Weeds.* Inspect orchards and fence-lines before spraying to determine whether bees are foraging on flowering weeds. Dandelions are particularly attractive to bees, but less conspicuous weeds such as dock can also be attractive. Avoid spraying when weeds are in bloom. Where it's practicable, mow or remove weeds before apple and pear blossom time.
- *Communication.* Orchardists should have a basic understanding of honey bee behaviour and which pesticides and application practices are hazardous to bees. When sprays are to be applied, neighbours and commercial suppliers of pollinating bees should be informed to allow them to move hives or take other precautions.

Biological control, biorational pesticides and organics

It can be assumed that there is some degree of natural predation of these insects by spiders and other common beneficial arthropods, but little specific information is available.

The insect-infecting fungus *Beauveria bassiana* was introduced into Australia in 1994 to be used as a control agent against *Campylopus liebknechti* in cotton, but it failed to give appreciable control of the insect and did not persist in the field.

Impact on bees of selected insecticides used to control pests of apples and pears that infest during the blossom period¹

Chemical used to control	Pesticide / Crop regulator	Impact on bees ²
Apple dimpling bug	Chlorpyrifos	I
Apple dimpling bug / Plague thrips	Bifenthrin	I
Blossom thinning	Carbaryl	I
Apple dimpling bug / Plague thrips / Early fruit caterpillars	Endosulfan	II
Apple dimpling bug	Thiacloprid	III
Western flower thrips	Spinosad	III

¹ Information compiled from Washington State University Orchard Pest Management Online, University of California IPM Online and the BCPC Pesticide Manual (see 'More information: Apple dimpling bug' p. 200).

² Ratings are as follows: I = Do not apply to blooming plants; II = Apply only during late evening; III = Apply only during late evening, night or early morning.

Apple scab (Black spot), Pear scab

IPM quick facts

- Orchard hygiene is important. Remove all hanging infected fruit and hasten breakdown of fallen fruit during dormancy by mowing and application of urea.
- Infections depend on temperature and leaf wetness. Control of the disease early in the season is very important.
- Avoid calendar-based cover sprays. They waste time and money and have undesirable off-target effects.
- Protectant fungicides should be applied before rainfall.
- If a protectant has been applied and a disease infection period is indicated by a forecasting unit, a curative fungicide should be applied within the kickback period.



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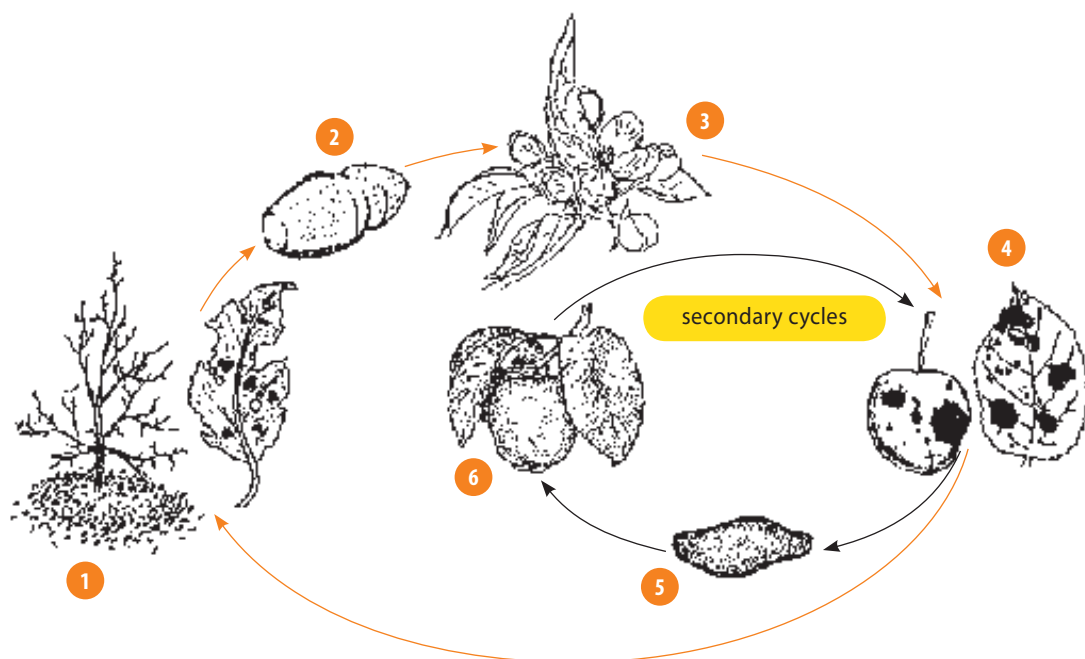
It is important that orchardists know as much as possible about the pathogen's life cycle, as this understanding will help in logical management decision-making.



© I&I NSW

The pests and their significance

Both pears and apples are affected by diseases known as either black spot or scab. These diseases are caused by similar pathogenic fungi. The fungi responsible for the disease in apples is *Venturia inaequalis* and in pears *V. pirina*. The pathogen that infects apples cannot infect pears, and the pathogen that infects pears cannot infect apples. Apple scab is present in all Australian production regions except Western Australia. Pear scab is present in all regions. If these diseases are poorly managed they can cause serious losses in terms of the cost of control, reduced pack-out and reduced tree vigour.



Life cycle of black spot © I&I NSW

Life cycle

As temperatures rise at the start of the fruit production season and when enough moisture becomes available, the spore-producing bodies within fallen leaves mature **1**. Primary spores from these bodies are shed into the wind **2**, settle on young, soft tree growth and infect it **3**. These primary infections occur only when leaves, fruitlets or flowers are moist from rain, dew or mist and the temperature is appropriate (see 'Monitoring' p. 44).

Primary infections result in lesions **4** that produce a different type of spore **5**. These spores can also spread through the orchard on wind currents and have slightly different temperature and moisture requirements that enable them to infect the leaves or fruits that they land on **6**. If management is poor, the secondary infection cycle can be repeated many times during a season and can result in a very rapid build-up of the disease, particularly during warm, wet periods.

As trees become dormant, infected leaves are shed and fall to the orchard floor or are caught in branches. Where the pathogen remains, it stays alive but becomes dormant within these fallen leaves and becomes active again at the start of the next season.



Symptoms of pear scab on a leaf
© Bayer CropScience

Damage

Leaves. Scab lesions on leaves can occur on either surface but are usually more easily seen on the upper surface. Initially lesions are very small, olive-green or brown and have diffuse edges. These lesions become olive-green and velvety as they enlarge and mature. This colour and texture is due to the enormous number of secondary spores produced by each lesion.

Where infections occur close together, lesions may coalesce to become very large.

In time, as spores are dispersed from the lesion, they become brown and areas of the leaf die. The leaves can also thicken and bulge upwards. Where infection is serious, leaves may yellow and fall prematurely, depriving the tree of nutrients and thus reducing fruit size in the current and future seasons.

Although symptoms of pear scab are very similar to those of apple scab, leaf infection is not as common as in apple scab on apple leaves.

Fruit. Symptoms on the fruit are similar to those on the leaves, although the lesions tend to have better-defined margins. As the lesions become older and shed their spores they become brown, dry-looking and corky, and cracks appear. At this stage the lesions look brown or black. Fruit growth is retarded in the vicinity of the lesions, and as the rest of the fruit continues to grow it may become distorted.

The lesions are superficial and the fungus does not extend to any great degree into the flesh of the apple.

Twigs. Twig infections are relatively rare in apple scab but can be common in pear scab. Early in the growing season, lesions on the young shoots appear as brown, velvety spots. These spots develop during the season to become corky, canker-like areas. Disease-causing spores can survive the winter in these lesions and cause disease the following year.



Young infection on apple; note the velvety green spores (left). Older infection (centre) and pear scab (right) © Bayer CropScience



Infected twig (left) and storage scab (right) © Bayer CropScience, © I&I NSW

Storage scab. If scab infections occur late in the season, symptoms may not have had time to develop before harvest and storage. During the period of storage and immediately after apples are removed from storage, the process of infection continues. Apples that appeared healthy when placed in storage have small, often pinpoint-sized, lesions peppered over their surfaces.

Prevention and good orchard management

Because it is difficult to control an apple or pear scab problem once it is established, every effort should be made to prevent these diseases. Even in years of high disease pressure, preventive measures will reduce the severity of the disease by reducing the numbers of infective spores available.

Varieties

Apple varieties incorporating scab resistance and commercial desirability are being bred in many places in the world, including Australia. Australia has an advantage here in that we have only one of six races of the scab fungus. This means that the susceptibility of varieties in fruit in Australia is stable. When resistant varieties become available they are likely to maintain their resistance for long periods. Currently all commercial varieties of apple are susceptible to scab, although the level of susceptibility varies. Although no variety shows sufficient resistance for this to be a factor in disease management, it is worth keeping in mind that:

- Cripps Pink (Pink Lady™), Lady Williams, Cripps Red (Sundowner™), Braeburn and Granny Smith are extremely susceptible to apple scab.
- Gala, Hi Early (and other Red Delicious types), Golden Delicious and Fuji are moderately susceptible.
- Jonathan is generally acknowledged as being less susceptible to apple scab.

Sanitation

Although the most commonly recognised source of primary inoculum is leaf litter, an appreciable number of spores can also come from diseased fruit that is left to hang on trees. This is especially the case if scab has been severe in the previous season. Whenever scabbed fruit is noticed it should be removed. At harvest all fruit should be removed from the trees and pickers encouraged to throw diseased fruit into the inter-row. It can then be run over with a slasher to increase the rate of breakdown.

Pruning and tree training

Trees should be pruned in late winter to create or maintain an open canopy. This will result in better air circulation, faster drying times and better penetration of any fungicides that are applied during the season.

Leaf raking and urea

Infected leaves harbour the scab fungus during the winter, allowing it to reinfect trees during early spring. The number of spores that survive through winter can be reduced by helping the leaves to break down more quickly.

A postharvest treatment of urea is good practice. It is a valuable supplement for scab control and should be used annually, but is especially valuable after a bad scab year. Urea also has some nutritive value.

Apply after picking as soon as the first signs of leaf fall are seen. It is essential to thoroughly cover the lower surfaces of leaves. If necessary, apply a light ground spray to contact all fallen leaves that might have been missed. No special attention to a ground spray will be necessary if dilute sprays applied by airblast are used. Better results can be expected if the orchard floor is clean at the time of spraying. Be aware that some damage to spurs and laterals can occur in very dry seasons; also take care to avoid over-spraying with urea. This is most likely to occur on headland trees.

Following a bad scab year, it is good practice to rake fallen leaves out from under the canopy into the inter-row early in winter and then run over them with a slasher. This physical breakdown helps the leaves to decompose more quickly.

Monitoring

Visual monitoring in autumn

Following harvest, but well before leaf fall, an assessment of scab should be carried out on the monitoring trees within your orchard (see 'Visual monitoring' p. 17). Examine a minimum of 600 shoots for scab lesions and record the total number of scab lesions. Count the leaves on a sub-sample of 20 shoots and determine the average number of leaves per shoot. Using this information, estimate the total number of leaves. If fewer than 0.7% of the leaves have scab lesions the orchard can be categorised as having low levels of inoculum for the next season, and the McHardy Model (p. 48) or a suitably programmed electronic forecasting unit is likely to give the most accurate prediction of infection during the next season. Otherwise, use Mills charts or an electronic forecasting unit (p. 47).

Monitoring the weather

Apple and pear scab develop in a predictable way under the influence of a number of factors:

- temperature: infection occurs most rapidly between 12.8°C and 23.9°C
- light
- wetness: leaves or fruit must remain wet continuously for 9 hours for infection to occur.

A number of mathematical models can be used to predict the likelihood of scab infections from the weather. The choice of which is most suitable for your orchard involves a trade-off between accuracy and simplicity.

These models are dealt with more completely in the section below on responsible use of pesticides.

Responsible use of pesticides

Where apple scab occurs, the majority of fungicide applications are primarily designed for its control. Other diseases are often controlled as a consequence of these sprays. It is therefore very important to be logical in developing a management schedule so as to gain effective disease control with the minimum possible number of applications, while reducing off-target impacts. In doing this it is important to consider:

- the types of fungicides and their advantages and limitations
- the likelihood that the weather will be conducive to diseases development
- the rate at which trees are growing and exposing unprotected tissue.

The primary objective of scab control should be to gain control of the disease by targeting any primary infections that occur on newly emerging leaves and young fruit. The combined effects of prevention (p. 43) and effective spring and early summer fungicide applications should allow the number of spray applications to be greatly reduced after Christmas.

Type of fungicide

The fungicides registered for apple and pear scab control can be placed in two categories: curatives or protectants. Orchardists should be aware of the advantages and limitations of these fungicides and decide on a management schedule according to their individual circumstances.

Protectant fungicides

Protectant fungicides work by killing the fungal pathogen on the surface of the plant. For apples and pears the protectant fungicides include:

- cyprodinil (activity group 9)
- kresoxim-methyl and trifloxystrobin (activity group 11)
- mancozeb, metiram, thiram and ziram (activity group M3)
- captan (activity group M4)
- dithianon (activity group M9)
- the proprietary mixture Pristine® (boscalid (activity group 7) + pyraclostrobin (activity group 11)).

These fungicides are characterised by their broad mode of action. In practical terms this means that they effectively kill a wide range of fungi and consequently can be used to manage many diseases. They do not penetrate into plant tissue, but act on fungal bodies on the surface.

The table below lists the advantages and disadvantages of protectant fungicides.

Curative fungicides

In addition to killing fungi on the surface of the plant, curative fungicides are able to penetrate within the plant and kill fungi that have penetrated and begun to cause disease infections. These fungicides act in a more targeted manner, affecting specific metabolic pathways within fungi. For example, the DMIs (activity group 3) target fungal cell wall synthesis, disabling the growth of fungal pathogens.

The table below lists the advantages and disadvantages of curative fungicides.

Where a curative is used for control of apple or pear scab it is important to be familiar with the characteristics of the particular fungicide chosen. Of particular importance is the kickback period. The kickback period is the length of time after an infection has occurred for which the fungicide can effectively prevent further development of the disease. The table on p. 46 lists the kickback period for a number of curative fungicides.

Advantages and disadvantages of protectant fungicides

Advantages	Disadvantages
• Residual action protects crops for 10 to 14 days after application. • Diseases are very slow to develop resistance to protectants. • Effective against a range of diseases. • On average, less expensive than curatives.	• Superficial and can be washed off if rain falls within the 'rain-fast' period. • Kill many fungi, including beneficial micro-organisms

Advantages and disadvantages of curative fungicides

Advantages	Disadvantages
• Protect crops for 10 to 14 days after infection and can be used to control or cure an infection that has occurred up to 6 days before application. • Less harmful than protectant fungicides to non-target fungi, including beneficial species. • Provide longer crop protection during prolonged wet weather.	• Fungal pathogens will become resistant following repeated application.

Kickback periods of various curative fungicides

Active ingredient (trade names)	Kickback period
Dodine (Syllit®)	1½ days
Pyrimethanil (component of Vision®)	3 days
Triforine (Saprol®)	3 days
Fenarimol (Rubigan®)	4 days
Hexaconazole (Hex®, Hexacon®, Viva®)	4 days
Penconazole (Topas®)	4 days
Difenoconazole (Bogard®)	5 days
Fluquinconazole (component of Vision®)	5 days
Myclobutanil (Systhane®)	5 days
Flusilazole (Nustar®)	5 – 6 days

The weather, spore release and infection

Two important events must take place before the apple scab fungus can cause disease, i.e. spores must be present and rain or free water (e.g. heavy dew or mist) must stay on the plant's surface for long enough to allow two critical parts of the pathogen's life cycle to occur:

- spore release for primary (early season) infections
- spore germination, penetration and infection.

Infections can occur only during the day. The length of time required for an infection to occur (the infection period) is determined by the temperature. The relationship between the temperature, the length of time for which free water is present, and scab infection is predictable and has been used to develop several forecasting models. These models form the basis of commercially available disease forecasting equipment that can be used to guide spray application. Some of these models are presented in the next pages.

Mills charts

Predictive models for apple scab were first developed in New York during the 1940s and can be summarised in the table on p. 47.

The information in the Mills chart relates to the disease-causing spores that are present at the start of the season (i.e. the primary spores or ascospores). After the primary infection is established, the disease goes through secondary cycles (see 'Life cycle' p. 41). The spores that cause these secondary cycles do not require as many hours of leaf wetness to infect. Therefore, later in the season the number of hours required is two-thirds of the figures shown.

Advantages of using Mills charts:

- They work well with orchards that have had serious scab problems in the previous year.

Disadvantages:

- May miss some infection periods that have occurred in shorter wet periods than the chart indicates.
- May over-predict infection periods that start at night.

Modified Mills or McHardy Model

Mills charts were significantly modified in the 1980s. The modified Mills or McHardy Model accounts for the fact that the disease-causing spores that start the disease at the beginning of the season are very rarely released at night. This means that leaf wetness (from dew, mist or rain) that occurs during the night is not included in calculating the severity of the infection. This results in fewer infection periods being predicted and fewer fungicides being applied as a result (see table p. 48).

Mills chart for predicting the occurrence of apple scab

Average temperature (°C)	Hours of wetness required for infection during spring			Days until lesions appear
	Light infection	Moderate infection	Heavy infection	
0.5 to 5	> 48	—	—	—
5.6	30	40	60	—
6.1	25	34	51	—
6.7	22	30	45	—
7.2	20	27	41	—
7.8	19	25	38	—
8.3	17	23	35	—
8.9	15	20	30	17
9.4	14½	20	30	17
10	14	19	29	16
10.6	13	18	27	16
11.1	12	18	26	15
11.7	12	17	25	15
12.2	11½	16	24	14
12.8	11	16	24	14
13.3	11	15	22	13
13.9	10	14	22	13
14.4	10	14	21	12
15	10	13	21	12
15.6	9½	13	20	11
16.1	9	13	20	10
16.7	9	12	19	10
17.2	9	12	18	9
17.8	9	12	18	9
18.3	9	12	18	9
18.9 to 23.9	9	12	18	8
24.4	9½	12	19	9
25	11	14	21	9
25.6	13	17	26	10

The McHardy Model

Average temperature (°C)	Hours of wetting for infection	
	Primary infection ¹	Secondary infection ²
1–3	>48	–
4	36	–
5	28	28
6	23	24
7	18	22
8	15	19
9	12	17
10	11	16
11	9	14
12	8½	13
13	8	12
14	7½	12
15	7	11
16	6½	10
17	6	9
18–19	6	8
20–22	5½	7
23	6	8
24	7	9
25	8	11
26	10	13
27	13	16
28	18	21

¹ Early spring infections: first leaf to mid-season (see 'Life cycle' p. 41)

² Main season infections: mid-season to leaf fall (see 'Life cycle' p. 41)

It is important when using either model that when trees are dry for less than 6 hours between wetness periods (e.g. during showery weather), the periods for which the leaves are wet should be added together in calculating the infection period.

Both models were initially developed to predict apple scab infections but are applicable to pear scab.

Advantages of using the McHardy Model:

- Works well in orchards which have only had low to moderate levels of scab the previous year.

Disadvantages:

- May not account for rare, massive spore releases that occur at night (most likely following a long dry period).
- Where scab has been a serious problem in the previous season and there is a lot of over-wintering inoculum, the small percentage of night-time spore release may be enough to trigger an epidemic.

RIMpro (Triloff) models
(www.biofruitadvies.nl/RIMpro/rimpro_e.htm)

RIMpro is a set of simulation models for the major pests and diseases of pome fruit. It is used widely throughout Europe but is relatively new, having been developed during the last 10 years, although it has been promoted in Australia.

According to its developers its main advantage is that it accounts for complex interactions between the pathogen, the tree and the weather by using 'dynamic population simulation'. This results in a more accurate prediction of disease infection. Typically, fewer infection periods are predicted during a given period than with other models, and subsequently fewer fungicide applications are necessary.

Importantly, this model accounts for the development of the tree in the period during which young, green leaves are present, presenting extra risk of infection.

Electronic forecasting units

Using an electronic forecasting unit will result in a more accurate prediction of when an infection is likely to occur. This increased accuracy is a result of the more complex prediction models that can be run, accounting for a greater number of factors that influence disease infection. These units are quick and easy to use. As with most electronic equipment, electronic forecasting units are becoming more affordable. All orchardists should consider purchasing at least one of these units.

As with other monitoring equipment, location within the orchard is important. Forecasting units should be placed within the orchard in a sheltered position, away from direct sunlight or excessive wind. It's also a good idea to position units away from the road out of sight of the public and secure them with a chain and padlock.

Forecasting units must be used with some caution. Many of Australia's apple and pear production regions have been established in hilly regions (e.g. Adelaide Hills, Perth Hills, Orange, Batlow, Stanthorpe). Because temperatures and rainfall vary considerably within these regions, predicted infection periods in one location are unlikely to correspond to infection periods in other locations. Many regions have forecasting services run by private consultants, co-operatives or government departments. These are a useful guide, but orchardists with their own forecasting units will obtain more accurate information.



An electronic apple scab forecasting unit
© I&I NSW

Tree growth and exposure of new leaves

Leaf emergence and expansion can occur very quickly early in the growing season. Often the weather that drives rapid leaf emergence is also responsible for exacerbating scab severity (e.g. warm, wet weather). In many cases fungicides offer no protection of leaves that emerge after application. This is often the reason why early-season applications fail to control the disease. The problem is more serious on young vigorous trees.

Rain-fastness vs. redistribution

A pesticide is rain-fast when it is retained on the plant surface in sufficient quantities to maintain its effectiveness following significant rain. In most cases this is a desirable attribute, and Australian orchardists often use Chorus® (cyprodinil), Strobry® (kresoxim-methyl) and/or mancozeb when heavy or extended rain is likely.

However, these 'rain-fast' fungicides are retained at their sites of deposition and are unlikely to protect emerging leaves, which are very susceptible. In this case some redistribution of the fungicide from sprayed leaves or bark on to emerging leaves would be desirable. Captan is not as rain-fast as other fungicides (particularly mancozeb), but it can limit scab damage to young leaves during the early part of the season, provided that rain is not extremely heavy. If heavy rain is expected, a tank mix of captan and mancozeb should be considered. Recent research in the USA has shown that trifloxystrobin has both significant retention and redistribution properties and can be used to protect new growth that emerges during rainy periods.

Fungicide schedules for scab: flexibility is important

The severity of the problem caused by apple and pear scab largely depends on the weather. The weather is never the same from season to season, so orchardists need to be prepared to modify their management practices to minimise the disease's impact.

As a starting point, the objective should be to protect leaves and fruit during the period when spores are being produced and infection can occur (the infection period). Calendar-based sprays that disregard the infection period result in wastage of pesticides, time and money and increase the damage to beneficial organisms.

Orchardists should aim to apply a protectant before rain (making allowance for the time that the fungicide requires to become rain-fast). If the rainfall event is sufficient to trigger infection, research has shown that it may also be useful to apply an additional curative fungicide after the rain (see Triloff 1997 in 'More information: Apple scab (Black spot), Pear scab' p. 200).

In several countries black spot has developed resistance to curative fungicides such as the DMIs. It is important to use them wisely and conservatively so as to prolong their usefulness. Curatives should be used after rain where:

- there has not been time to cover the entire orchard with protectant sprays before rain because it has arrived with little warning
- it has not been possible to apply protectants before rain.

It may also be necessary to consider the use of curatives during periods of prolonged rain if orchard access is difficult. Curatives effectively lengthen the time for which a crop is protected by offering both a forward protection period and a kickback period. This allows orchardists the greatest opportunity to protect a crop during times when orchard access may be limited.

Biological control, biorational pesticides and organics

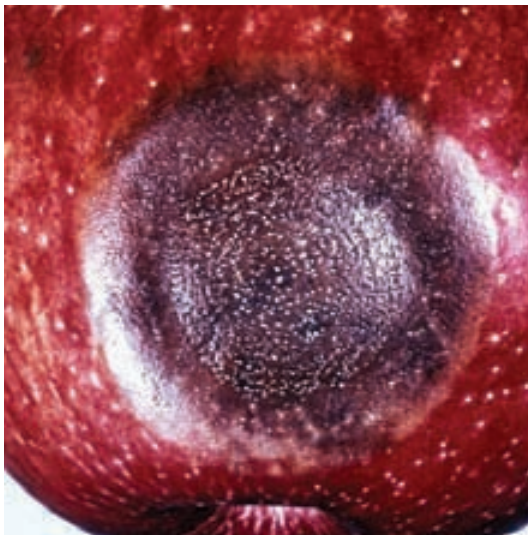
Although use of the cultural management techniques outlined in this chapter will reduce the severity of scab, successful organic apple production with conventional apple varieties in scab-prone regions is virtually impossible. There have been reports of good scab control using organically acceptable fungicides applied according to RIMPro models (see Withnall 2008 in 'More information: Apple scab (Black spot), Pear scab' p. 200), but growers should be cautious in their interpretation of 'one-off' anecdotal articles.

Sulfur and copper are the only chemical measures available for organic control of scab in apples, but both have undesirable side-effects and are not considered by many orchardists. Sulfur is slightly phytotoxic and may reduce photosynthesis. Copper can cause fruit russet; its use is constantly under review and may not be allowed in the future. Organic production of apples in scab-affected regions overseas is largely dependent on resistant varieties. A breeding program is nearing completion in Australia, and resistant varieties with commercially desirable traits should be available soon.

Bitter rot

IPM quick facts

- Bitter rot is most likely to become a problem in areas with hot, humid summers.
- Bitter pit symptoms are usually found only on the fruit; infections often appear as sunken, round lesions with concentric circles of spore masses. Internally the disease is characterised by a conical area of brown rotting flesh.
- Symptoms can appear as early as 3 weeks after petal fall but are more common later in the summer.
- Orchard sanitation is an important element of controlling this disease. Remove and destroy all diseased fruit, regardless of whether it has fallen or is hanging in the tree.



University of Georgia

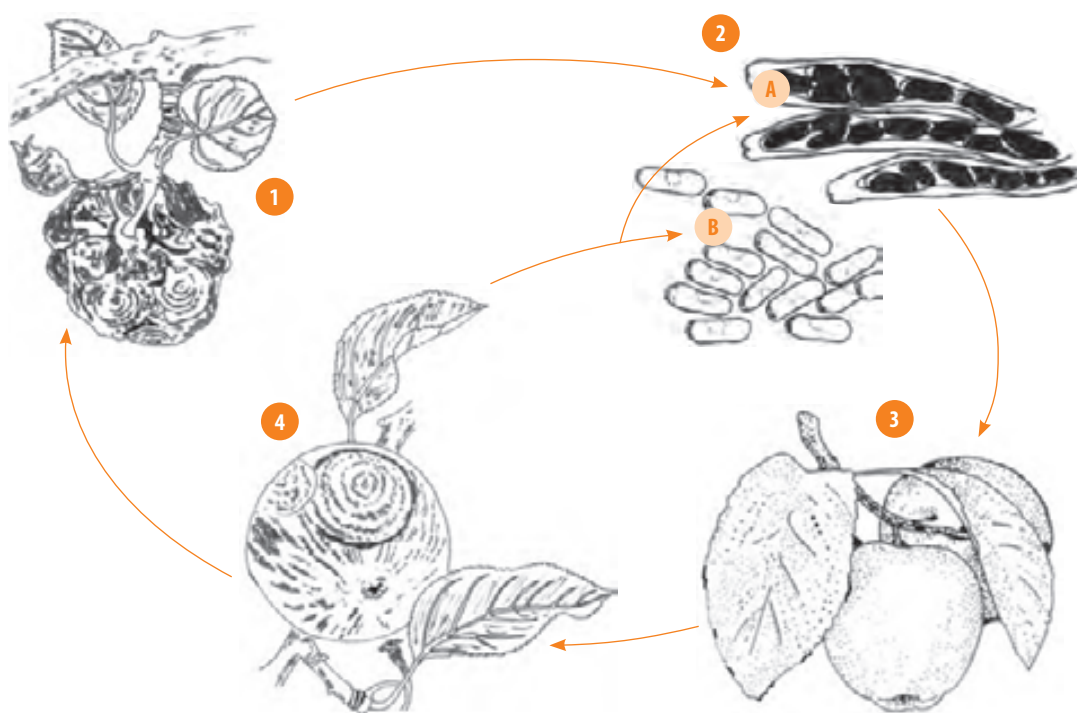
The pest and its impact

The disease bitter rot is caused by the fungal pathogen *Glomerella cingulata* (also known as *Colletotricum* spp.). It affects both apples and pears. Orchardists may also know this disease as summer rot, target rot or Glomerella rot. Bitter rot is often the most serious fruit rot to effect apple orchards in warmer, more humid production regions such as the Sydney Basin and Stanthorpe. However, most regions report that the disease can cause trouble given the right weather and orchard conditions.

Historically, the disease was responsible for major losses and entire crops could be destroyed. The advent of broad-spectrum fungicides led to a significant decline in its impact, and most now regard it as an occasional problem. However, orchardists in some regions (e.g. Stanthorpe) report a re-emergence of this disease and speculate that this may be because of industry's transition to more disease-specific fungicides.

Life cycle

The fungus causing bitter rot of apples and pears survives through winter on shrivelled infected fruit (mummies) either on the orchard floor, hanging in trees ❶, or in dead wood. As is the case on fruit that is infected during the season, the fungus produces two types of spores that perpetuate the disease. There are a number of important differences between these spores. They cause different symptoms when they infect fruit (see 'Damage' p. 52), and their dispersal within the orchard is different. Sexual spores ❷ (A) are produced after rain, are airborne, and can therefore spread the disease quickly across relatively large distances. Asexual spores (called conidia; ❷ (B)) are spread by splashing and wind-blown rain. Insects and birds can also be involved in their dispersal. For most rot-causing fungi, fruit needs to be damaged to allow the pathogen to enter and cause disease. *Glomerella* is unusual because it doesn't need this initial damage and can penetrate otherwise healthy fruit ❸. Infected fruit develops characteristic lesions that produce many millions of spores ❹. Depending on the conditions, many disease cycles can occur in a single season.



Life cycle of Glomerella cingulata © I&I NSW

Damage



Bitter rot. Note the concentric circles of spores.
University of Georgia

Fruit

Damage is almost entirely confined to the fruit. Where infection pressure is extremely high leaves can become infected with the disease, causing small, red flecks that enlarge to irregular brown spots. In rare cases this can lead to premature loss of leaves. Usually infection of leaves is of no economic importance.

Fruit damage is of two types, depending on whether the infection was caused by a sexual or asexual spore (see 'Life cycle' on this page). In Australia infection by asexual spores is more common. Circular lesions become larger and sunken as the disease progresses. Copious quantities of ooze containing spores develop in roughly concentric circles on the surface of the lesions around the point of infection. Under moist, humid conditions these spore masses appear creamy and are salmon-coloured to pink.

The lesions that develop following infection by sexual spores are less sunken than those caused by asexual spores. They are brown and are more irregularly shaped. They also tend to produce fewer spores.

Regardless of which type of spore causes the infection, one feature is diagnostic for this disease. The rot that extends from the surface lesion is brown and conical. This gives a characteristic 'V' shape when the fruit is cut so as to bisect the lesion.

Infected fruit that has not yet developed symptoms is said to have latent infection. Bitter rot is a fungal disease that can develop in storage if fruit has latent infections at harvest. Postharvest fungicide treatments are usually not effective for controlling latent infections caused by this fungus.

Similar damage

Fruit that is damaged by hail or mechanical injury can develop sunken brown lesions that at first glance look similar to bitter rot. Sometimes damage due to sunburn (see image below) can also appear similar. This is especially the case because this type of damage often has a red halo around it, as does the early stage of bitter rot. The presence of concentric spores distinguishes asexual bitter rot infections from other types of damage. Infection arising from sexual spores is more difficult to distinguish, and samples should be sent to a specialist diagnostic laboratory.



Sunburned fruit © I&I NSW

Prevention and good orchard management

Sanitation

Sanitation is critical for effective control. The disease survives through winter on mummified fruit or on dead wood (see 'Life cycle' pp. 51–52). Remove all prunings from the orchard floor and destroy them. They can be left in the orchard if they are run over with a mower to mulch them.

Remove and destroy all fallen fruit from the orchard floor both during the season and after harvest. After harvest it may also be possible to hasten decomposition of fallen fruit by mowing and/or treating with urea ground sprays. Fruit should not be left hanging after harvest in areas where bitter rot has been a problem during the season. Encourage pickers to remove all fruit and throw diseased or damaged fruit into the inter-row, where it can be mulched by mowing. This removes an important source of overwintering spores.

Fruit that is infected by bitter rot and is left hanging in the tree during the season effectively becomes a disease dispenser. Although it may be labour intensive, removal and destruction of diseased fruit during summer will reduce damage to the crop and may let you get away with fewer sprays.

Also see the recommendations given for the control of storage rots (see 'Storage rots' p. 117).

Monitoring

In areas where bitter rot has been a problem in the past, careful monitoring should be done during fruit development. Fruit is susceptible to infection from 3 weeks after petal fall until harvest. Relatively high temperatures (27°C to 32°C) and high humidity favour disease development; therefore, be particularly vigilant during summer. During inspection walks through the orchard pay particular attention to the tree tops, where spray applications for other diseases such as black spot may not have reached.



Removal and destruction of infected fruit from the ground (left) and hanging in trees (right) will slow the development of bitter rot. University of Georgia

Management

Responsible use of pesticides

As with most diseases, application of copper is likely to reduce the number of overwintering spores available to initiate disease early in the season.

Mancozeb, dithianon and ziram are registered for the control of bitter rot on apples. Of these fungicides only mancozeb is registered for control of the disease on pears. In orchards that are likely to experience mite infestations take care with the application of mancozeb and ziram, as they are toxic to beneficial organisms, including certain predatory mites (*Galendromus occidentalis*; see 'Mites: Two-spotted mites, European red mites, Bryobia mites' p. 93).

Often fungicides applied for other diseases such as powdery mildew or black spot will also control bitter rot. However, where monitoring indicates that bitter rot is present, a thorough, early application will be needed.

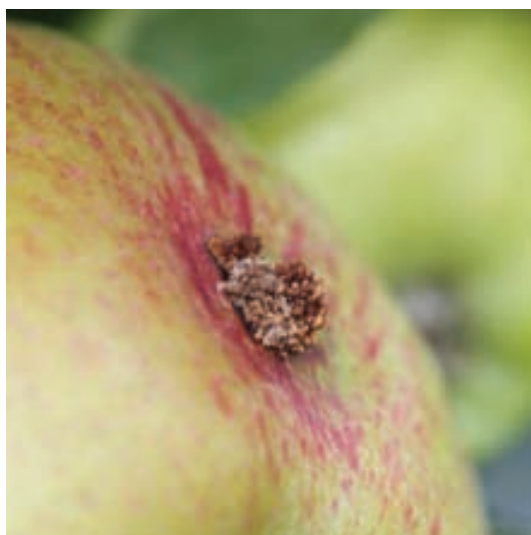
Biological control, biorational pesticides and organics

A number of microscopic biological control agents, including yeasts and bacteria, have been trialled experimentally overseas and have shown some promise. As yet, none has been developed commercially.

Codling moth

IPM quick facts

- By taking preventive action such as destroying infested fruit, bulldozing and burning neglected trees, and cleaning bins and orchard machinery, the number of codling moths infesting the orchard can be reduced.
- Codling moth numbers can be monitored by using pheromone traps; these traps can be used to optimise spray timing.
- Mating disruption can be an effective tool against codling moth. Mating disruption works best when used in large blocks of similar trees.
- Care should be taken when applying pesticides so as not to deplete populations of the natural enemies of apple pests.



© I&I NSW

The pest and its impact

In most Australian apple and pear production regions codling moth (*Cydia pomonella*) is considered the most damaging pest of both apples and pears. Western Australia is an exception. In that State, rigorous, eradication, surveillance and quarantine measures have excluded the codling moth. In other regions, maintaining low numbers of codling moths is a high priority, and most orchardists are willing to invest heavily in management. If the moth is not managed it is possible for 95% of fruit to be damaged. It has been estimated that the establishment of codling moth in Western Australia would expose the apple and pear industry to an additional 2 million dollars a year in spraying costs and production losses.

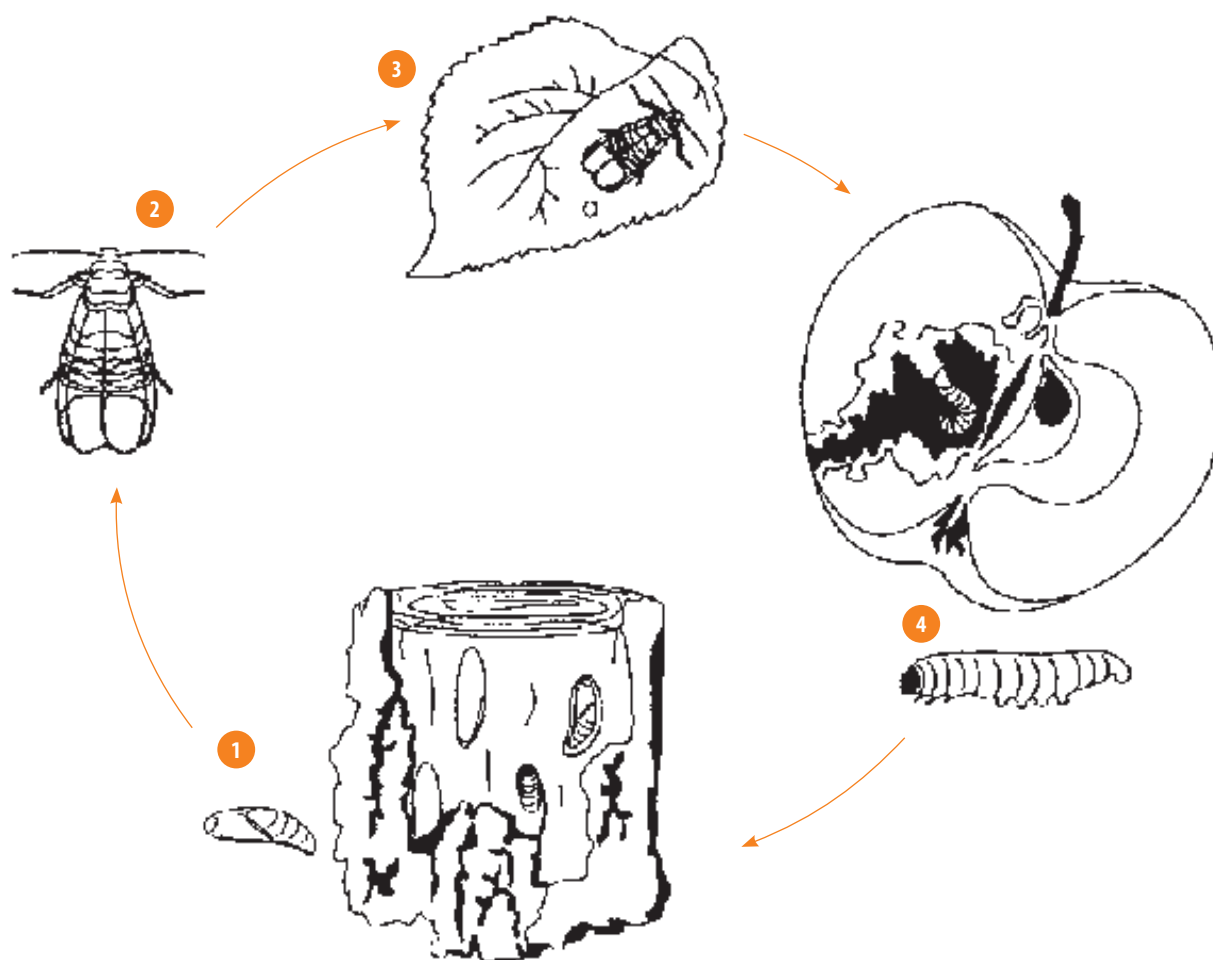


A codling moth © I&I NSW

Codling moth originated in Europe but is now present in almost all fruit growing regions worldwide, except Western Australia and Japan. In recent years codling moth numbers have tended to increase, most likely as a result of the introduction of 'softer' insecticides and management practices.

Adult codling moths have a 12- to 19-mm wingspan and a body length of around 9 mm. They have a grey-brown body with patterns of white lines on the wing. A bronzed area at the tip of the wing is characteristic of this species.

Larvae (grubs) become larger as they develop through a number of instars (development stages). First-instar larvae are white with a black head. Later instars become progressively darker shades of pink. At maturity the larvae measure 10 to 15 mm.



Life cycle of the codling moth

Adapted from University of California Pest Notes. Publication 7412

Life cycle

During winter, codling moth larvae enter diapause (a physiological state of dormancy) within thick silken cocoons ❶. These cocoons are hidden under loose bark or in soil or debris around the base of the tree. Within the cocoons the larvae pupate to become adult moths and emerge, usually around the time of bloom ❷. These moths are active for only a few hours before and after sunset, and they mate when the sunset temperature exceeds 16.6 °C. Each mated female moth will lay around 20 to 70 tiny disc-shaped eggs, singly on leaves, fruit or spurs over a period of around a week ❸. The time that these eggs take to develop and hatch into larvae is influenced by temperature (see 'Pheromone traps' p. 58).

Upon hatching, young larvae immediately seek out a fruitlet. They may feed briefly on the surface of the fruitlet before tunnelling into the fruit to feed on its flesh and seeds ❹. Within the fruit the larvae progress through further

developmental stages ('instars'). The fifth-instar larva emerges from the apple and falls to the orchard floor. It then finds a sheltered position – often by crawling part-way up a tree and sheltering under loose bark – and pupates to later emerge as an adult moth.

This cycle is repeated a number of times during a single season. The number of cycles (or generations) per season is largely dependent on the temperature within the fruit-growing region. Warmer regions are more likely to have greater numbers of generations. Typically there is one generation per season in Tasmania, two in the major pome fruit producing regions of New South Wales and three in Victoria's Goulburn Valley, parts of South Australia and south-east Queensland. As the season finishes and temperatures fall, once more the pupa within its cocoon enters diapause and remains dormant until the following spring.

Damage

Damage caused by codling moth can be of two types. The first larvae to reach fruit often feed on the surface of the fruit before finding a site into which to tunnel. This initial feeding results in shallow excavated areas known as stings. Stings can also occur where young larvae penetrate a short distance and then are killed by insecticides or other means.

Deep tunnels within the fruit are caused by the larvae tunnelling toward the core of the apple, where they feed on the seeds. Often the fruit flesh around these tunnels is broken down by bacteria and the tunnels are plugged by the insects using excreta (frass), which can be seen exuding from the entry hole. As the larvae leave the fruit they again tunnel through the flesh to reach the exterior. This internal injury can lead to premature ripening and fruit drop.

Similar damage

Damage resembling codling moth stings can be caused by heliothis (budworms) or loopers. Tunnels in fruit can also be caused by oriental fruit moth. It is important to make sure that the insect causing the damage is codling moth, as control measures may not be effective against other insects.

Prevention and good orchard management

In areas where this pest is present commercial orchardists will always need to use some form of dedicated codling moth control strategy, such as mating disruption or pesticide application. However, the severity of codling moth infestations and the cost of control can be moderated by good orchard management.

Orchard hygiene

Infested fruit is often reasonably obvious, more so where adequate thinning has removed clusters. Depending on the size of the enterprise and labour availability, it may be practical to remove and destroy infested fruit during the season. Similarly, fruit that falls to the ground prematurely and windfall fruit should be removed from the orchard and destroyed. Alternatively, fallen fruit should be thrown into the inter-row and run over with the slasher.

Clean bins and orchard machinery

Codling moth can survive the winter in crevices in bins. Where practical, if codling moth damage has been a problem, plastic bins should be used. Wooden bins should be regularly cleaned using steam and/or pressure washers.

Where possible, wooden bins should be stacked inside away from apple trees, as they can be a source of infestation. Movement of dirty bins between properties should be avoided.

Deserted or neglected orchards

Deserted or neglected orchards are a serious problem for commercial orchardists in all Australian pome fruit production regions. This can be a frustrating and often intractable problem. Although legal provisions exist in most States for forced destruction of abandoned orchards, the time required for legal proceedings is often long.

Negotiation is often the key. Increasingly urban-based land-holders are buying orchards as weekend getaways. In these cases it may be possible to suggest to them that they should remove all of the trees except those that they need for their own consumption. It may also make good economic sense to offer to spray these reduced blocks for your neighbours for a minimal cost.

Destroy neglected or roadside trees

Neglected trees around packing sheds or home gardens should be removed and destroyed, as they are reservoirs for codling moth. Possible feral hosts of codling moths include apples, pears, quinces, stone fruits and walnuts. Local councils should be encouraged to remove feral trees from roadsides.

Burn bulldozed trees

Where blocks are to be removed or renewed, burn the windrows of pushed trees as soon as possible, and certainly before the start of the next season. As codling moths survive during dormancy under rough bark, this can be a prime source of infestation for surrounding orchards.

Quarantine

On-farm quarantine is important for orchardists who pack for others. Be aware of codling moth in fruit arriving for packing, and refuse to pack consignments that are severely infested.

Western Australia maintains rigorous quarantine through surveillance and limitations to trade with eastern States. Full details of Western Australia's surveillance for codling moth can be found at <http://agspsrv34.agric.wa.gov.au/ento/Surveillance/Codling%20moth.html>

For fruit destined for export markets, orchard blocks where codling moth is trapped must be treated according to quarantine guidelines.

Better spray penetration

If orchardists use insecticides to control codling moth, increased application efficiency will be achieved with properly calibrated equipment (see 'Step 1: Prepare and prevent' p. 3). Pruning and training are also critical, as better spray penetration occurs when trees are short and have an open limb structure.

Monitoring

For codling moth, monitoring is used to determine:

- whether management – usually with pesticides – is required
- when management should be applied to be most effective
- how effective the current management is.

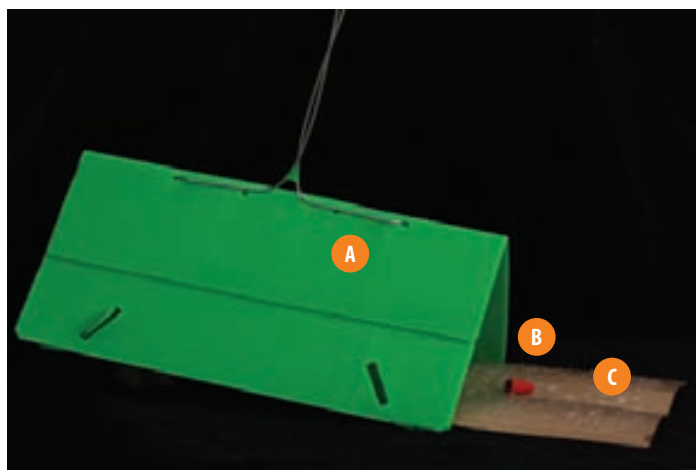
Fruit damage assessments

Before deciding on the codling moth management strategy to be used, gather information from previous seasons. Pest damage to fruit should be carefully assessed at, or just before, harvest. A minimum of 200 fruit per block (and preferably 1000 fruit) will need to be inspected. If block size and shape are suitable (see 'Visual monitoring' p. 17), no other codling moth control should be needed if infestation in the previous season was less than 0.3% (3 fruit in 1000). If infestation was more than 0.3%, partial or full supplementation with insecticide is recommended.

Monitoring for codling moth activity throughout the season is also important, as it provides an indication of the effectiveness of what is being done. This manual provides a suggested method of conducting visual monitoring in orchard blocks (see 'Visual monitoring' p. 17). For each flagged monitoring tree, visually inspect 30 fruit (10 at the top of the tree, 10 in the middle and 10 lower) and record the proportion that have signs of codling moth damage (particularly stings). Any increase in the proportion of damaged fruit from week to week is an indication that the management regime should be altered. For example, mating disruption may need to be augmented with insecticide applications. This technique is also useful for monitoring damage caused by western flower thrips (see 'Thrips: Western flower thrips, Plague thrips' p. 123) and lightbrown apple moth (see 'Lightbrown apple moth' p. 73). For both of these pests, extra attention should be paid to fruit assessments done on lower branches.

Pheromone traps

Pheromone traps are used to monitor populations of male moths. Adult female codling moths release a sex-attractant chemical (pheromone) to attract male codling moths. Products such as codlemone lures use a chemical analogue of the codling moth pheromone.



Monitoring trap. Delta trap (A), Codlemone lure (B) and sticky base (C) © I&I NSW

If pesticides are the primary means of codling moth control (see 'Responsible use of pesticides' p. 60), it is important to time applications so that moths are at a stage where the insecticides will be effective. A good knowledge of the codling moth life cycle is therefore needed (see 'Life cycle' p. 56). Application of pesticides at times when susceptible codling moth is not present will not reduce fruit damage at harvest and wastes money.

Adult moths emerge from diapause and begin to look for a mate at a reasonably predictable time each year. This is called first flight. In cooler production regions such as Tasmania, the main emergence is between November and January. From this point, the codling moth life cycle proceeds in a predictable manner regulated by temperature. Warmer weather results in a more rapid progression through egg-laying, hatching, development of larvae and fruit infestation. Pheromone traps can be used to establish the time of the first sustained moth flights (known as biofix). Temperatures are then monitored to predict the rate at which moth development is occurring and this information is used to time spray applications appropriately. The most useful units for monitoring moth development are degree days (see box below).

The procedure is therefore:

- Place 1-mg codlemone lures in traps in the orchard approximately 1 month before the expected time of moth emergence. For example, in Tasmania traps would be placed out in mid-October.

Traps containing lures should be placed in the top 30 cm to 1 m of the trees and should be at a density of approximately 1 trap per 2 ha. Traps should be in the outer third of the canopy and on the southern or northern side. Never rely on a single trap, as it may have been accidentally placed in a position with high moth prevalence (a hotspot) or low moth prevalence and the result will be distorted. However trap density is not important and a small number of traps is almost always sufficient. Average out the results from all traps in a similar block (same variety, similar topography, same management).

Check traps every second day during the period when moths are expected to emerge. There is no need to check the traps on cold nights (less than 12 °C at dusk) or if there is a strong wind or it is raining as codling moth will not be active under these conditions. Change the lures every 3 to 4 weeks.

- The first sustained flight occurs when new moths are trapped on three consecutive observations. When this occurs, begin to calculate and accumulate degree days from the date of the first catch in this series.

Calculating degree days

Codling moths cannot develop when temperatures are below 10 °C. Development proceeds at faster rates as the temperature increases up to an optimum point (31 °C). In this case, a degree day is essentially each degree of temperature by which the average temperature on a day exceeds 10 °C.

Degree days provide a useful index to the rate at which insects develop and can be used to predict the developmental stage of the majority of the moth population. There are many more-or-less complicated equations for calculating degree days, but a simple and useful approximation can be found by using:

$$\text{Number of degree days} = (\text{min temp} + \text{max temp}) \times 2 - 10$$

Maximum and minimum daily temperatures can be determined by using a max-min thermometer.

More complex and accurate equations exist. If orchardists are using a monitoring station for apple or pear black spot, they should ask the manufacturer if it is possible to program the station to also monitor codling moth degree days.

- Decide which insecticide you would like to use. Remember that, in IPM, preference should always be given to effective alternatives that have a low impact on beneficial organisms such as predatory mites (see 'Appendix 4: The effect on beneficial arthropods of pesticides registered for use on apples and pears' p. 173). The table below provides information on how many degree days are required for the first application of the chosen pesticide to be at its most effective against codling moth.
- Apply the selected insecticide when continued trap catches indicate persistent moth presence. Apply pesticides in line with the manufacturers' recommendations outlined on the product label and as indicated by fruit damage assessments. Also consider your insecticide resistance strategy.
- Continue to monitor codling moth activity by using pheromone traps. Use fruit damage assessments to determine how successful your management has been and record all results.

Timing pesticide applications

Pesticide	Time when effective against codling moth	Degree days after emergence (biofix)
Fenoxycarb	eggs	60
Thiacloprid, rynaxypyr	eggs and larvae	110
Parathion-methyl, azinphos-methyl	newly emerged larvae	140

Monitoring in mating disruption blocks

Mating disruption is a form of codling moth control (see 'Mating disruption' p. 23) that uses pheromones similar to those used for monitoring. These two sets of pheromones have the potential to interfere with one another. Monitoring in a mating disruption block is therefore slightly different from the procedure used in a block in which pesticides are the main means of moth control.

The purpose of monitoring in a mating disruption block is to check the effectiveness of the management in keeping moth numbers low. If moth numbers become unacceptably high, monitoring will provide an indication that mating disruption needs to be augmented by pesticide application.

The major difference from monitoring in other blocks is that the pheromone lure is more concentrated (e.g. a 10-mg codlemone lure) or is based on a food attractant, such as pear esterase, rather than a sex attractant.

There is also some suggestion that if monitoring lures are placed higher in the canopy than mating disruption dispensers, they provide a more accurate assessment of codling moth numbers.

Management

Mating disruption

Products for mating disruption are widely available in Australia. See 'Mating disruption' (p. 23), which provides practical guidelines for applying mating disruption in your orchard.

Responsible use of pesticides

Pesticides will be needed under certain circumstances:

- Mating disruption by itself will not work when codling moth infestations are moderate to very high. It will be necessary to use pesticides to reduce populations to a level where mating disruption is effective.
- When blocks are small or irregularly shaped and/or surrounded by conventionally sprayed blocks, pesticides will need to be applied.

Pesticides should be used when mating disruption is not possible or when the level of control still results in unacceptably high damage. Mating disruption is likely to be ineffective if orchard blocks (or contiguous neighbouring blocks) are smaller than 3 ha or if blocks are irregularly shaped. When moth numbers are high, resulting in high infestation pressure, mating disruption may occasionally fail and require supplementation with pesticides.

Where orchard size and shape are suitable, conversion to mating disruption is desirable. Pesticides may be used over a season or series of seasons to drive infestation pressure to a lower point. Where fruit damage of 0.3% or less is achieved at harvest, conversion to mating disruption is recommended.

Managing resistance

Resistance to azinphos-methyl in codling moth has been confirmed in orchards in all mainland apple- and pear-growing districts in Australia. In addition, resistance to almost all insecticides has been recorded worldwide. The key to avoiding resistance is to avoid overdependence on a single group of insecticides such as the organophosphates and to rotate insecticide groups among pest generations. Any management that reduces the overall number of pesticide applications (e.g. mating disruption) will also help to slow the development of resistance.

Biological control, biorational pesticides and organics

The most serious limitations to organic apple and pear production in eastern and southern Australia are codling moth and apple scab (black spot). In the case of codling moth a number of organically acceptable treatments (e.g. mating disruption) are now used by the mainstream orcharding community. However, mating disruption is not suitable for many organic farmers, largely because their blocks are small. However, small size may be an advantage in that it may be possible to hand-thin and destroy infested fruit. A number of other management strategies may be useful. In situations with high numbers of carryover moths or pupae, the removal of loose and flaking bark from the bases of the trees early in spring to about 40 cm high will remove most of the overwintering pupae, reducing the pressure on mating disruption pheromones. Then, if a 10-cm strip of corrugated cardboard can be wrapped tightly around the trunk at the start of December, any larvae that have succeeded in leaving the apples from the first generation of moths will make their homes in the cardboard. With careful monitoring the cardboard can be removed in time to stop the next generation of moths emerging. This works extremely well on outside rows and areas on tops of hills, where the pressure is always greater.

Natural enemies

Trichogramma wasps are part of a range of parasites and predators that may assist in reducing the impact of codling moth in organic apple and pear orchards. The tiny female wasp lays its own egg inside the codling moth egg and a single Trichogramma adult has the potential to parasitise up to 50 codling moth eggs. This wasp can be purchased commercially in Australia but does not provide adequate levels of control to warrant the expenditure. However, natural populations of Trichogramma can be encouraged and maintained by growing plants that it can use as food sources close to the orchard. These plants include clover (but not in areas prone to western flower thrips; see 'Thrips: Western flower thrips, Plague thrips' p. 123, buckwheat, mustard, Queen Anne's lace, parsnip, daikon, alyssum, dill, coriander and cosmos.

Other natural enemies of codling moth are tachinid flies, ichneumon wasps, braconid wasps, chalcid wasps, carabid beetles, earwigs and ants. Spiders also eat moths and larvae.

This manual provides tables that give an indication of the likely effects of all registered pesticides on natural enemies (see 'Appendix 5: Using pesticides in IPM' p. 179). If there are a number of effective pesticide options, always choose the pesticide that has the lowest impact on natural enemies.

Fruit flies: Queensland fruit fly, Mediterranean fruit fly

IPM quick facts

- *Queensland fruit fly and Mediterranean fruit fly are among the most serious pests of horticulture in warmer regions.*
- *Quarantine and orchard hygiene are critical to good fruit fly control.*
- *Monitoring by using pheromone-based traps is recommended to improve the accuracy of spray applications.*
- *Where sprays are necessary, consider bait sprays for light to moderate infestations.*
- *Be aware that use of broad-spectrum insecticides is likely to cause secondary pest problems.*



GT O'Loughlin; Department of Agriculture, Australia

Queensland fruit fly

The Queensland fruit fly (*Bactrocera tryoni*; QFF) is endemic to the Northern Territory, Queensland, parts of New South Wales and north-east Victoria. Outbreaks occur sporadically in other mainland States. In 1989, an outbreak was detected in Perth, Western Australia. An eradication campaign was undertaken using baits, male lures and sterile insect techniques. Intensive monitoring has not detected QFF in Western Australia since November 1990.

QFF has a red-brown thorax and dark brown abdomen and is about 6 to 8 mm long.

QFF infests over a hundred species of fruit and vegetables and in addition to pome fruit it is a significant pest of citrus, stone fruit and many tropical fruits.



Queensland fruit fly GT O'Loughlin; Department of Agriculture, Australia

The pests and their impact

Two species of pest fruit flies have a major impact on pome fruit production in Australia. In addition to their potential to severely damage fruit, their presence imposes restrictions on interstate and international export markets.

Mediterranean fruit fly

Mediterranean fruit fly (*Ceratitis capitata*; medfly) is able to tolerate cooler climates better than most tropical fruit flies. It therefore has the potential to spread to southern production regions that are climatically unsuitable for QFF. It is currently restricted to areas of Western Australia as far south as Esperance and as far north as Derby. The main area of infestation extends from Carnarvon to Bunbury.

Medfly has an extremely large host range and is able to infest over 200 fruit and vegetable species.

The adult fly is 3 to 5 mm long. The body is light brown and the wings are mottled, with two distinct bands extending to the wing tips. The abdomen is brown and is encircled by two light-coloured rings. The thorax (middle) has irregular patches of black and silver.

Although medfly is capable of spreading to eastern States, its distribution is likely to be limited because it is outcompeted by QFF.



Mediterranean fruit fly Scott Bauer, USDA Agricultural Research Service

Life cycle

The diagram on p. 64 is a generalised fruit fly life cycle. There are significant differences between QFF and medfly in terms of development. During warm weather in spring or early summer, adult fruit flies feed and mate ❶. Adult flies feed on sweet exudates, including nectar, from plants. Females follow the scent of ripening fruit or vegetables and lay their eggs ❷. Female fruit flies can lay 500 to 800 eggs during their

6-month life. Eggs are white and banana-shaped and are placed in a cavity in the flesh close to the skin using the female's retractable, needle-sharp egg-laying organ, called an ovipositor ❸. This results in a distinctive 'sting' on the surface of the fruit. In warm weather, the eggs hatch in 2 to 4 days. Development of larvae (maggots) takes 6 to 8 days in summer. Maggots have cutting jaws that allow them to cut fruit into pieces small enough to swallow. They tend to chew and create tunnels that lead toward the centre of the fruit. This chewing introduces bacteria and fungi, which in turn cause the fruit to develop a severe internal rot. Fruit may appear perfect from the outside ❹.

Infested fruit often falls to the ground. When the maggot has completed growing, it chews its way out of the fruit and burrows into the soil ❺. In the soil, the larva become inactive and develops into an oval, brown pupa, in which the adult fly develops. Often the fruit fly is able to survive through winter in this pupal form. Both medfly and QFF can exist in their adult forms during winter in warmer regions, although development and the life cycle slow.

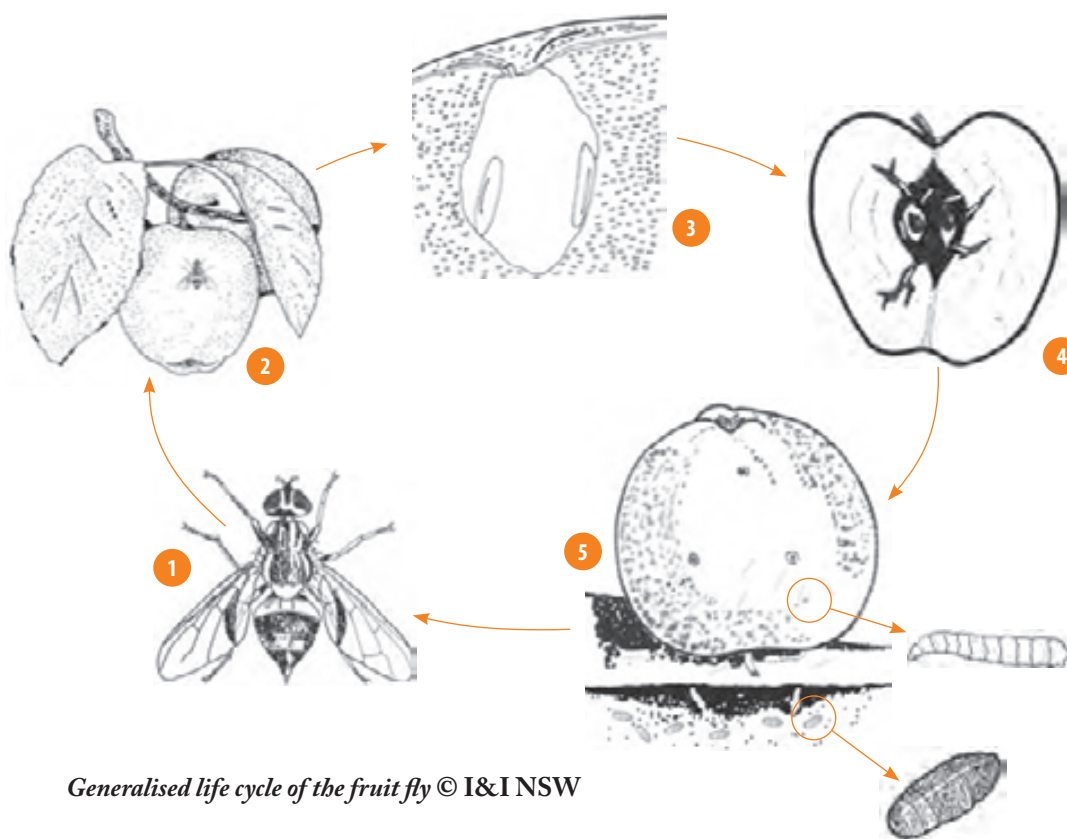
Damage

The egg-site punctures in the fruit are commonly referred to as 'stings'. Stings are more obvious on pale, smooth-skinned varieties such as Granny Smith or Cripps Pink apples or Bartlett pears. Infested fruit may fall from the tree as a result of larval infestation. The style of damage caused by fruit fly larvae varies with the type and maturity of fruit, the number of larvae in it, and the weather. In most fruits the larvae burrow toward the centre and a brown, mushy decay usually develops quickly.

In hard fruit (such as Granny Smith apples or immature fruit) a network of channelling is usually seen, followed by internal decay.

Similar damage

Damage caused by fruit fly infestation is quite distinctive. Although a range of fungal pathogens cause internal breakdown of fruit, the presence of maggots is diagnostic for fruit fly damage. Fruit flies can cause premature fruit fall, even if the fruit appears externally perfect. This symptom is shared with a number of other pests. Where the problem is caused fruit fly, cutting the fruit should reveal maggots.



Generalised life cycle of the fruit fly © I&I NSW

Prevention and good orchard management

Quarantine and exclusion zones (clean zones)

Although adult fruit flies can fly considerable distances (several kilometres), the main means of pest dispersal is through transport of eggs or larvae in infested fruit. Fruit flies are often transported over large distances by travellers. Australian quarantine screens incoming consignments of fruit and travellers who may be carrying this pest. In addition, domestic quarantine limits the distribution of the pest between States and excludes it from established fruit-fly-free regions. These quarantine zones are regulated and monitored by State government departments of agriculture.

The fruit fly concerns of the States vary in accordance with which fly species are endemic and which are likely to pose incursion threats:

- *Queensland, NSW and Victoria*: QFF is endemic; medfly is not present.
- *South Australia*: neither QFF nor medfly is endemic, but outbreaks occur sporadically and are eradicated.



Larvae (top) and pupae (above) of Queensland fruit fly © I&I NSW

- *Western Australia*: medfly is endemic; QFF outbreaks have occurred but the pest has been eradicated.
- *Tasmania*: neither fruit fly species occurs. Because of the more temperate production region, fruit fly may not be a serious threat. However, the dependence of this industry on export markets warrants strict quarantine regulation.

Specific details of the quarantine measures relating to individual States can be found on the websites of their departments of agriculture and primary industries.

Hygiene

It is important to remove and destroy waste fruit that is, or could become, infested with fruit fly. Fruit that has fallen or is left hanging after harvest should be removed and soaked in water topped with a layer of kerosene for 4 to 5 days. Remember that even fruit that appears perfect may harbour infestations, so be conservative and treat all unharvested fruit in this way.

Alternatively, waste fruit can be frozen or boiled, pureed and fed to pigs or poultry.

Do not bury waste fruit. Because the pupal stage of the fruit fly life cycle (p. 64) occurs underground, burying facilitates fruit fly development and may lead to more severe infestations. Do not dump untreated fruit. Fruit flies can fly considerable distances and will rapidly infest orchards near the dump site and radiate further into the region.

Tree pruning

Keep trees well pruned. Do not allow trees to become too tall. Tall fruit-bearing trees are difficult to cover adequately with sprays, and it is difficult to pick the fruit on them. This fruit becomes increasingly susceptible to fruit fly attack and is then a source of fruit flies that attack other fruit crops.

Remove alternative breeding and feeding sites

Any fruiting trees that are unwanted or regularly remain unharvested should be cut down and removed. This includes trees from around sheds and houses and along boundary fences and irrigation channels. Practise good packing shed hygiene, with thorough inspection to remove and destroy any infested fruit.

Monitoring

Fruit fly becomes a problem in warmer seasons when greater than average rainfall occurs. Growers should be extremely vigilant during these seasons, as early detection of the pest will result in easier control and lower fruit damage.

Visual monitoring

Adult fruit flies can be present in the orchard throughout the year. They often rest on the undersides of leaves and can fly quite quickly. They are also easily confused with other flies in the orchard that have a similar appearance, such as ferment/vinegar flies (*Drosophila melanogaster*), metallic-green tomato flies (*Lamprolonchaea brouniana*) and others.

Around the middle of the season monitoring for stings should commence. Eggs are often laid up to 8 weeks before fruit is mature. The sting sites on fruit show as discoloured (sometimes prematurely coloured), often blackish spots. If you're unsure, cut through the tentative sting with a very sharp knife or razor blade and inspect with a hand lens. You should be able to see fly eggs.

Although visual monitoring provides useful information, setting traps that use pheromone or food baits is likely to give earlier detection.

Which pheromone, which trap?

The most suitable type of trap and the best bait to use as a fruit fly attractant are chosen according to:

- the type and sex of the fly you intend to monitor
- the size of the block to be monitored.

Wet traps

Wet traps are simple traps that can be home-made at low cost and use food baits to attract fruit flies. Simplicity and economy are offset by a number of disadvantages. The food bait attracts a wide range of insects, including many fly species (including blowflies). To interpret trap catches you must be able to identify fruit flies and exclude any other species caught. The food source within the traps also tends to go off, and baits need to be renewed every few weeks (or more frequently in hotter weather). This lack of accuracy and high labour input mean that wet traps are seldom used in commercial orchards.

Pheromone-based traps

A pheromone is a chemical signal that triggers a natural response in another member of the same species. Although many types of pheromones exist, sex pheromones indicate the availability of the female for breeding, and many insect species release sex pheromones to attract a mate. These types of pheromones attract only a particular species and gender. Pheromone-based monitoring traps use synthetic pheromones to attract, capture and monitor the numbers of specific pests within the orchard.

The most common type of trap used in Australian orchards is the Lynfield lure trap. Traps are available from rural suppliers in fruit-fly-prone areas. Traps attract only the male fly and therefore do not give an accurate indication of female fly activity. This is a major limitation of this monitoring technique, as females are responsible for fruit damage through egg-laying and subsequent maggot infestation.

Two types of synthetic lures are commonly used:

- *Capilure*: a pink, aromatic liquid used for medfly
- *Cue-lure*: a lemon-coloured liquid used for QFF.

These lures must not be mixed together or allowed to contact your hands or the trap body, otherwise their attraction to different fly species is affected. This could lead to non-target fruit fly species being caught and make identification difficult.

Traps should be hung in the tree canopy at about head height and about two-thirds of the way out from the trunk. The trap should be in semi-shade and well clear of foliage. This allows easy access for the flies through the entry hole of the trap.

Hang traps at around late blossom. Hang one trap in the centre of each large block. In regions with high fruit fly pressure (South East Queensland, South East Western Australia) check traps every 3 or 4 days as the fruit softens, and count the male fruit flies. Empty the traps after counting.



A Lynfield trap for fruit fly monitoring
© I&I NSW

Responsible use of pesticides

Bait spraying

Bait spraying is also known as splash bait, bait spotting or foliage baiting. It is a good alternative to orchard cover sprays in areas where fruit fly pressure is low to moderate. Bait spraying will kill only adult flies and must therefore be used before large numbers of fruit are stung. It will not kill eggs or maggots.

Once monitoring indicates that fruit fly is present in the orchard, start the bait spraying program and continue this every 7 to 10 days until the harvest is completed.

In endemic areas, at least eight bait applications are recommended for all fruit trees 3 years and older:

- spring (September to October): four or more bait sprays at 7-day intervals
- autumn (March to April) four to eight baits at 7-day intervals.

Baits are prepared using a protein source and an insecticide (chlorpyrifos, maldison or trichlorfon). Both males and females are attracted to the protein. As they feed they are killed by the insecticide.

Observe the mixing and safety directions on pesticide labels. To make 100 L of bait spray based on maldison, take:

- 435 mL maldison (1150 g of active ingredient (ai)/L), plus
- 2 L yeast autolysate 50% or Natflav® 500.

Add the protein lure (yeast autolysate or Natflav® 500) to 75 L of water. Mix thoroughly, add the maldison, and top up to 100 L with water. The bait can also be prepared using maldison (500 g ai/L), as follows:

- 2.5 L maldison (500 g ai/L), plus
- 2 L yeast autolysate 50% or Natflav® 500
- 100 L of water.

In low-density plantings, about 100 mL of the prepared bait should be applied to the foliage of every second tree in every second row. For higher-density plantings, apply bait to every fourth tree in every second row. Use 30 L of the mixture per hectare of orchard.

Baiting is more effective when carried out in the morning, when fruit flies are most active. It is important to avoid direct contact between the bait and fruit, as the protein may induce phytotoxic damage in some pome fruit.

Male annihilation blocks

In towns it is possible to use an 'attract-and-kill' technique for male fruit flies. Killer pads have cue-lure (for QFF) as the male fly attractant and maldison as the killing agent, impregnated in a block about 5 cm × 5 cm made from low-density particle board or material such as felt or cardboard. The pads are nailed to trees in the orchard at a density of between 10 and 30 per hectare, depending on fly pressure.

Cover sprays

Where possible, avoid using cover sprays. Spraying with the broad-spectrum insecticides registered for fruit fly control often leads to the destruction of the populations of predatory organisms that naturally control other pests such as two-spotted mite.

However, bait spraying alone may not be enough to control high populations of fruit fly. Pre-harvest cover spraying of the trees and fruit with insecticide will kill the fruit flies that seek shelter in the tree canopy and kill any larvae in the fruit. Trees and foliage should be sprayed to leaf saturation (i.e. when droplets just begin to drip from the foliage). Do not pick fruit until the withholding period for the insecticide has expired. For best results make sure that you achieve satisfactory coverage of the fruit. It is therefore essential that you use correctly calibrated spray equipment.

Biological control, biorational pesticides and organics

Organic control of fruit fly is difficult, particularly for larger producers. Fruit flies have several natural predators, including parasitoid braconid wasps. Ants and ground beetles also feed on larvae that are in decaying fruit on the ground. These predators are unlikely to provide significant control, and several attempts at introduction of biological control agents during the last century have not been successful. QFF is a native species and it is likely to be better adapted – and more competitive – than introduced biological control agents.

Poultry in the orchard may reduce pest populations by eating larvae in fallen fruit and pupae from the soil under trees.

Sterile insect technique (SIT)

SIT has been employed by Australian government agencies as a component of fruit fly eradication programs in several States. For example, in the event of a fruit fly outbreak in South Australia, government staff use bait sprays to attract and kill flies for 2 weeks and then release sterile male flies for a further 12 weeks. During the 12-week period around 100 000 laboratory-reared sterile male fruit flies are released per square kilometre twice a week. The sterile insects mate with 'wild' fruit flies and any eggs laid are infertile, eventually eradicating the fruit fly population.

Helicoverpa and loopers

IPM quick facts

- In most cases insecticides applied for other pests such as codling moth will control *Helicoverpa* and loopers. Natural predators, parasitoids and diseases also play a part in regulating their numbers.
- If monitoring indicates a need for an insecticide specifically for *Helicoverpa* and / or loopers, timing and coverage are crucial.
- Biopesticides based on the bacterium *Bacillus thuringiensis* (e.g. DiPel®) may play a part in controlling these insects but cannot be used in an emergency.
- Weed control is important in managing these pests.



Stewart Learmonth, WA Department of Agriculture and Food

Larvae of these moths do serious damage to a wide range of crops, including apples and pears. In a moist spring, *Helicoverpa* caterpillars can infest weeds and other plants on the orchard floor. As these plants dry out the caterpillars migrate to trees. Colours are variable and can be yellow, green, buff or red-brown, with a variable number of brown markings or with broad longitudinal stripes.

Helicoverpa can cause substantial crop damage and is becoming more common across all Australian regions. This is likely to be the result of more specific insecticide applications for the control of common pests such as codling moth and lightbrown apple moth.

Infestation is most common during spring to early summer and in late summer to autumn; it declines during hot, dry periods when moths are unable to emerge from pupae in the ground. Normally *H. punctigera* damages crops during spring to early summer, whereas *H. armigera* is most common in late summer to autumn.

The pests and their impact

Helicoverpa (Heliothis) or budworms

Helicoverpa armigera (the cotton bollworm, corn earworm, tomato grub or tobacco budworm) and *H. punctigera* (the native budworm) cause damage on Australian apple and pear fruit. They are commonly known as heliothis, although this name has been superseded by the name *Helicoverpa*.

Damage

Helicoverpa larvae bore into developing fruitlets. Some of the fruitlets fall, but those that remain attached are often deformed at maturity by deep depressions with scar tissue. Larvae also feed on the leaves and young buds of trees. This can be particularly damaging to young trees suffering from heavy infestations and can result in ill-thrift and distortion of emerging growth.



Adult (left) and larvae (right) of Helicoverpa armigera © I&I NSW

Loopers

A number of species of loopers (also known as inch-worms) cause damage to apples and pears. Species recorded as damaging Australian crops include *Phrissogonus laticostata* (apple looper); *Chloroclystis testulata* and *C. approximata* (pome loopers) and *Ectropis excursaria* (twig looper or pear looper).

In addition to the damage caused on pome fruit, some species (e.g. apple looper) also infest other crops such as wine grapes.

Larvae range in colour from greyish-white to yellowish to pale brown and may be mottled with brown and dark grey. They move with a characteristic looping of the body. Although present in all mainland States, apple loopers have recently caused significant damage in Manjimup, Western Australia.

Damage

Often the first sign of damage is holes eaten in the leaves. However, in recent infestations in Western Australia there were no signs of leaf feeding, with larvae feeding on the fruit only. Loopers graze on the surface of fruit, and damage is more superficial than that caused by heliothis, but exceptions can occur and in some cases larvae are capable of causing deep cavities in fruit. As fruit matures the wounds caused by loopers become corky. In some cases these corky wounds develop into small lumps, whereas in other cases the wounds remain shallow and concave.



Adult male apple looper (Phrissogonus laticostata, left) and twig looper caterpillar (Ectropis excursaria, right) © Donald Hobern and Stewart Learmonth, WA Department of Agriculture and Food

Life cycles

Helicoverpa

Helicoverpa deposits its eggs on leaves, or on buds, flowers or young fruit of the host plants. The eggs are almost spherical (about 0.5 mm in diameter) and vary from white to yellow or brown, depending on the stage of development. Larvae emerge after 3 to 17 days, depending on temperature, and start feeding on the young, soft growth of their host plant. Larvae feed for 14 to 18 days externally on the plant tissues, often moving from one fruit to another (particularly if fruit clusters are present). After completing five or six developmental stages (or instars), the larvae drop to the ground and tunnel into the ground to a depth of about 10 cm, where they construct an earthen cell before pupating. The rate of pupal development depends on temperature, and in warm, humid weather adult *Helicoverpa* can emerge from the soil in as little as 12 to 14 days. If conditions are likely to be unfavourable for development, moths can delay emergence through facultative diapause. In this case, adult moths may not emerge for 300 days or more.

Loopers

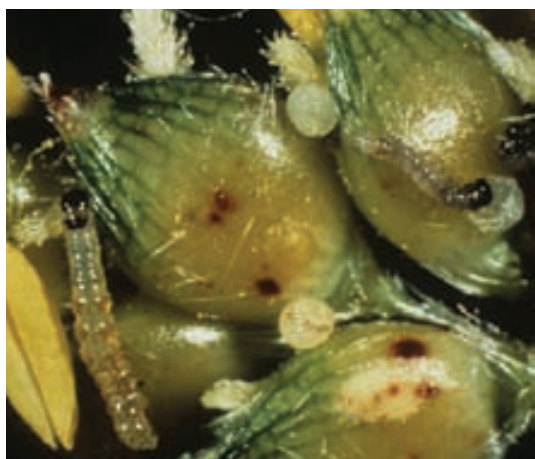
Most loopers have similar life cycles to each other. Typically, eggs are laid singly on the surfaces of the host plant or nearby weeds and hatch 3 to 5 days later. Larvae feed for about 2 weeks and can migrate from weeds to fruit during this period. Mature larvae range in length from 3 to 5 cm, and the first signs of their presence are ragged-edged holes through the leaves or in from the leaf margins. Caterpillars have only two pairs of abdominal prolegs and can be distinguished by their 'looping' behaviour when moving.

Loopers commonly overwinter as pupae in cocoons in plant debris or under the leaves of orchard weeds. Adults begin emerging in late September or October.

Similar damage

Helicoverpa damage can appear similar to the damage caused to fruit by protruding metal parts in harvest equipment or badly aligned shed equipment.

The calloused tissue that remains after black spot lesions have exhausted their spores can be mistaken for damage caused by loopers. Unlike lesions from looper damage, old black spot lesions are usually neither raised nor sunken but level with the fruit surface. Close examination with a hand lens also usually reveals some dark black spores, which remain attached to the old black spot lesions.



Helicoverpa eggs and first instar larvae (left) and pupae (right) © I&I NSW

Prevention and good orchard management

Moths often migrate significant distances before settling in orchards. Prevention is therefore often difficult. If *Helicoverpa* is the problem, it is useful to know which species is responsible. *Helicoverpa armigera* tends to be more localised than other species; prevention of damage from this species is more likely to be successful.

Weed management

Helicoverpa will lay eggs on, and feed on, a wide range of plants, including weeds such as deadly nightshade, Noogoora burr, galvanised burr, Scotch thistle, common sowthistle, capeweed, dock, fat hen, pig weed, sand spurry, stinging nettle and marshmallow. Management of these weeds—particularly during dormancy and early in the season—may reduce the numbers of caterpillars that can migrate to trees.

Monitoring

In cotton and broadacre vegetable crops, monitoring with pheromone traps and computer models is used to determine the arrival of the first *Helicoverpa* moths and subsequent development to the point where the larvae are most susceptible to insecticides. For pome fruit this is not practical, and the levels of damage rarely warrant this level of monitoring.

Helicoverpa may have four or five overlapping generations in warmer regions. Early detection and management will reduce the impact of later generations.

Monitoring of both *Helicoverpa* and loopers can be done at the same time by using identical techniques. The youngest developmental stages of these pests tend to feed on leaves before the older caterpillars move on to graze on fruit. This can give an early indication of their presence. During spring and early summer the undersides of damaged leaves should be carefully monitored for the presence of young caterpillars.

Helicoverpa damage can also occur in early autumn, around harvest time or later, and trees should also be monitored at this time of the year.

Responsible use of pesticides

Many of the insecticides that effectively control other serious moth pests, such as codling moth and light brown apple moth, will also kill *Helicoverpa* and loopers. These include softer chemicals such as spinosad, indoxacarb, spinetoram and chlorantraniliprole. Application of these chemicals early in the season for control of other pests may provide coincidental control of *Helicoverpa* and loopers.

If monitoring indicates that an insecticide application is necessary specifically for the control of *Helicoverpa* or loopers, correct timing and good coverage are essential.

Insecticide applications should be timed so that the caterpillars:

- are very small (1–3 mm) to small (4–7 mm)
- are feeding or moving in the open and are therefore more easily contacted by spray droplets
- have not moved into protected feeding locations.

Growers who are confident that they can recognise *Helicoverpa* eggs under a hand lens can time spray applications with respect to egg development. The best time to spray crops, especially when egg-laying has been heavy, is when eggs are blackish-brown, immediately before hatching. Application of insecticides at this time should kill newly hatched caterpillars before they have a chance to cause significant damage.

The number of treatments required, and their frequency, will depend on the duration and intensity of egg-laying in the crop and the speed of egg development. In extremely heavy infestations significant crop damage may occur despite good spraying.

Biological control, biorational pesticides and organics

Bacillus thuringiensis

Bacillus thuringiensis (Bt) is a bacterium that is the active component of DiPel® and similar products. This bacterium affects only the caterpillar stages of certain insects.

The product is applied in the same way as a conventional spray, preferably in the very early stages of infestation, so that it is on the leaf or fruit and will be eaten by the grazing caterpillar. Enzymes in the caterpillar's gut break down the natural 'capsule' surrounding the bacterium and a toxin is released. The caterpillar stops feeding and soon dies. Bt is recommended for the control of lepidopteran (moth) pests of apples and pears, including *Helicoverpa* and some species of loopers. It is not suitable for use as an emergency treatment, and its residual activity is short. However, if it is applied before an infestation becomes established it will provide control that is non-disruptive to other beneficials.

Natural enemies

Infestations of *Helicoverpa* caterpillars are sometimes controlled by predatory birds and insects, parasitic insects and diseases. In most cases the level of control achieved by biological agents is not sufficient, and without the use of pesticides as a supplement unacceptable crop damage is likely.

Two predatory shield bugs, *Cermatulus nasalis* and *Oechalia schellenbergii*, commonly attack *Helicoverpa* and other caterpillars, piercing them and sucking out their body contents. A small black wasp, *Microplitis demolitor*, commonly parasitises young *Helicoverpa* caterpillars. Older *Helicoverpa* larvae are attacked by various other wasps and tachinid flies. The parasite larvae feed in, or on, the caterpillars and pupate in or near the dead caterpillars or in the soil.

Two slim, brightly coloured wasps, *Netelia producta* and *Heteropelma scaposum*, are common parasites of *Helicoverpa* and other caterpillars.

Helicoverpa caterpillars are sometimes killed by a nuclear-type polyhedrosis virus (NPV) disease during warm, humid weather. Early-stage caterpillars are most susceptible. The dying caterpillars usually hang suspended, with the head downwards. They turn brown to black soon after death; the body contents liquefy, then the skin ruptures, releasing a dark brown or pink odourless fluid. The black, dried, burst skins often remain attached to the plants. Other commonly occurring diseases are caused by the fungal pathogens *Metarhizium*, *Nomurea* and *Beauveria*.



Parasites of Helicoverpa. The parasitic wasp Netelia producta (top) and the egg of a wasp parasite on a Helicoverpa caterpillar, near its head (above). The caterpillars can bite off eggs that are placed farther back along the body. © I&I NSW

Lightbrown apple moth

IPM quick facts

- *Lightbrown apple moth damage can be reduced by thinning fruit and controlling the weeds that are alternative feeding and shelter sites for this pest.*
- *Mating disruption is widely used for management and offers good control of this pest.*
- *If insecticides are applied for codling moth, lightbrown apple moth is often controlled as a side-effect.*
- *Biological control agents such as the egg parasite *Trichogramma* can also reduce lightbrown apple moth populations.*
- *Always monitor to make sure that a problem exists before managing.*



© I&I NSW

The pest and its impact

Lightbrown apple moth (LBAM) is a serious pest infesting over 250 crops (e.g. apples, pears, citrus, grapes). Some studies have provided evidence that it may infest a further 2000 types of plants, including ornamentals such as roses and jasmines and pasture species such as clovers, lucerne and lupins.

LBAM is present in all Australian pome-fruit production regions. Damage is also likely to be more severe where conditions promote good growth of host plants, and where cool conditions extend well into summer. In cool seasons LBAM can cause damage from spring until harvest in autumn.

The moth is an Australian native species but has become naturalised in a number of other countries, including New Zealand. However, it is considered a quarantine pest in other countries, including the USA, where a recent (2007) outbreak led to a large eradication campaign.



Lightbrown apple moth larvae feeding on an apple leaf © I&I NSW

Life cycle

Unlike many other moth species, LBAM does not truly hibernate. Female moths lay eggs in early autumn ❶ and the young moth larvae survive the winter on ground-cover plants, fallen leaves and fruit buds and occasionally under bark ❷. These larvae continue to feed on warm winter days and complete their development. They spin a loose silken cocoon and change to pupae in the spring and early summer ❸. The newly formed pupa turns from green to brown. After a few weeks the insect emerges as an adult moth ❹.

Male moths emerge a short time ahead of female moths. The moths are seldom seen, but are about 10 mm long. Their colouring is variable but is usually buff with darker brown markings on the forewings. Females often have a dark spot on the hind margin of the fore wing. Female LBAMs produce and emit a powerful sex attractant, also known as a pheromone. The pheromone is released in the evening, particularly around dusk, and attracts male moths over long distances.

Females normally mate only once and begin to lay eggs 1 to 7 days later ❺. Most eggs are laid 6 to 10 days after the moths emerge. A single female can lay up to 1500 eggs (average 300) over a period of up to 3 weeks. Eggs are laid in batches of about 30 to 35 per batch. They are laid almost exclusively on the upper surfaces of leaves. The eggs are scale-like and an aqua colour; they are difficult for the untrained eye to detect and identify. The eggs darken before hatching.

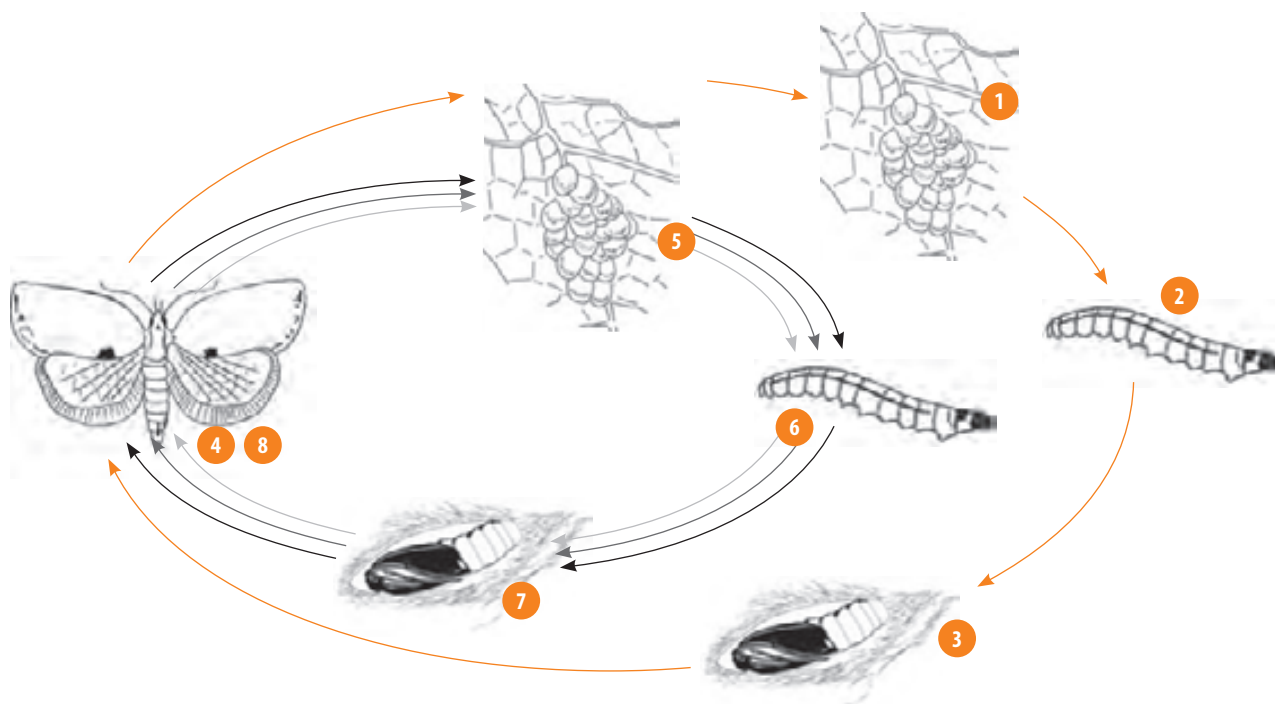
The larvae (caterpillars) typically hatch within 1 to 2 weeks ❻. Young larvae are pale yellow and small (about 1 mm long) and disperse by crawling or dropping silken threads. They settle on the under-surface of the leaf (often near the mid-rib) and spin a small protective cocoon, where they feed and complete their first moult. The larvae then abandon this shelter and move to a feeding site where they construct a more substantial feeding shelter or nest. Feeding nests are made by webbing together two sides of a leaf, two adjacent leaves, or leaves to a fruit or several adjacent fruit. Fruit calyces are also frequently used as feeding nests.

The larva passes through six developmental stages (or instars), increasing in length to about 18 mm. Mature larvae are pale to medium green, with a darker green central stripe.

Fully mature larvae develop into pupae at the feeding site ❼. The moth emerges a few weeks later ❽. This pest can complete several generations in a single fruit-production season. For example, in Victoria there are three or four distinct generations each year; the number is governed by the climate (principally temperature).

Growing season

- First Generation
- Second Generation
- Third Generation
- Dormancy**
- Overwintering



Life cycle of lightbrown apple moth © I&I NSW

Damage

Fruit

LBAM prefers sheltered feeding sites; hence damage is often restricted to green areas on the fruit's skin. This is in contrast to the damage caused by codling moth, which tends to be on the exposed, coloured side of the fruit. In addition to the fouling caused by webbing and excreta, fruit damage can be of three types:

- *Extensive shallow wounds.* Surface damage is common in short-stemmed varieties that form compact fruit clusters. Although this damage is superficial it may cover a wide area of the fruit surface and make the fruit unmarketable. The maturing damaged fruit produces a layer of corky tissue over the damage; this helps to prevent secondary infection by pathogens.
- *Stings.* Small circular stings are caused by young larvae biting through the surface of the fruit.
- *Internal damage.* Internal damage is much less common than surface damage. It occurs when young larvae enter the interior of the apple via the calyx. This type of damage can appear similar to that caused by codling moth, but there are a number of distinguishing characteristics. If the damage is due to LBAM there will be extensive silk. Additionally, the excrement produced by LBAM tends to be ejected from the fruit as discrete pellets that are scattered around the fruit surface, whereas codling moth excrement is seen as a sticky mass at the hole by which the insect gained entry to the fruit.

Leaves and buds

The early developmental stages (instars) of the larvae feed on leaf tissue and typically create small windows in the leaves. As the larvae become larger the damage becomes correspondingly more severe. The larvae have a preference for softer leaf tissue and tend not to eat the leaf veins; hence leaves become tattered or—in extreme cases—net-like. This damage is seldom of economic significance, even when severe.



Larvae of light brown apple moth feed on the surface of fruit and produce webbing (top) and, damage caused by light brown apple moth is shallow but often extensive, particularly around the base of fruit (above) © I&I NSW

Prevention and good orchard practice

Crop thinning and varieties

LBAMs prefer to feed in sheltered sites, and much of the damage they cause can be prevented by thorough thinning. Damage is most severe where large clusters of fruit are allowed to remain. Thinning also allows for better spray penetration and improves insecticidal control.



LBAM damage between pears in a cluster
© I&I NSW

Weed control

LBAMs survive through winter on a variety of broad-leaved weeds and pasture species. Commonly dock and capeweed are used as sources of both food and shelter over winter. Good control of broad-leaved weeds and maintenance of a grass sward through winter are likely to make it more difficult for LBAM to complete its life cycle and emerge in large numbers in spring. Good weed control will also help in the control of western flower thrips where this pest is also a problem. Tree lupins are also a favoured overwintering site, and removal of this species will also help to control apple dimpling bug (in mainland Australia).

LBAM also infests pasture species that may have been placed in the inter-row as green manure crops or to boost nitrogen. If LBAM has caused severe problems, be cautious about using cover crops that contain red and white clovers, lucerne and lupins.

LBAM can also move in from adjacent native vegetation or adjoining pasture that contains suitable host plants. This pest is particularly difficult to deal with under these circumstances, and in some instances it is more cost effective to tolerate some commercial damage.

Monitoring

Early-season control is essential. Careful monitoring allows orchardists to deal with potential problems before they cause crop loss. Lure pots containing a port-wine and water mixture can be used to monitor adult moth flight activity. However, as these lures also attract other moths, they are often difficult to interpret and may result in unnecessary insecticide applications.

Pheromone-based lures for LBAM provide more useful information, as they attract only the target species. They are commercially available in Australia. It is important to realise that these lures trap adult male moths and are therefore, at best, an indication of the imminent arrival of females. Flying moths are not directly responsible for crop damage and are extremely difficult to control using insecticides. Use pheromone trap catch information to increase the surveillance of leaf and fruit clusters for early-stage larvae. If insecticides are to be used, it is more effective to target the larvae than moths. Timing is critical. (see 'Responsible use of pesticides' p. 77) for guidelines on pesticide application timing.

The numbers of larvae and pupae on broad-leaved weeds such as docks and capeweed in early spring can also provide an indication of the threat posed by LBAM. If larvae and pupae are easily found it may be advisable to make an early spray application.

Management

Mating disruption

Products for mating disruption are widely available in Australia. The 'Mating disruption' chapter (p. 24) provides practical guidelines for the application of mating disruption in your orchard.

Responsible use of pesticides

In most cases it is not necessary to apply insecticides to control LBAM in regions where codling moth is endemic. Most insecticides used for codling moth are also registered for LBAM. Where a good program for codling moth control exists, LBAM is usually controlled without the need for additional sprays.

When in-season monitoring indicates the presence of larvae and/or pupae, a specific spray may be required. Suitable sprays are listed in the tables in Appendix 5: Using pesticides in IPM (p. 179).

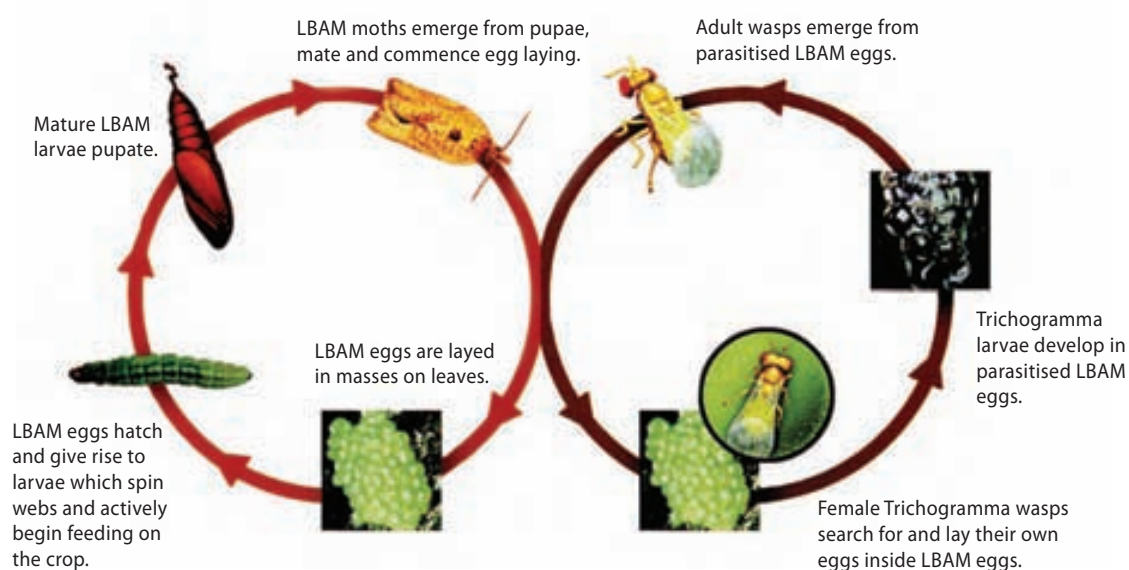
Control with insecticides may be difficult, as LBAM lives and feeds in sheltered positions. Insecticides must be applied at high volume with spray equipment that achieves maximum penetration into the tree canopy.

Biological control, biorational pesticides and organics

Before the introduction of broad-spectrum insecticides (principally to control codling moth), natural populations of biological control agents were able to play a role in reducing numbers of a variety of pest species, including LBAM. Broad-spectrum insecticides reduced the numbers of biological control agents and hence their importance in pest management. In recent years the introduction of insecticides that act more specifically on pest species has led to a re-emergence of biological control agents. Orchardists should look to proactively reduce their use of broad-spectrum insecticides as a means of encouraging naturally occurring biological control agents.

LBAM eggs, larvae and pupae are killed by various egg parasites (parasitoids), predators and diseases. The parasitoid *Trichogramma funiculatum* is often active during autumn. A disease caused by a nuclear polyhedrosis virus has been known to decimate local populations of LBAM. Spiders and European earwigs (*Forficula auricularia*) are also important predators.

Many insect biological control agents such as *Trichogramma* are now commercially available (see 'Appendix 3: Suppliers of biological control agents' p. 171). They can be released inundatively to supplement natural populations. Because these biological control agents are living organisms their suitability for specific areas may vary. In some cases they may fail to become established in other areas, they may need periodic replacement as their populations decline, or they may become established and provide ongoing pest control.



How Trichogramma intercepts the life cycle of lightbrown apple moth.

Richard Llewellyn, BioResources Pty Ltd

Longtailed mealybug

IPM quick facts

- Longtailed mealybugs hide in sheltered spots on the tree (including in the fruit calyx) and contaminate fruit with honeydew and sooty mould.
- The first developmental stage is called a crawler because it is very mobile. If pesticides are necessary, this is the stage at which they should be targeted. Timing is critical.
- Native, naturalised and commercially available biological control agents may be effective. Always consider the off-target effects of pesticides before application.



David Cappaert, Michigan State University

The pests and their impact

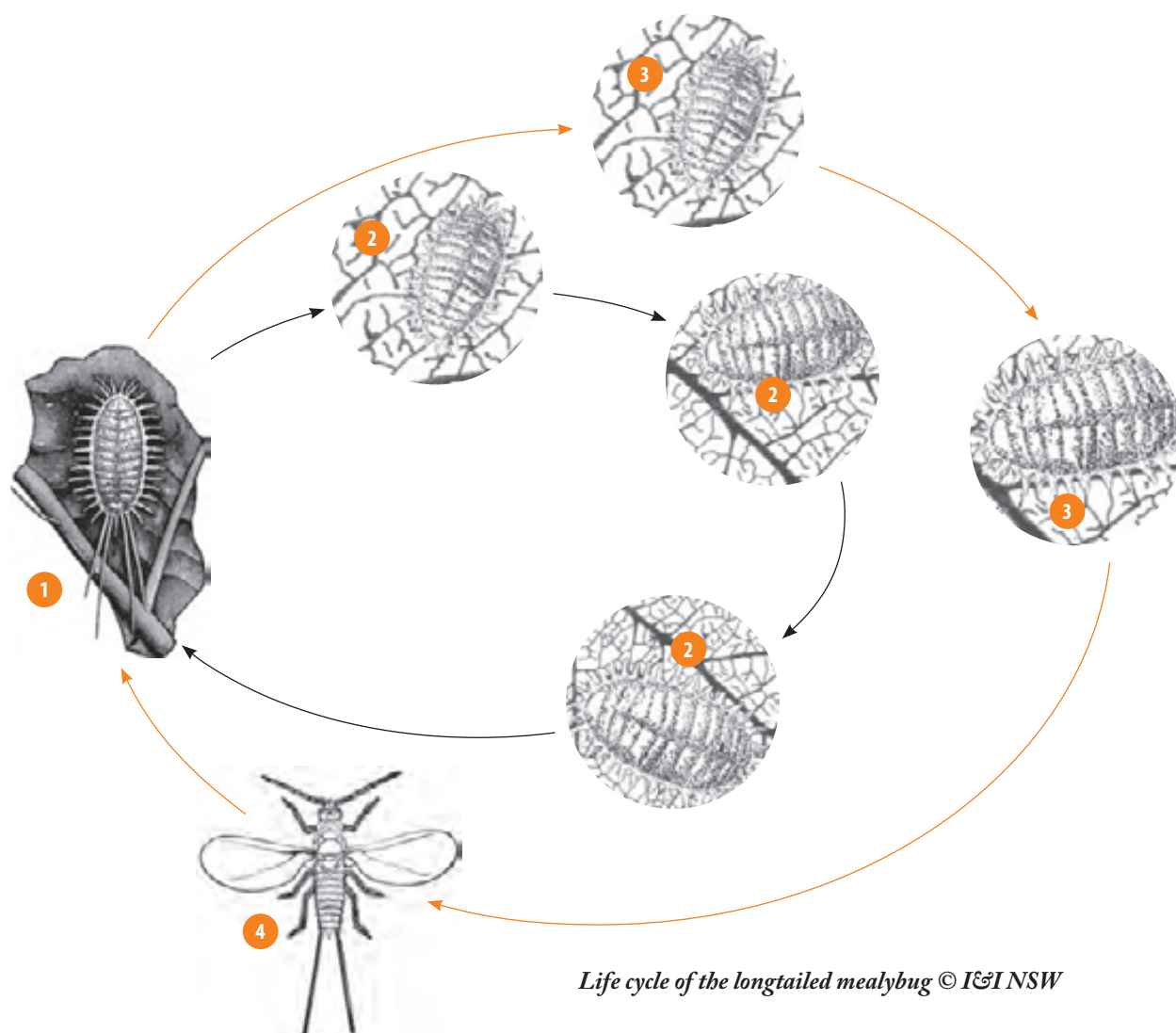
Longtailed mealybugs (*Pseudococcus longispinus*) are serious pests of a wide range of horticultural crops in Australia, including citrus and grapes. Although they are recorded as a pest of apples they are a more serious problem on fresh and canning pears.

They are primarily a concern in the Murray River irrigation areas. Although they are reasonably widespread in NSW, their numbers rarely build up to pest abundance. This mealybug is relatively rare in Queensland. Obscure mealybug, *Pseudococcus viburni*, is an important pest species in South East Queensland. This species and longtailed mealybug are important in some apple orchard regions in Western Australia.

Life cycle

Adult female mealybugs are about 3 mm long and elongated oval in shape. They are covered in a white mealy (waxy) secretion and are capable of moving sluggishly around the host plant ❶. Waxy filaments extend from around the female's body: the two at the posterior end are elongated, hence the name 'longtailed mealybug'. Nymphs, not eggs, emerge from the female; about 200 nymphs hatch just before or during laying and shelter en-masse under the parent female for a few days before dispersing. Male and female nymphs pass through slightly different developmental stages. However, the first developmental stage (or instar) is about 0.3 mm long; it is very mobile and can be found in all parts of the tree. Because of its mobility it is commonly called a crawler. First instar crawlers are the most likely stage of the life cycle to be affected by insecticide applications. Early-stage nymphs can also move from tree to tree on the wind and by visiting insects and birds, and on the clothing of orchard workers. Female nymphs pass through three stages, which are essentially smaller versions of the adult ❷.

The male nymph passes through only two developmental stages (which are similar in appearance to those of the female nymph) ❸ before spinning a white cocoon and becoming pupae. Shortly after pupation the winged males emerge ❹; they later find and mate with the much larger wingless females.



Life cycle of the longtailed mealybug © I&I NSW

Two aspects of the life cycle are particularly important when considering management of this pest:

- The crawlers are highly mobile, occupy all parts of the tree and are exposed.
- Longtailed mealybug tends to seek shelter under bark and in crotches during other stages of the life cycle.

It is therefore difficult to control the pest throughout the majority of its life.

This life cycle is repeated a number of times during a single season. Among other factors, temperature is important in determining the number of generations. There are generally three generations in South Australia and three or four generations in Victoria and NSW.

Beyond the number of generations, it is important to consider whether these generations are separate. Where generations overlap, late instar nymphs and adults are likely to be in sheltered positions throughout the season. This makes control very difficult and makes early-season pesticide applications critical.

Hot, dry conditions are unfavourable for population increase, and infestations are not likely to be serious when these conditions are encountered during early spring.

Damage

Feeding damage and contamination

Mealybugs insert their piercing, sucking mouthparts into plant tissues to feed. This feeding can weaken trees. Infested plant parts may be spotted, curled, or wilted. Infestations reduce the vigour and growth of foliage. Mealybugs occasionally feed on the calyx end of maturing pear fruit, which may become prematurely soft as the pear ripens. Mealybugs that shelter in the calyx end of fruit are extremely difficult to remove by the present washing methods. Contaminated consignments are rejected by canneries and the fresh market.

Honey dew and sooty mould

Honey dew is a sticky, sugary substance produced and exuded by mealybugs (and other sucking insect pests) as they feed. This substance covers both the feeding site and plant parts below the feeding site upon which it falls. Honey dew provides a nutritive base for a number of different types of fungi, which become black and soot-like as they mature on the plant surface. Depending on the density of the insect infestation and subsequent honey dew production, this sooty mould can appear as peppery spots or as a contiguous black coating. The majority of this sooty mould can be washed off, but typically some remains and renders the fruit unfit for the fresh market.

Similar damage

Many sap-feeding insects produce honey dew, which subsequently results in sooty blotch contaminating plant surfaces, including the fruit. The presence of sooty mould indicates the presence of mealy bugs but is not diagnostic.

Prevention and good orchard management

Sanitation is important in field control. Mealybugs can disperse very effectively and inhabit sheltered positions throughout the tree. Infested material should not be used as mulch, but should be removed from the field and destroyed. This will be helpful but is unlikely to provide adequate control.

Control movement in the orchard. As far as possible, limit movement in infested blocks and visit them last. Where possible, pick infested blocks last and avoid moving from infested blocks to blocks that contain varieties that mature later. As with mites, mealybugs are worse on dusty trees. Avoid vehicle movement on trees on the windward side of infested blocks and, where possible, wet tracks down regularly.

Monitoring

It may be possible to detect mealy bugs during dormancy by checking under bark or other sheltered places for overwintering larvae or adults. It is more likely that mobile nymphs (crawlers) will be seen early in the season, as their development is synchronised with the arrival of warmer weather. Carefully monitor mealybug by collecting two spurs from each monitoring tree several times during the period from finger bud to cluster stage. Early monitoring is very important in order to properly time any insecticide applications if they are necessary.

Monitoring later in the season can provide an indication of the management necessary for next season, but control during the current season is unlikely. Look in the calyx of the developing fruit during harvest at weekly intervals and record the presence of any mealybugs.

Responsible use of pesticides

Before using insecticides to control longtailed mealybug it is important to be sure that the damage they are causing warrants the risk of side-effects. Natural biological control agents are often active against long-tailed mealybugs (see 'Biological control, biorational pesticides and organics' p. 82), and the insecticides registered for use against this pest are very likely to kill them and other beneficial species.

Control of longtailed mealybug with insecticides is difficult, but possible. Timing is crucial. Because later nymphal and adult stages aggregate in sheltered positions (see 'Life cycle' pp.79–80), it is important to time spray application to contact the mobile first nymphal stage. Monitor wood for the presence of overwintering longtailed mealybugs, but do not spray until large numbers of young nymphs emerge in spring. Apply pesticides to near the point of runoff to all above-ground parts of the tree between green tip and the start of flowering. It may be necessary to make a second application 10 to 14 days after the first, but do not spray after flowering has begun.

Biological control, biorational pesticides and organics

There is often a resurgence of mealybug activity after the application of an insecticide. This suggests that natural biological control agents may regulate the number of pests. Known predators of longtailed mealybug that are common in Australian orchards include larvae of the native green lacewing (*Mallada signata*). It is possible to purchase larvae of this biological control agent, but if reasonable numbers of lacewing eggs are seen during monitoring it may be possible to promote natural populations. In addition to the need to carefully consider pesticide application, flowers should be promoted in the orchard, as adult lacewings feed on nectar (but be aware of thrips if late in the season).



Lacewing larvae

Richard Llewellyn, BioResources Pty Ltd

A coccinellid beetle, *Cryptolaemus montrouzieri* (the 'mealybug destroyer') was introduced into Australia in 1894 to control green shield scale in citrus. Both adults and larvae feed on longtailed mealybugs. This predator is most successful in sheltered agriculture (e.g. in greenhouses) but can be reasonably successful in orchards if used well.



Cryptolaemus, 'the mealybug destroyer'

Richard Llewellyn, BioResources Pty Ltd

There are a number of other native or naturalised predators of mealybugs that can be important control agents. The encyrtid wasp *Anagyrus fusciventris* parasitises longtailed mealybug and is the most abundant predator of longtailed mealybugs in the Murray River region of Victoria and South Australia.

There is some evidence to suggest that ants play an important role in protecting mealybugs from natural biological control agents. Ants feed on the honey dew produced by mealybugs, and it has been suggested that they attack and kill biological control agents so as to increase the security of this food source. Ant control is likely to increase the number of natural predators and, in turn, reduce the number of mealybugs.

Mites:

Two-spotted mites, European red mites, Bryobia mites

IPM quick facts

- Four types of pest mites are common in Australian apple and pear orchards: two-spotted mite, European red mite, Bryobia mite and the eriophyid mites (pear leaf blister mite). The eriophyid mites are dealt with elsewhere in this manual (see 'Pear leaf blister mite' p. 148)
- Mite problems can be minimised by reducing dust and making sure that trees are not water-stressed.
- There are well-established monitoring techniques for pest mites, and pesticides should be applied only when monitoring indicates that damage is likely. This reduces unnecessary spraying and avoids the potential for mites to develop resistance.
- Endemic and introduced biological control agents exist for all three pest species; the activity of these agents can be optimised by reducing applications of pesticides that are toxic to them.

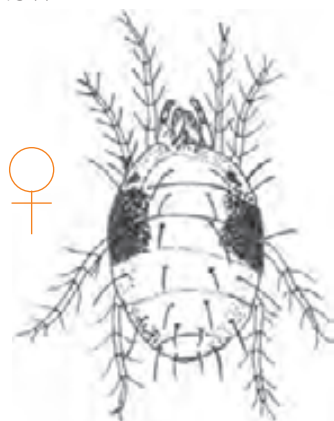


© I&I NSW

The pests and their impact

European red mite (ERM; *Panonychus ulmi*)

Adult females are about 0.4 mm long and rounded and dark maroon. Their dark red colour contrasts with the green of the foliage, making them obvious to the naked eye. There are several rows of prominent whitish curved spines on the body. The spines originate from pale, raised lumps on the body. Adult males are smaller and less numerous than females and tend to be yellowish, rather than dark red. They look flatter and have a pointed triangular abdomen.



Two-spotted mite (left), European red mite (centre), Bryobia mite (right) © I&I NSW

Bryobia mite (Bryobia rubrioculus)

Adults are relatively large (0.5 mm long), broad, flat mites with long legs, the first pair protruding well in front of the body. The colour is usually deep reddish brown but may be deep greenish-grey. Bryobia mites are usually pressed flat against the leaf surface.

Two-spotted mite (Tetranychus urticae)

Adult females are approximately 0.6 mm long, oval and pale green or yellowish green, with a dark spot on each side of the body. Adult males are a little smaller and less abundant than females. Males have a triangular pointed abdomen and look flatter.

Life cycle

Most mites have similar life cycles. Adult females tend to be approximately half a millimetre long, so they are just visible to the naked eye. Females lay small eggs that hatch into six-legged larvae. After they finish developing, larvae metamorphose into eight-legged proto-nymphs. These in turn grow and become deutonymphs and finally adults, also with eight legs. Between each of the immature stages is a resting stage, or nymphochrysalis, in which the mites become motionless and shed their skins. The old skin forms a glossy cocoon-like structure around the mite as it transforms to the next stage.

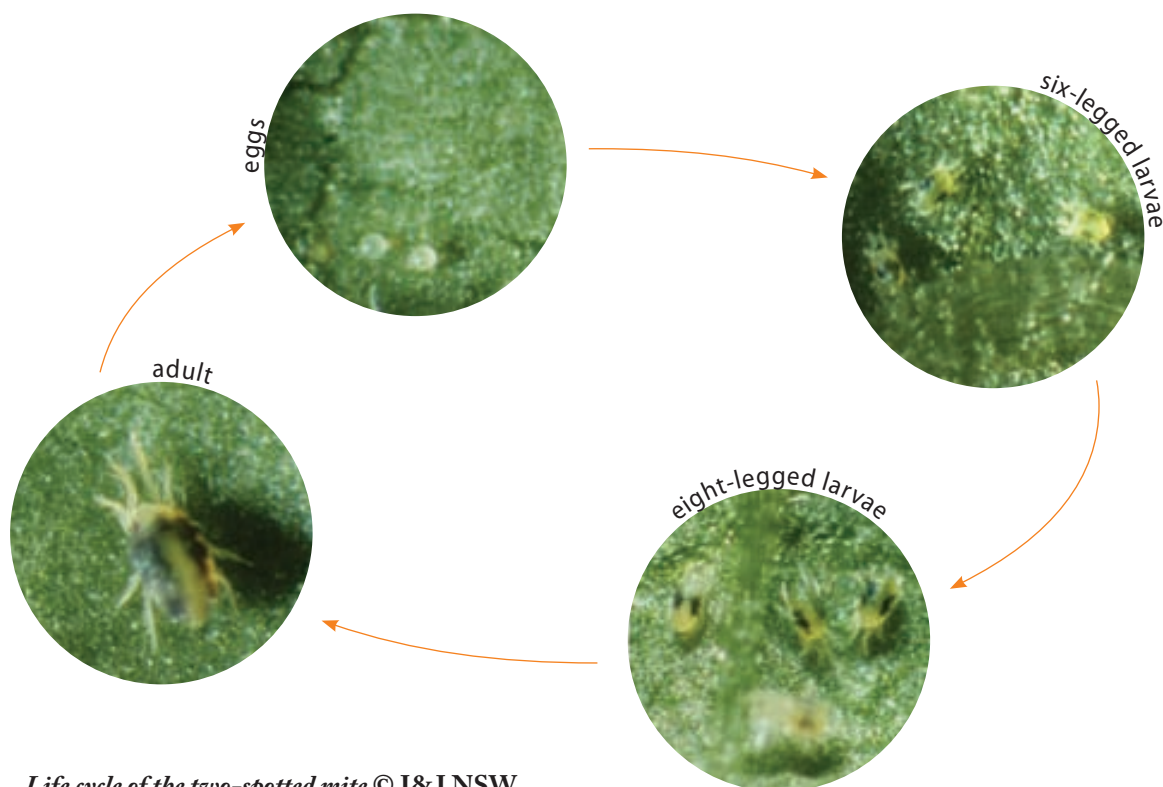
The rate of development of mites depends on the temperature. Pest mites are usually a more serious problem in hot years than mild ones.

Although all of the mites dealt with here have similar life cycles, the following points are relevant in the context of IPM.

European red mite

All life stages of the ERM are red (including eggs), as are those of Bryobia mite, distinguishing them from two-spotted mite. The presence of a slender stalk rising from their top centre further distinguishes ERM eggs from Bryobia mite eggs. ERM survives through winter as dormant, onion-shaped, bright red eggs laid in dense clusters on the under-surfaces of branches and twigs of trees. These eggs hatch in the period between green tip and pink. Subsequent egg-laying during the summer occurs on the undersides of leaves. Early in the season, ERMs are found mainly on the under-surfaces of leaves.

ERM prefers cooler, moist conditions. It was first identified in Western Australian apple orchards in January 2005, having been present in all eastern States since at least 1954.



Life cycle of the two-spotted mite © I&I NSW



European red mite eggs Plant Pathology Archive, University of Georgia

Bryobia mite

Bryobia mites overwinter in the egg stage. Eggs hatch from early September to mid-October, depending on the spring temperatures and location. The mites pass through several generations each season. Their development is favoured by hot, dry weather and hindered by wet weather.

Two-spotted mite

Two-spotted mites survive through winter as diapausing, motionless females, usually under rough bark scales at the bases of apple or pear trees, on groundcover plants, and in ground litter and trash. Development restarts in spring and becomes more rapid in the warm to hot conditions of summer. Adult females are pale green or yellow-green, with a dark green spot on each side of the body. Adult males are a little smaller and less abundant than females. They have a triangular pointed abdomen and look flatter.

Eggs are laid on the under-surfaces of leaves.

Populations can build up very quickly particularly in warm, dry weather. Females can lay up to 200 eggs (average 70) at a rate of 3 to 14 per day during their life span of 3 to 4 weeks. In warm conditions the time from egg to adult is 7 to 14 days, and many overlapping generations occur each season. Females spin fine webbing, which forms sheets over foliage in heavy infestations. As foliage quality declines in heavily infested trees, adult mites can disperse on wind currents to foliage on other trees.



Diapausing female two-spotted mites (inset) and adult two-spotted mites and eggs I&I NSW, © Richard Llewellyn, BioResources Pty Ltd

Damage

Pest mites cause damage by sucking the contents from the leaf cells of a wide range of host plants including pears and apples. Generally as a result of this feeding leaves turn brown and sometimes fall. In severe infestations trees can be badly defoliated, with small, poorly coloured fruit. Early season infestations may reduce the size of crops in the following season by inhibiting the development of fruit buds.

There are subtle differences in the damage caused by the different species of mites. These differences can provide evidence of the type of mite present enabling application of appropriate management.

European red mite

Defoliation of pear trees is more common than for apple trees following European red mite infestation. In pears feeding causes leaves to lighten in colour, becoming mottled or stippled. As infestations become more severe leaves develop a characteristic bronzed appearance.

In hot weather European red mites can cause pear leaves to appear burned. The leaf blade or its entire surface may turn brown and dry. Leaf burn can even occur after mites have been controlled if high temperatures occur after feeding damage. Severe mite infestations and burning can cause substantial defoliation. In turn this is likely to result in bloom occurring in Autumn and a subsequent reduction in yield in the following year.

Bryobia mite

Damage due to *Bryobia* mites is usually not considered as serious as that caused by two-spotted mites or European red mites. *Bryobia* mites feed on the upper surface of the leaves, sucking the contents from leaf cells. Damage from this feeding appears as whitish grey spots giving the leaf a stippled appearance. Rarely newly emerged leaves can be severely affected, discolour and fail to grow. Fruit growth is rarely affected.

Two-spotted mite

For apples, the early signs of two spotted mite damage look similar to the damage caused by *Bryobia* mite. The leaves become stippled and pale green. With time the leaves turn yellow with bronzed areas. Damaged leaves frequently fall and where infestations are severe almost complete defoliation can occur. Where mites are abundant the tree terminals become covered in copious amounts of fine webbing.

For pears, two-spotted mite may cause scorching and dropping of leaves in periods of hot, dry weather, particularly in shallow soils of poor moisture-holding capacity. This effect can be produced by relatively few mites.

Similar damage

The speckling caused by *Bryobia* mite and initially by other pest mites can resemble damage caused by leaf hoppers (see 'Apple leafhopper' p. 141).

Iron deficiency causes yellowing of the leaves. However, with iron deficiency, the major leaf veins retain their deep green.

In either case, close inspection with a hand lens will show the presence of mites where there is stippling.



Apple leafhopper damage © I&INSW

Prevention and good orchard management

Limiting dust

Mite infestations become worse when trees are dusty. When the weather is hot and dry, limit orchard traffic as much as possible and always drive slowly so as to limit dust; where possible drive on the downwind side of blocks. Where water is available, wet down tracks.

Ground cover and weeds

Maintaining healthy, green ground cover discourages mites in two ways. It reduces dust (see 'Limiting dust' on this page) and provides an attractive alternative habitat for mites that might otherwise infest trees and, in association with pest mites, for predators (including predatory mites) that may also be present. If mites have been a problem in the past it is advisable to apply herbicides to weeds before the trees develop leaves. If herbicides are applied later, mites may be forced from the dying weeds into tree canopies. Take particular care to control tall or climbing weeds (e.g. morning glory) that provide a bridge between weeds and trees.

Note that, in orchards managed using IPM, mites are seldom in large numbers in weeds because of the large number of biological control agents that can be used.

Irrigation

Trees under water stress are more likely to become infested with mites than those that are well irrigated. Keep trees appropriately irrigated. Although overhead irrigation or irrigation that wets the lower part of the tree can reduce mite infestations, it is not recommended. These forms of irrigation are inefficient; they waste water and can often lead to other problems such as diseases.

Varieties

Leaves on European pears are more sensitive to mite feeding than those on apples or Asian pears. During the early part of the season as few as one mite per leaf can cause serious damage to European pears, whereas in apples 10 to 20 mites per leaf are unlikely to cause economic damage.

Bartlett and Comice pears are particularly prone to mite damage.

Although all apple varieties can be damaged by mites, Golden and Red Delicious and Fuji are more susceptible than others.

Delaying the damage to 'condition' leaves

Both apples and pears are able to withstand higher populations of mites in the mid-late season than during the early part of the season. This is particularly the case if mite infestations have built up slowly, allowing the leaves to become conditioned to their feeding. Conditioned leaves are able to tolerate two or three times as many mites as leaves that experience sudden outbreaks early in the season. Mite control to suppress numbers early in the season is vital.

For apples, European red mite eggs on spurs, laterals and main limbs should receive an application of horticultural mineral oil during the period from green tip onwards. These eggs become more susceptible to oil as they approach hatching. This usually occurs around flowering. Most spray oil products are registered for use only up to green tip, and generally at 2%. A small number of horticultural mineral oil products can be used later at 1%. The preferred timing for application is just after full bloom.

Monitoring

Appropriate management of mite infestations early in the season is critical. Early-season monitoring should concentrate on the inner, lower part of the tree, as this is where infestations often begin.

Monitoring and sampling once a fortnight should be sufficient but, if populations are close to thresholds, weekly sampling may be required.

A closer watch on mite populations is needed in hot, dry weather, particularly as they approach critical levels. The decision to spray should allow for explosive increases in hot weather. It is important to remember that quite high numbers of predators are needed to control pest populations approaching damage thresholds. It is better to err on the side of caution and apply a spray than to wait too long and allow damage to occur.

Various Australian Departments of Agriculture recommend slightly different methods for monitoring to determine whether management should be applied to control mites. The majority of these techniques monitor both pest mites and predators. To use these techniques it is necessary to be able to identify both pest and beneficial species. Orchardists should trial the various techniques and use whichever provides the most reliable mite control.

Technique 1:

(State of Victoria, Department of Primary Industries, D. Williams)

For two-spotted mite infestation of apples

- Select 10 trees at random in each block.
- Sample five leaves from low down in the centre of these trees—that is, sample a total of 50 leaves.
- Use a hand lens to find out whether any two-spotted mites and predators are on each leaf. Most *Galendromus occidentalis* (a mite which preys on pest mites; see 'Biological control, biorational pesticides and organics' p. 92) tend to be found close to the midrib on the underside of the leaf. You do not have to count the numbers present—just the numbers of leaves they are on.
- A technique for sampling and mite population assessment is provided on p. 91 ('Mite population assessment').

- Record mite presence or absence on each leaf:
 - » If fewer than 45 leaves (90%) are infested by active stages of two-spotted mite, a miticide application is not required
 - » If more than 45 leaves (90%) are infested by two-spotted mite and fewer than 35 leaves (70%) have active stages of predators (this includes small and adult predators), apply a miticide.
 - » If more than 45 leaves (90%) are infested by two-spotted mite and more than 35 (70%) have active stages of predators, a miticide is not required, because control of two-spotted mite by the predator should occur within 2 weeks.

For two-spotted mite infestation of pears

Pear growers should use the same sampling technique but convert the % leaves infested value to cumulative leaf-infested days (CLIDs) (see table below). Because pears are more sensitive to mite infestation, CLIDs accounts for the length of time for which an infestation has been occurring.

Technique 1: Calculating cumulative leaf-infested days (CLIDs) in two-spotted mite infestation of pears

$$\text{CLIDs} = \frac{\% \text{ leaves infested last week} + \% \text{ leaves infested this week}}{2} \times \text{number of days between samples}$$

A CLIDs calculation may look like this:

	Date	% leaves infested (LI)	Average % LI	No. of days between samples	Average % LI × no. of days	Running (cumulative) total (CLIDs)
Fortnightly	20.12.09	0	0	14	0	0
	03.01.10	0				
Weekly			1	7	7	7
	10.01.10	2 (1 leaf)				
			3	7	21	28 (21 + 7)
	17.01.10	4 (2 leaves)				
			5	7	35	63 (35 + 28)
	24.01.10	6 (3 leaves)				
			10	7	70	133 (70 + 63)
	31.01.10	14 (7 leaves)				

These units are calculated after each leaf sample is taken, and a running or cumulative total is kept for the season. The CLID figure is an excellent guide to the mite pressure experienced by trees in a block. Leaf scorch develops when certain CLID levels are exceeded. This relationship can be used to indicate damage thresholds. These will indicate when leaf scorch damage will develop *before* it actually occurs and will allow appropriate control to be applied *only if necessary*:

- 1% leaf scorch will develop at approximately 1000 CLIDs
- 5% leaf scorch will develop at approximately 1500 CLIDs

- 10% leaf scorch will develop at approximately 2400 CLIDs
- 20% leaf scorch will develop at approximately 3000 CLIDs.

Remember that the % leaf scorch damage figure is averaged over the whole block. Some individual trees may have significantly higher levels of damage, and others lower or no damage.

The decision to apply a miticide is then at the discretion of the orchardist and depends on the amount of damage that he or she is willing to tolerate and the economic loss that he or she is willing to suffer.

Technique 2:

(NSW Department of Primary Industries, Bower and Thwaite 1995)

This technique is particularly useful if the infestation is patchy. Walk through the orchard and identify any hotspots of mite activity. Visible symptoms such as bronzing and leaf fall are usually sufficient to indicate infestation, but a hand lens should be used to confirm that the cause is mites. Rate the trees with the worst infestation according to the table below.

If there are two or three patches of trees with a rating of three or greater in a block where most trees do not exceed a rating of 1, the entire block would receive a rating of three.

If this assessment gives a rating of 3 or more, a miticide should be applied, unless it is clear that most of the block is under biological control. In the latter case, it may be worthwhile applying a spot spray in sections where predators are lagging. A spray should also be considered when most trees have been rated at 2, as it will not be long before many will reach a rating of 3, if predators are lagging.

Technique 2: Rating trees for mite infestation

Rating code	Description	Visible damage
0	Nil	No damage
1	Trace	Detectable by close inspection
2	Slight	Some bronzing in inner, lower areas of tree
3	Moderate	Obvious bronzing confined to lower quarter of the tree
4	Severe	Bronzing extending to halfway along limbs
5	Extreme	Extensive bronzing and defoliation

Technique 3:

(NSW Department of Primary Industries, Bower and Thwaite 1995)

For apples

- Sample two leaves from each of the sample trees in the block.
- A technique for sampling and mite population assessment is provided (see 'Mite population assessment' p. 91).
- Assess each sample leaf for the presence or absence of pest mites and predators. There is no need to count the number of pests or predators. For speedy assessment, place each leaf in one of four piles after examination.
- The four piles correspond to the four categories in columns A, B, C and D in the following table.

Technique 3: Assessing each sample leaf for the presence or absence of pest mites and predators

Sample date	A Zero mites or predators	B Pest mites only	C Both pest mites and predators	D Predators only	E Total leaves	% pest mites	% predators
20.12.09	32	12	4	2	50	32	12
27.12.09							

After you have examined all of the leaves, count the number in each category and calculate the percentages with pest mites or predators.

$$\% \text{ predators} = \frac{(D+C) \times 100}{E} = \frac{(2+4) \times 100}{50} = 12\%$$

$$\% \text{ pest mites} = \frac{(B+C) \times 100}{E} = \frac{(12+4) \times 100}{50} = 32\%$$

The data obtained can be used to decide on the need for a miticide application according to the following table.

Technique 3: Deciding whether to apply a miticide

Percentage of leaves occupied by...		
Pest mites	Predators	Action
0–49 Very low chance of economic damage	0	Check again in 2 weeks.
50–64 Low chance of economic damage	0–5	Effective biological control is unlikely. Apply a miticide at the non-IMC* rate.
	6–20	Biological control may succeed. Check again in 1 week.
	>20	Effective biological control is imminent or is occurring. Check again in 1 week.
65–79 Moderate chance of economic damage. Damage imminent	0–5	Effective biological control is unlikely. Apply a selective miticide at the non-IMC rate, if applicable.
	6–40	Effective biological control is unlikely to succeed before damage occurs. Apply a selective miticide at the IMC rate, if applicable.
	>40	Effective biological control is imminent or is occurring. Check again in 1 week.
80–94 High chance of economic damage	0–10	Apply a selective miticide at the non-IMC rate.
	11–50	Apply a selective miticide at the IMC rate, if applicable.
	>50	Effective biological control is imminent or is occurring. Check again in 1 week.
95–100 Very high chance of economic damage	0–10	Apply a selective miticide at the non-IMC rate.
	>10	Apply a selective miticide at the IMC rate. Biological control is unlikely to occur quickly enough to prevent excessive damage, which may already be occurring.

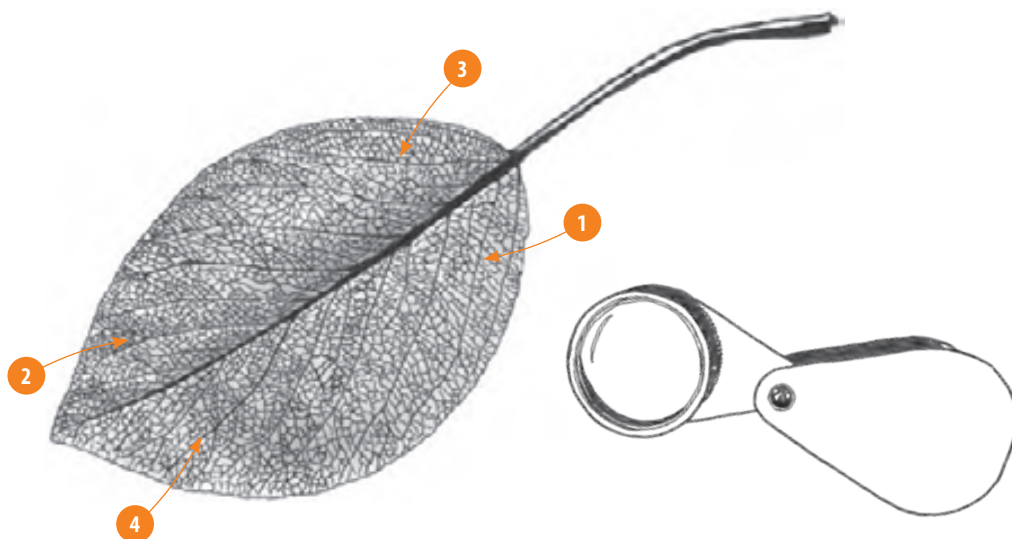
* IMC = integrated mite control. IMC rates are specified on miticide labels.

Mite population assessment

Sampled leaves should be dry and mature and come from the lower part of the tree, below head height. Pick leaves at random; don't deliberately select heavily infested ones. Put them in a paper or plastic bag and transport them in a foam cooler or portable refrigerator. It is essential to keep the samples cool; don't leave them in the sun or in a car. Prolonged exposure to the sun causes leaves to turn brown and may kill mites, making counting very difficult. The sample bag should be labelled with the orchard name, block number and sample date.

The leaf samples should be stored in a domestic refrigerator or coolroom at 4 °C before examination. If the leaf samples are in paper bags, place these in larger plastic bags before storage to prevent drying out. Samples should be assessed within 2 days of collection.

The underside only of each leaf is examined individually, using a binocular microscope at 8× to 10× magnification or a hand lens (which can be purchased from most rural suppliers). Each leaf should be scanned systematically; pay particular attention to the area next to, and below, the midrib, where predators may be sheltering. Lay the leaf on a firm surface. The leaf should be closely examined in four sweeps, as shown in the diagram below.



Examine the leaf for mites in four sweeps, using a hand lens or microscope © I&I NSW

Management

Responsible use of pesticides

Delay application of miticides for as long as possible, as indicated by monitoring. This will allow predatory mites the maximum opportunity to control pest mites. If an application is necessary, consider whether a spot-spray of 'hot-spots' is likely to give sufficient control.

Select miticides that are likely to have the minimum effect on populations of predatory mites and other biological control agents.

Managing resistance

Mites have proven to be one of the most difficult groups of pests to control, largely because of their ability to develop resistance to pesticides. Pesticides that are at first manage mites well lose their effectiveness and need to be replaced. Mites can develop resistance very quickly; therefore, the use of pesticides must be carefully managed to ensure that mites are not continuously exposed to the same type of pesticide.

Two rules must be strictly followed to avoid the development of resistance:

- Miticides are allocated groups depending on their mode of activity. The group information can be found on the label. This information is also in this manual (see 'Appendix 5: Using pesticides in IPM' p. 179) Never apply more than one miticide from the same group during a single season.
- Never apply consecutive sprays of miticides from the same group between seasons.

Biological control, biorational pesticides and organics

Naturalised biological control agents

A large number of types of predatory mites and insects are likely to be present in orchards without deliberate introduction. Although some of the species below can be commercially obtained, they tend to be persistent in well-run IPM orchards, and their numbers should not require replenishment.

Ladybird beetles

Both adult and larval ladybird beetles are predators. Younger larval stages tend to pierce their prey and ingest their body fluids, whereas older larvae and adults chew and consume their entire prey.

In general, ladybird beetles are easily recognised by their shiny, half dome shape and short, clubbed antennae. They are often brightly coloured, with contrasting spots. Ladybird larvae are elongated, often colourful and have long legs and feeding parts. They are active and voracious predators.

Stethorus beetles

Stethorus is a tiny (2-mm diameter), jet-black ladybird beetle. The larvae of this beetle have dull grey hairs, giving them a velvety appearance. Stethorus is a voracious feeder on many species of mites and is particularly effective against two-spotted mite. It is likely to suppress mite populations if it is present at high enough levels early in the cropping season.



Stethorus beetle © I&INSW

Hoverflies (*Syrphidae*)

Adult hoverflies have black and yellow bands around their abdomens and are often seen hovering above flowers early in the season. Adults feed on pollen and nectar and make no contribution to biological control at this stage of their life cycle. However, their larvae feed on mites. The presence of large numbers of hoverflies early in the season is likely to mean fewer mites during the warmer months.

Female hoverflies lay their eggs among colonies of mites. The legless maggots that emerge grope along plant surfaces, lifting their heads in search of prey. When they find a mite they seize it, suck it dry and discard the skin.

Lacewings

Both green and brown lacewings are common in Australian apple and pear orchards—particularly those using IPM. Adult lacewings are approximately 15 mm long and feed on nectar and pollen.

Female lacewings lay their eggs on long stalks. A single female lacewing can lay up to 600 eggs during her 3- to 4-week adult life. Larvae hatch from the eggs and grow from 1 mm at first emergence up to 8 mm.



Adult lacewing (top) and stalked lacewing eggs (above) Pia Scanlon, WA Department of Agriculture and Food; Richard Llewellyn, BioResources Pty Ltd

Lacewing larvae are generalist feeders and consume a wide range of orchard pests, including mites. Adult lacewings tend to fly at night and the larval stages are often camouflaged and inconspicuous. Therefore, monitoring for these insects should rely on the presence of stalked eggs early in the season.

Predatory mites

During the 1970s and 1980s Australian orchardists began to trial predatory mites to control pest mites. A number of species are now commercially available and their use has become common practice in many regions. Appendix 3 (p. 171) lists a directory of suppliers of commercial biological control agents. Effective use of biological control agents reduces the need for pesticide applications; this, in turn, slows the development of resistance and reduces the amount of pesticide residues present at harvest.

However, use of biological control agents is more complex than relying on pesticides. Growers need to be more aware of:

- the pest's biology
- the biological control agent's biology
- the crop's biology
- monitoring techniques and threshold population sizes of pest populations
- the implications of each course of action they take.

Effective IPM for pest mites requires orchardists to monitor predatory mites in addition to pest mites (see 'Monitoring' p. 87). IPM will succeed only where these predatory mites can be recognised.

There are three major predatory mite species in commercial orchards in Australia. All are resistant to organophosphate insecticides and a range of other chemicals used for pest and disease control.

Galendromus occidentalis (formerly *Typhlodromus occidentalis*)

Adult females are about 0.4 mm long, with a broad, rounded abdomen tapering gradually toward the pointed head region. The body has a more flattened appearance than that of two-spotted mite. Colour varies from white to cream or pinkish. *G. occidentalis* feeds mainly on the eggs and larvae of two-spotted mites. It will also prey on immature European red mite, but is a less effective predator on this pest. In the absence of mites, *G. occidentalis* adults will feed on pollen and may maintain themselves on apple leaves. However, immature predators cannot complete their development and females cannot lay eggs without feeding on mites or pollen.



Adult female Galendromus feeding on two-spotted mite. © CSIRO

Galendromus occidentalis overwinters as adult females in cracks in the bark and under bud scales. Females undergo diapause in colder districts but may remain active in warmer areas. Activity may start in early spring before budburst, and egg-laying will occur as soon as a source of prey is found and feeding has begun. The eggs are slightly larger than those of two-spotted mites. Females may consume an average of 10 two-spotted mite eggs per day and will themselves lay up to five (average about two and a half) eggs a day when food is abundant. Up to 50 eggs may be laid in a female's lifetime of 2 to 4 weeks. At 25°C a generation is completed in as little as 7 days, and there may be 10 or more generations in hot districts.

Galendromus occidentalis is usually found on the underside of leaves in association with its prey. They shelter close to the main vein and may be hard to see if they are tucked underneath. When they run out of food, adult females disperse themselves into the wind on a silk thread, achieving quite rapid dispersal within and between orchards.

***Galendromus pyri* (formerly *Typhlodromus pyri*)**

This mite is difficult to distinguish from the closely related *G. occidentalis*. Adult females have a slightly broader abdomen.

Galendromus pyri is a more effective predator of European red mite than *G. occidentalis*. It readily responds to the chemical stimuli associated with European red mite and feeds mainly on immature stages. It does not respond to the chemical stimuli from two-spotted mites but will eat them if they are encountered during random searching. A number of other pest mites are also eaten, including apple rust mite and Bryobia mite.

Notably, unlike *G. occidentalis*, *G. pyri* tends to remain on the tree when it runs out of prey mites, and dispersal between trees is much slower. *Galendromus pyri* is most useful in regions with significant summer rainfall, but it is still a very useful predator in other regions.

Phytoseiulus persimilis

Phytoseiulus persimilis is best suited to warm, humid regions but has been used successfully in the Goulburn Valley. This mite is only slightly larger than its pest mite prey but can be distinguished by its orange colouring and long, forward-facing front legs. When examined with a hand lens it can be seen moving much more quickly than its prey. The adult female is pear-shaped. The eggs are about twice the size of two-spotted mite eggs and are laid singly on the undersides of leaves among pest mite colonies. The immature predators are similar in appearance to *G. occidentalis*, except that they are more active and have a pinkish tinge.



Phytoseiulus persimilis female adult (left); two-spotted mite (centre); two-spotted mite egg (top right); and *Phytoseiulus persimilis* egg (lower right) Richard Llewellyn, BioResources Pty Ltd

This mite is an effective predator. A single mite can eat two female two-spotted mites per day or dozens of two-spotted mite eggs. Its levels should be monitored carefully. This species often needs to be reintroduced, as it is so effective that it consumes all of its available prey.

Phytoseiulus persimilis preys almost exclusively on two-spotted mite and its near relatives. It does not control European red mite.

Horticultural mineral oil

Horticultural mineral oils are particularly useful for controlling European red mite. They also favour the survival of predatory mites and are hence useful for IPM. Registration of horticultural mineral oil products varies among States. Carefully read the product label before making an application, particularly if your orchard is in Queensland or Tasmania. The use of horticultural mineral oils also varies between apples and pears.

Oil is more effective against European red mite eggs as they approach hatching. Egg-hatch usually coincides with flowering. Recent refinements in the manufacture of horticultural mineral oils have made them safer to apply without risking damage to blossom. Correspondingly label recommendations have been changed. Currently, label recommendations for the timing of application are:

- for pears: up to and including petal fall
- for apples: up to half green tip.

In any case, check the product label before making an application.

As with all applications of oil products, good coverage is essential. Slow tractor speed if necessary to cover the tree thoroughly. Unlike early-season two-spotted mite, European red mite eggs can be anywhere on the tree – not just in the lower portion.

Oil sprays are useful components of a good resistance management strategy. Their mode of action is physical (the oil blocks the mites' breathing apparatus) rather than chemical; therefore mites are unlikely to develop resistance to the oil.

Applying an oil spray to control European red mite should be based on the prevalence of the pest during the previous season and the presence of high numbers of overwintering eggs (as indicated by monitoring). If an orchard is known to have had a high population of European red mites (e.g. more than 40% of leaves infested) during the post-January period of the previous season, it is advisable to apply a registered oil product at the appropriate time.

The oil spray will at least delay the need to take further action against European red mite. If predatory mites are active, no further action may be necessary. At worst, a single knockdown miticide might be needed late in the season.

Acknowledgments

Some of the information in this chapter was derived with permission from the *Mite Management Manual: A practical guide to integrated mite control in apples* (Bower CC and Thwaite WG 1995, Published by NSW Agriculture, Orange).

Monitoring techniques were cited from the following works:

Bower CC, Thwaite WG 1995. *The Mite Management Manual*. NSW Agriculture, Orange

Williams D 2000. *Integrated Control of Twospotted Mite in Orchards*. Department of Primary Industries, Victoria. AG0157

Pear blossom blast

IPM quick facts

- *Bacterial blast is a problem in cooler pear production regions, particularly when they experience wet weather during an extended flowering period.*
- *As frost damage predisposes blossom to bacterial blast, any measure to prevent frost damage will also reduce damage from the disease.*
- *Control of bacterial diseases is difficult, and there are no registered pesticides for the control of this disease. Application of copper-based products for pear scab control may also help to manage blossom blast.*



Jay W Scheidt, Oregon State University
Extension

The pest and its impact

Pear blossom blast is a disease caused by the bacterium *Pseudomonas syringae*. The disease can become a serious problem in regions that commonly have cool, wet weather that persists during long, extended bloom periods. In Australia, orchardists in Shepparton and the Adelaide Hills have noted problems with pear blossom blast.

The most obvious damage caused by the disease is blossom death, which often results in reduced fruit set. As with all bacterial diseases it is difficult to manage, and there is good evidence that serious infections are usually followed by further problems in subsequent years in which weather favours the disease.

The disease almost exclusively infects pears. Although infection on apples is known to occur, symptoms are mild and of no economic significance.

Life cycle

The pathogen can live on a wide range of plant types without causing symptoms. During winter it commonly survives in the buds and leaf scars of pear trees. In spring, as leaf and fruit buds begin to develop and the weather becomes warmer, populations of the pathogen increase. Unless the weather becomes cool and wet, bacterial populations continue to survive and grow without causing disease symptoms. During this time, and subsequently, the bacteria are spread to neighbouring trees by wind-blown rain.

Blossom infection is favoured by cold, wet periods during bloom. Infection invades blossoms through natural openings within the flower. However, where the bacterium is present frost is more likely to form. The bacterium then uses the subsequent frost damage to enter the flower and cause disease.

The bacterium then survives on, and in, fruit and aborted blossom through the growing season.

Damage

Flowers

If buds are infected, they fail to open, dry out and die. After flowering, blast initially develops on the outer surfaces of the green portions of the blossom: the sepals, pedicels and receptacles. Small depressed, shiny black spots initially form and then coalesce to form large diseased areas. These areas become black, and if the weather remains favourable this blackening spreads to the entire flower truss. The entire spur is often killed.

These infections seldom progress past the base of the spur and are usually concentrated in the lower portion of the tree's canopy. Nashis tend to be more severely affected, as they often bloom earlier and are subject to more frost damage.

Shoots

In young trees, symptoms may also develop on the shoots when the outer bark separates from underlying tissue, giving the bark a papery appearance. This condition is sometimes known as blister bark.

Leaves

Although leaf infection is secondary in importance to blossom infection, the number of leaves can be quite severely reduced, particularly in Nashis. The symptoms are commonly no more than dark, depressed shiny leaf spots.

Similar damage

Late frosts during blossom can kill flowers and developing buds. The blackened, water-soaked appearance of frosted flowers is similar to that of flowers killed by bacterial blast.



Blossom blast infection on pears. In early stages the disease develops on the green parts of the blossom, including the sepals (left). The disease rarely spreads beyond the pedicels (above). © I&I NSW

Prevention and good orchard management

Varieties

Nashis are more severely affected than European pears. Apples are almost never infected.

Although all pear varieties are infected, susceptibility varies among varieties of European pear.

Research conducted in the USA has shown that, in general, green-fruited pear varieties suffer a higher incidence of blossom blight than red-fruited varieties. Although not all red-fruited varieties of pear available in Australia have been tested, it may be worth considering planting the following in blocks prone to bacterial blast:

- Red d'Anjou*
- Crimson Gem
- Sensation
- Forelle*
- Cascade.

* Tested experimentally in the USA (Whitesides and Spotts 2006)

In the USA the variety Corella is regarded as relatively resistant to blossom blast, but Australian orchardists report this as one of the varieties most prone to damage.

Preventing frost damage

The disease will be more severe where trees are frosted.

Anything that can be done to reduce frost damage will have flow-on effects in reducing damage due to blossom blight. Where fitted, use overhead irrigation or wind machines. Maintaining a clean weed-strip under trees also reduces frost damage. Orchards with a high, thick weed cover between trees can be more than 1.7°C colder than orchards with clean, moist, smooth floors.

Avoid planting susceptible varieties such as Nashi in frost-pockets.

Pruning

Pruning and destroying affected tissue helps to lower the amount of disease in the orchard in the future. Be extremely cautious. Do not prune during wet, cold and windy weather, and disinfect pruning tools before pruning disease-free blocks.

Monitoring

Once bacterial blast is seen it is too late to do anything about it during the current season. Pay particular attention where cool, wet weather persists during extended blossom periods. The disease's occurrence should be noted, because the disease is likely to recur in the same location next season. Extra management (frost protection) can then be applied to this area.

Management

Responsible use of pesticides

Bacterial diseases are difficult to control. Australian orchardists do not have access to a range of agricultural antibiotics (e.g. agromycin), and there are no copper products currently registered for the control of this disease on pear. However, application of various copper products to control pear scab may also help to manage bacterial blossom blight. These products should be applied at green tip. If extended wet weather occurs during blossom, additional applications (with caution) are allowed and are advisable. Caution should also be used when applying copper-based products to Winter Cole and Josephine pears, as damage may occur.

Biological control, biorational pesticides and organics

In the USA, New Zealand and other countries a wide range of biological control agents are available for control of pear blossom blast. Most of these products are primarily registered for control of fireblight. As fireblight does not occur in Australia there seems to be no commercial incentive for their import. Many are based on strains of the non-pathogenic *Pseudomonas fluorescens* bacterium and are compliant with local regulations governing organic production.

Pear slug, Pear sawfly

IPM quick facts

- *Monitoring and detection in early spring are important.*
- *Infestations develop more quickly when weather in early spring and late summer is hot.*
- *Infestations are more likely in orchards using mating disruption to control other pests.*
- *Where an insecticide application is necessary, choose spinosad.*
- *Because this pest's distribution is patchy it should be possible to control it by using targeted spot sprays*



© I&I NSW

The pest and its impact

The pear slug (*Caliroa cerasi*) is also known as the cherry slug or pear sawfly. Larvae feed on the leaves of a wide range of shrubs and trees. They cause most damage on pears and cherries, but they also feed on plums, apples, quinces, cotoneasters and hawthorns.

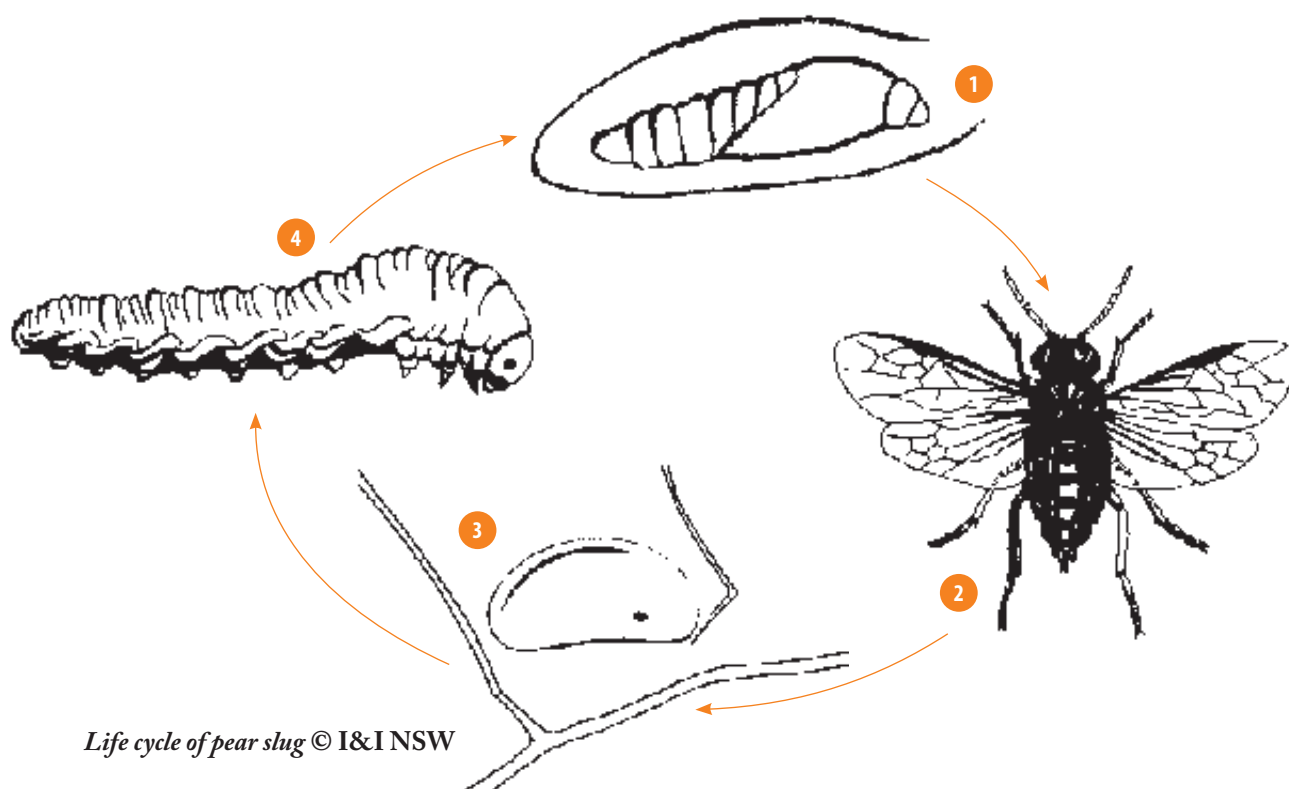
They are not true slugs but are the slug-like larvae of stingless wasps, called sawflies. The larval stage skeletonises foliage by feeding on the upper leaf surface, removing fleshy, green leaf tissue and leaving a network of fine leaf veins and paper-thin epidermis (the outer covering of the leaf).

Although the damage is unsightly, its effect on trees and productivity is variable. Infestation late in the season can cause trees to lose their leaves prematurely and reduce the amount of blossom in the following season.

In Australia there is anecdotal evidence that this pest is re-emerging as a problem as orchardists adopt IPM techniques such as mating disruption to combat major pests such as codling moth and lightbrown apple moth and reduce the number of broad spectrum insecticide applications.



Pear slug © I&I NSW



Life cycle of pear slug © I&INSW

Life cycle

This insect pest survives through winter as a pupa in a cocoon underground **1**. Adult, flying sawflies emerge in spring **2**. They are small (about 5 mm long), shiny black wasps. Mating takes place and female sawflies lay a single egg on the lower leaf surface of a suitable plant **3**. The upper portion of the canopy is the preferred laying site, and this is where damage is first seen (see 'Monitoring' p. 101). Pear sawfly eggs are oval-shaped, slightly flattened on one side, and very small (approximately 0.5×0.9 mm). Depending on the temperature, larvae emerge 9 to 15 days after laying and migrate to the upper surface of the leaf **4**. Newly emerging larvae (slugs) are pale and free from slime, and the head is light brown. As they begin to eat they grow rapidly and secrete a coat of slime, giving them a translucent yellow to black appearance. Older slugs turn olive green and may be lighter in appearance. They reach a maximum length of 0.5 to 1 cm. Fully mature larvae drop to the soil and burrow in to the ground to pupate in fragile cocoons. There are often two generations of this pest each season. The second generation usually matures more rapidly; because of this, tree damage is often more severe late in summer.

Damage

Leaves

Following the emergence of larvae, leaf damage occurs quickly. The first signs of damage are yellow spots on the upper leaf surface. As the larvae continue to feed these spots enlarge and merge. Feeding leaves only the net-like leaf veins and the epidermis (skin), and infested areas look bleached and tissue-paper-like. Some trees react to this damage by producing reddish brown pigments; in this case, entire trees may appear scorched. Severe infestations can cause premature leaf fall.

Although the damage looks unsightly, trees that are otherwise healthy can withstand several seasons of late-season infestation without undue adverse effects. However, trees may gradually lose thrift and productivity if:

- severe infestations occur over many years
- the weather is conducive to a rapid build-up of larval numbers early in the season. Warmer than usual springs will favour pear slug.
- young trees are not treated effectively.

Prevention and good orchard management

Encourage natural biological control agents

Pear slug never becomes a problem in many orchards. In these cases, natural biological control agents such as lacewings and hoverflies are usually responsible for keeping pest populations low. Encourage these natural predators and parasitoids.

Monitoring

Monitoring is an important element of pear slug control. Early detection makes eradication easier and reduces the risk of re-infestation in following seasons. This pest is most amenable to control during the larval (slug-like) phase of its life cycle. The larvae make easy targets, exposed on the upper leaf surface, but control must be applied early before substantial damage is done.

Pear slug should be included in formal monitoring schemes in orchards with a history of infestation (i.e. those in which the pest has caused significant damage during any of the last four seasons). Eggs are very small and almost impossible to distinguish from those of other (perhaps beneficial) insects. It is therefore vital to detect larvae on the top surfaces of leaves as early as possible. Begin to carefully examine shoots in monitoring trees shortly after leaves have emerged. Be particularly vigilant where spring has been unusually warm, as larvae will develop more rapidly under these conditions. Continue to monitor throughout the growing season, with renewed emphasis late in summer when a second generation of this pest may emerge if the first generation was not adequately controlled.

Management

Responsible use of pesticides

Pear slug infestations are easily seen (see 'Monitoring' on this page), and damage tends to be patchy throughout the orchard. It is often possible to spot-spray infested trees, thus avoiding the expense and off-target damage associated with an unnecessary cover spray.

Pear slug is easy to control with almost any insecticide. In Australia three products (azinphos-methyl, carbaryl and spinosad) are registered for this use, but their mode of actions and off-site toxicity vary widely. Spinosad is preferred where it is necessary to apply an insecticide.

Biological control, biorational pesticides and organics

There is some evidence that covering young larvae with wood ash is an effective control technique. This method is likely to be practical for spot applications. Applications of particle-film products containing kaolin may also reduce the number of larvae.

Fence poultry under infested trees during winter, as their foraging will help to reduce the number of overwintering pupae in the soil.

In both Europe and New Zealand there has been some work done on a highly successful biflagellate biological control agent, but this is unlikely to be explored in Australia because of the ease of controlling this pest with insecticides and the difficulty in obtaining permission to import such agents here.

Phytophthora root and crown rot

IPM quick facts

- *Phytophthora* root and crown rot are difficult to control once established. Effort should be put in to preventing them from entering the orchard, particularly when replanting on soil that has already been used for apples or pears.
- Prepare new blocks well and avoid planting in areas likely to become waterlogged. Control weeds and avoid root and crown damage.
- Some rootstocks are more resistant to *Phytophthora* than others. If *Phytophthora* has been a problem in the past, consider using M9 or M26 rootstock.



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The pest and its impact

The significance of *Phytophthora* in Australian apple and pear orchards varies among regions and seasons. It is widespread in Victoria and can cause significant losses. In areas where fruit is grown on lighter soils (e.g. Western Australia and Queensland's Granite Belt) this pathogen is less significant.

Three species of the fungal pathogen *Phytophthora* (*P. cactorum*, *P. cinnamomi* and *P. cambivora*) cause disease root and collar rot in Australian orchards.

The disease commonly infects relatively young trees and occurs in patches of one to five trees throughout the orchard block. *Phytophthora* is more likely to kill young trees, as their root and crown areas are smaller than those of mature trees.

Remedial treatment (p. 105) is labour intensive and often unsuccessful. More commonly orchardists choose to remove the trees and soil and replant. This is costly and makes orchard management more difficult, as the blocks then contain trees of various ages. The replacement trees are smaller than their neighbours and require less water. It is difficult to make adjustment for this, and the new trees are commonly watered at the same rate as the others, leading to over-watering, waterlogging and re-infection.

Life cycle

The species of *Phytophthora* infecting pome fruit have slightly different life cycles. The diagram shows a simplified life cycle that will help growers to understand the conditions favouring root and crown rot and the best strategies for controlling it. The pathogen can survive in soil, as hardened resting spores called oospores, for about two seasons under ideal conditions ❶. When the soil becomes saturated with water ❷, the oospores germinate and form sac-like structures called sporangia, which, in turn, germinate, releasing small swimming spores called zoospores ❸. These spores are unusual in that they can move freely in the soil moisture. They are attracted by chemicals given off by fresh

young roots ❹. When they reach these roots they attach and send a thread-like infection structure into the root. These structures bud off small, round bodies that mature to form oospores ❺. Within the roots, the oospores are protected and continue to grow ❻. As the fungus develops and gains nutrition the roots begin to break down and are less efficient at providing water and nutrients for tree growth. Above-ground trees at first appear wilted, unthrifty and stunted. The fine root hairs are gradually broken down ❼. As the roots rot, the oospores are released into the soil and become available to continue the disease cycle when the soil moisture and temperature are appropriate ❽.



Life cycle of Phytophthora © I&I NSW

Damage

Roots

Following infection there is an overall reduction in the number of roots. This reduction is particularly the case for the fine secondary roots responsible for much of the trees water and nutrient absorption. The resulting lack of water and nutrients affects the above-ground growth of the tree. Initially leaves will begin to drop, giving the canopy an 'open' appearance when compared with its healthy neighbours. Subsequently there is a lack of terminal growth and the leaves wilt and yellow. Because infected trees do not have many roots they tend to lodge during high winds if they are unsupported. Eventually the terminal shoots die; this is followed by the death of the whole tree. The disease is usually well established before above-ground symptoms are noticed, and infected trees are almost always beyond cure.

Infected roots have a red-brown appearance. When the bark is removed there may be dark lesions that extend into the root tissue. The root tends to look constricted in some areas because of the rot associated with the disease

Crown

The pathogen can also infect the trunk, at or immediately above the soil-level. Trees with crown rot (also known as collar rot) die very quickly. The infection begins with one or a number of lesions which rapidly grow and girdle the trunk. Crown rot usually kills younger trees (up to 3 years old) within 2–3 months.

The disease is more common in trees with herbicide guards or where there is a lot of weed growth in the row. Removal of guards and bark reveals the wood at the base of the tree is a distinctive orange-brown.



Phytophthora-infected Pink Lady apple (right), and a washed, infected root showing lesions (above)

© I&I NSW

Similar damage

Above-ground symptoms can be confused with those of a number of other root diseases that infect Australian apples. These include white root rot (caused by *Rosellinia necatrix*; see 'White root rot' p. 155) and Armillaria root rot (see 'Armillaria root rot' p. 144).



Orange-coloured cambial region indicating a Phytophthora infection © I&I NSW



Prevention and good orchard management

Nursery stock and soil movement and improvement

Where Phytophthora is present it is impossible to eradicate. It is therefore important to avoid bringing Phytophthora in from outside of the orchard block. Buy trees only from reputable nurserymen, and talk to other growers about the health of recently purchased nursery stock.

Reject trees with damaged or discoloured roots.

The soil

The disease is favoured by heavy, cool soils where water tends to pool and stay in contact with the crown and roots. However, it should also be noted that where the disease is established on lighter soils it can spread very quickly as a consequence of more rapid movement of water through the soil. In either case, water should be forced to move downwards through the soil profile as quickly as possible.

Rows should be mounded to allow rapid drainage. Mounds should be a minimum of 20 to 25 cm high, and trees should be planted as shallowly as is practical. Make sure that the graft union is well above the soil level, as scions are generally more susceptible to Phytophthora than the rootstock.

Improving soil to make it more free-draining will help to control this disease. Incorporation of organic material (commercially available compost) into the soil will also encourage soil micro-organisms. Some of these will act as natural biological control agents against Phytophthora.

Some species of Phytophthora are common in Australian bushland in some regions. Establishing blocks in areas previously occupied by bush can lead to Phytophthora problems.

Think carefully before moving soil around the orchard. Avoid moving soil from suspect areas into areas with healthy trees. Many orchardists consider that the only safe way to replant trees is to remove the infected tree, remove all of the soil surrounding the planting site (1 × 1 × 1 m) and import soil from outside of the orchard to replace the removed soil. In this case, obtain the imported soil from an area away from other trees.

Soil from a well-drained fertile paddock is ideal.

Avoid moving equipment from areas containing Phytophthora-infested trees into healthy areas of the orchard, particularly when the orchard is muddy.

Water management

Movement and development of the disease depend on water. Water allows zoospores (see 'Life cycle' p. 103) to swim through soil pores and infect root tips. As a rule of thumb, to infect, these spores need soil to be saturated for 24 hours, although this varies with the temperature and species. Finding ways to reduce waterlogging are critical to managing Phytophthora problems.

Generally symptoms of the disease are more severe following prolonged wet weather. However, in well-managed orchards, above-ground symptoms of the disease sometimes appear during drought. In these cases the initial infection occurred during a period of wet weather and may have led to a reduction in root numbers, but irrigation has allowed the tree to survive for a period. During extremely hot, dry weather the tree can no longer cope and dies.

Avoid planting in areas where water accumulates; planting on shallow slopes will help to control Phytophthora.

Irrigation should be applied so that it meets the trees' need for optimum growth and fruit production during key periods of demand. Overwatering is a waste of a precious resource and can lead to waterlogging. Frequent but short irrigations (pulse irrigation) reduces the risk of root and crown rot.

Irrigation water quality is also important. Stagnant, green dam water is more likely to support infective spores of Phytophthora. If this water is used for irrigation, the disease can spread quickly to areas in the orchard that were previously free of the disease.

Rootstocks

Choose rootstocks and varieties to match growing systems, soil types and consumer preferences. If Phytophthora is likely to be a problem, give some extra thought to the disease resistance of the planting material.

Because more than one type of *Phytophthora* is responsible for this disease, information on resistance tends to be general and exceptions are likely to occur.

Pears have greater resistance to *Phytophthora* than apples and are therefore more suitable for planting in relatively wet sites.

Apple rootstocks vary widely in their susceptibility to *Phytophthora*. The following table offers some guidance, but because of the variation among *Phytophthora* species growers are encouraged to trial small numbers of a particular rootstock before planting widely.

Avoiding root and crown damage

Damaged roots release more chemicals into the soil and therefore attract more zoospores (see ‘Life cycle’ p. 103). The wounded roots also allow these disease spores to enter the roots more easily. Any practice that damages either roots or crowns will allow higher levels of *Phytophthora* infection.

Ripping to prune roots on overly vigorous rootstocks should be avoided in soils that are prone to waterlogging or where *Phytophthora* has been a problem in the past. Before planting, consider choosing dwarfing rootstocks that restrict scion vigour.

Newly planted young trees must be supported with stakes or attached firmly to trellising. Because these trees have not had time to develop strong root systems they are prone to move in the wind unless secured. This movement results in damage to fine roots and creates wounds.

In orchards where poultry are being used to control snails, oriental fruit moth larvae, earwigs etc. it is important to limit access to the crowns of the trees and to make sure that foraging does not damage or expose roots. Fencing may be necessary.

Controlling weeds

Do not allow excessive weed growth under trees. The above-ground portion of weeds slows evaporation, making the crown and soil surface stay wet for longer. The roots of weeds slow water drainage through the soil profile, and the soil can become waterlogged. *Phytophthora* infection is more likely where weeds are growing densely under trees.

Do not leave herbicide guards on trees for any longer than is necessary. The humidity inside the herbicide guards encourages *Phytophthora*.

Monitoring

Even early detection of diseased trees is unlikely to lead to successful remedial action. By the time above-ground symptoms are observed, root damage is severe and permanent.

If early signs of the disease are seen, action must be taken to minimise further losses (see ‘Management’ p. 107). Bear in mind, though, that there is often a lag time between infection, the appearance of symptoms, and tree death. Trees may be infected but not showing signs of the disease. Even if management is applied, these trees are still likely to die. Monitoring and management protect only those trees that have not already been infected.

Pay extra attention to the general health (particularly the canopy density and colour) of trees in low-lying and waterlogging-prone areas of the orchard. Because trees are often replaced after infection it is important to keep a record of the locations of *Phytophthora* infections so that care can be taken in the future.

*Apple rootstocks for *Phytophthora*-prone areas**

Plant		Avoid
M9 M2 M4	M7 M26 MM111	MM104 MM106

* These are generalised recommendations. Note warnings in text.

Management

Responsible use of pesticides

If trees are showing signs of *Phytophthora* infection, application of fungicides is almost always futile. However, in areas prone to *Phytophthora* infection, or where other trees have died as a result of the disease, it may be advisable to adopt a routine schedule of sprays.

Fosetyl as the aluminium salt (Aliette® WC) is registered in all States except Queensland for management of *Phytophthora* collar rot. Two sprays per season are advisable. The first of these sprays should be applied in early spring when trees are in full leaf, and the second spray should be 12 weeks later, when the spring growth flush has matured. Dilute spraying is recommended, ensuring that the lower portions of the tree are thoroughly saturated.

The same product is registered as a soil drench for this disease. Curing infected trees is difficult. Soil drenches should be used only for high-value trees in the very earliest stages of infection and as a precautionary treatment for young trees in very high density plantings that are next to seriously infected trees.

Non-fungicidal methods

Some Australian orchardists have attempted to manage the disease by using a root-drying technique. This is labour intensive and has not been very successful.

In spring the soil is removed from the base of the tree to expose the infected collar and roots. Exposure permits drying of the area and arrests further development of the disease. It is important to support the tree during this period to prevent lodging. In autumn the exposed roots and crown are re-covered with pathogen-free soil from outside of the orchard.

Biological control, biorational pesticides and organics

Natural enemies

The addition of organic matter to the soil reduces the occurrence of root and crown rot. This is partly attributable to improved drainage, but increased numbers of micro-organisms encouraged by greater soil organic matter also play a large part in disease control. Although no products are specifically registered as soil adjuvants, overseas research has shown that common soil-inhabiting fungi such as *Trichoderma* and *Streptomyces* reduce *Phytophthora*'s effect on a range of crop plants.

There has been a large research project examining this issue at the University of Auckland (see 'More information: *Phytophthora* root and crown rot' p. 203).

Powdery mildew

IPM quick facts

- *Powdery mildew distorts growth and can mark fruit.*
- *Pruning out infected shoots during dormancy and early spring can be an effective management strategy.*
- *Fungicides applied often for black spot control coincidentally control powdery mildew.*
- *If dedicated fungicide applications are required for powdery mildew, extra vigilance will be needed between the cluster and pink stages.*



© Bayer CropSciences

The pest and its impact

Powdery mildew of apples is caused by the fungal pathogen *Podosphaera leucotricha*. It is the second most serious disease of apples in most Australian production regions (after black spot). In Western Australia it is the most serious disease. Although the disease has also been reported on pears and quince it is rarely seen on these hosts in Australia.

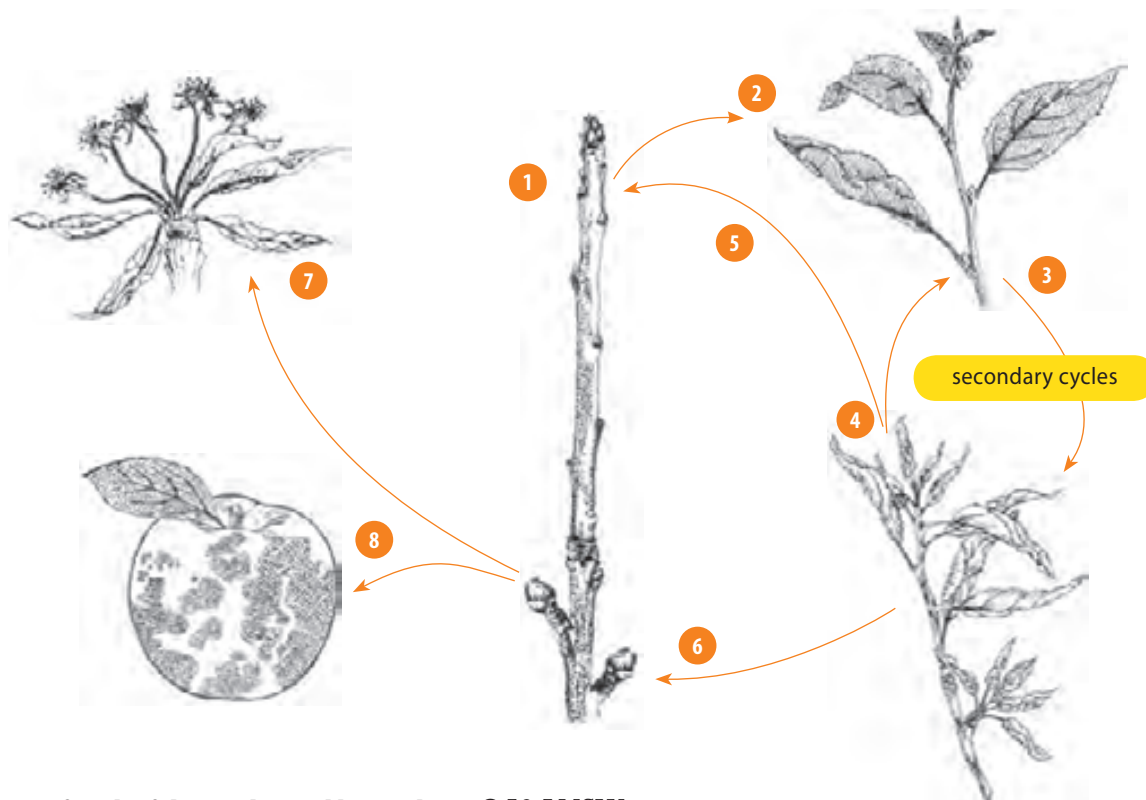
The disease affects apple trees in a number of ways, all of which have economic impacts. Fruit russetted as a result of this disease is unmarketable. Damage to leaves and shoots slows and distorts growth. This is particularly significant in young plantings, making pruning and training very difficult.

Because much of the damage caused by powdery mildew is not directly to the fruit it is difficult to quantify losses. There is some evidence that heavy infections, season after season, can reduce yields by up to 80%.

Life cycle

During winter the powdery mildew pathogen remains sheltered in floral or vegetative buds ❶. As the leaves expand in early spring the pathogen becomes active and infects the new growth. Early infections appear as small white-grey lesions that have a powdery appearance. Because these infections slow normal growth, the infected leaves become twisted and distorted. They also often fail to become deep green and remain chlorotic ❷. As the infection spreads, the leaves become more twisted and the powdery substance (spores and fungal mycelium) becomes more obvious ❸. During the season the disease spreads through the orchard as spores are blown on the wind or splashed by rain. Diseased shoots infect healthy growth ❹, and the disease can pass through many cycles before the trees lose their leaves. As the trees become dormant, fungal bodies from infected shoots become entrapped in next season's vegetative ❺ and floral ❻ buds.

Infected floral buds play little part in the life cycle. When the pathogen becomes active in spring, infected floral buds often abort before fruitlets are formed ❼. If fruit does form from infected buds it is usually russetted ❽. The pathogen does not form spores on either aborted buds or russetted fruit. Secondary disease cycles can occur only when leaves are infected.



Life cycle of the powdery mildew pathogen © I&I NSW

One unusual aspect of the life cycle of the powdery mildew pathogen has an effect on managing the disease. Unlike other diseases, powdery mildew does not require rain to develop. In fact, rain is harmful to the fungus and suppresses the production of spores. The disease develops most rapidly when humidity is high (more than 70%) and temperatures are above 20 °C. Under these conditions the fungus completes its life cycle very quickly, and there are always plenty of spores available for infection. When these conditions coincide with the emergence of soft, green tissue during early spring, protection with fungicides is very difficult.

Damage

Leaves and shoots

Leaves and shoots are most susceptible to infection in the first few days after they open. The very first symptoms of the disease are yellow (chlorotic) patches or spots on the upper surface of the leaf. These spots are difficult to see and resemble symptoms caused by other pests or diseases. The disease is therefore unlikely to be detected early. The patches become powdery and white and cover both the upper and lower side of the leaf. Later they turn brown. Infected leaves often have crinkled and cupped edges, giving them a narrow appearance.

Infected leaves often fall early during the summer, giving trees a sparse appearance. Photosynthesis is reduced. When conditions are favourable (see 'Life cycle' pp. 108–109), the disease will spread to cover the entire leaf surface and progress down the petiole on to young green shoots.

When the terminal buds burst in early spring, the disease advances with the young succulent growth. Terminal buds and young shoots are stunted or die. Because of this, young trees often become contorted and are difficult to train.

Floral buds infected during the season may abort, produce small or stunted fruit, or produce russeted fruit. The cream to light-brown, corky russetting can be extensive.



Cripps Pink shoot infected with powdery mildew
© I&I NSW

Similar damage

Damage due to powdery mildew is quite distinctive. At first glance, the webbing and distortion of leaves caused by two-spotted mite appears similar. However, the surface of leaves infected with powdery mildew is covered by powdery or dusty particles rather than webs.

Application of some herbicides (e.g. as overspray) can also lead to cupping and paleness of the leaves and distortion of growth. Again, the presence of dust- or powder-like spores is diagnostic for powdery mildew.

Prevention and good orchard management

Removal of infected buds

Infected terminal vegetative buds are the primary means by which the disease survives the winter and infects new leaves and buds in early spring. Removal of infected terminal buds during dormant pruning can be effective in reducing the disease load if infections are light. Infected buds tend to be narrower than healthy buds, and their scales are more open. Pruning during the season to remove diseased shoots is seldom effective, and disturbance can spread the disease farther in the orchard.

Pruning to open the canopy

Because of the reliance of this disease on high humidity there is an opportunity to influence disease development through pruning. High relative humidity occurs at the leaf surfaces when the air is calm but is reduced by turbulence. Pruning to open the canopy and allow a layer of turbulent air to pass over the leaf surface can be very effective in reducing the occurrence of disease. Burn all prunings.

Windbreaks, netting and tree planting should also be managed to optimise air flow, particularly in regions where this disease is a problem.



Open scales on an infected bud
© Bayer CropSciences

Varieties

All commercial varieties of apple grown in Australia are susceptible to powdery mildew. The worst-affected varieties include Cripps Pink, Jonathan, Bonza, Jonagold, and Granny Smith. In regions where powdery mildew is particularly a problem, growers should be aware of the risk associated with planting these varieties. Red Delicious and Fuji are less susceptible. Growers in warmer regions should also exercise caution with Braeburn, Gala and Golden Delicious. Opinions vary on their susceptibility. It is likely that their susceptibility is intermediate and the degree to which they are infected depends on the region in which they are grown.

A more complete listing of the susceptibility of apple varieties to powdery mildew is available at www.caf.wvu.edu/KEARNEYSVILLE/tables/powmilsus.html

Monitoring

This manual contains details of a monitoring strategy that is suitable for many pests and diseases. It can be used to monitor for powdery mildew and is based on the use of predetermined, labelled trees in your orchard block.

Orchardists who can recognise infected dormant buds should examine the designated trees in late winter, quantify the number of infections, and plan their management on the basis of this number. A comparison with a similar recording from previous seasons is especially helpful in determining the success (or otherwise) of past management strategies. Detected buds can be removed, and, where powdery mildew infections are likely to be serious, in-season management can be biased to suit.

During spring and summer, under conditions ideal for the disease, it takes approximately 5 days for the fungus to complete a secondary cycle (i.e. infect, produce symptoms and produce new spores). This rapid development leaves a very narrow window of opportunity for effective management. Where the disease has been a problem in the past, monitoring must be thorough and frequent and must concentrate on known 'hot spots'. The critical time for monitoring is the period from green cluster to pink stages, especially on late-blooming varieties.

On each of the designated monitoring trees, assess 10 extension shoots. Inspect the top five unfolded leaves per shoot for mildew, and record the incidence of mildewed shoots. The disease develops rapidly; therefore, frequent monitoring is suggested with a maximum interval of 10 days during shoot development. If mildew levels increase, either during the season or when compared with previous seasons, control measures need to be improved.

In warmer regions, increasing temperature suppresses this disease and management is unlikely to be required after new leaf growth is completed.

Management

Responsible use of pesticides

Almost all of the pesticides used to manage powdery mildew are also registered for, and effective against, black spot. The exception is bupirimate (Nimrod®), which does not have registration for black spot control. Many of these fungicides are curatives, and their use should be considered in the context of a resistance management strategy. In regions where apple black spot is a problem (all regions except Western Australia), powdery mildew control may be coincidental because of fungicide applications made principally for black spot. However, if black spot sprays are not applied or powdery mildew remains a problem despite applications for black spot, applications specifically for powdery mildew may be necessary.

Sprays dedicated to powdery mildew control should be concentrated on the period between green cluster and pink stages, particularly if the disease is detected during monitoring. In extreme cases it may be necessary to apply cover sprays during the blossom period at 10- to 14-day intervals, but this practice is not sustainable and should be reviewed every season. In any case, sprays for powdery mildew should be necessary only on the most susceptible of varieties beyond the blossom period. When applying fungicides for powdery mildew it is important to consider the following:

- The white cottony growth (mycelium) associated with this disease repels water, and many fungicides will need a wetting agent to be effective. Read the label carefully and follow the manufacturer's recommendations.

- Powdery mildew can be very damaging to non-bearing trees and they should receive a full fungicide schedule where necessary. However, in blocks of young trees where spraying can be thorough and observations frequent, it is often possible to reduce the number of applications below that usually required for older and larger trees.
- Powdery mildew control by chemicals is particularly important on young trees that are being trained as central-leader or palmette types, where lateral tipping is undesirable.
- If only certain sections of the orchard are affected it may be possible to control powdery mildew with selective or spot spraying. If only a portion of the orchard is sprayed it is important to be very diligent with monitoring in other areas.

Managing resistance

Almost all of the fungicides registered for use against powdery mildew belong to chemical groups that have very specific modes of action. When this fact is combined with the pathogen's propensity to be difficult to control, resistance may become a problem in the future. It is important to use these fungicides carefully to avoid this problem. Take care to read product labels carefully and not exceed the total number of sprays for each group of fungicides, as recommended by the manufacturer.

Careful monitoring and use of non-chemical management will also lead to a reduction in the total number of sprays needed, reducing the rate at which resistance is likely to develop.

Biological control, biorational pesticides and organics

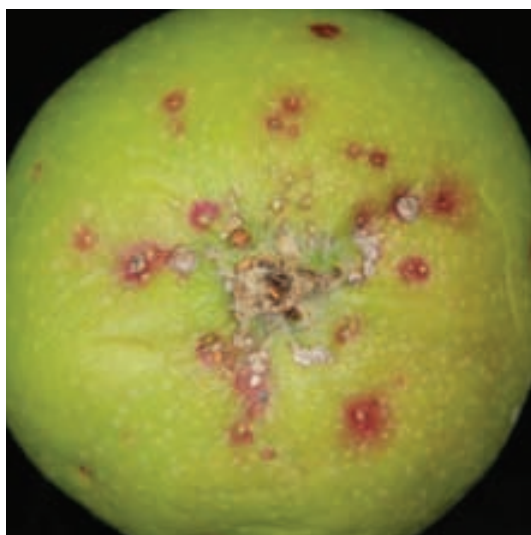
Various forms of sulfur are registered for the management of powdery mildew. However, they should be used with care. They may disrupt populations of predatory mites (and their food sources) that are present in the orchard during blossom, and this may result in pest mite problems later in the season.

Despite significant international research, a putative biological control agent based on a yeast fungus has not been commercialised.

San José scale

IPM quick facts

- *San José scale is difficult to control with conventional insecticides, largely because adults and most juvenile stages have a thick waxy covering.*
- *Pesticide applications must be precisely timed to when the highly mobile but unprotected 'crawlers' are present.*
- *Effective control can be gained by making regular, dormant, high-volume applications of horticultural mineral oil.*
- *Unnecessary and poorly timed application of insecticides should be avoided, because effective biological control agents (such as *Rhyzobius lindi*) are likely to be killed.*



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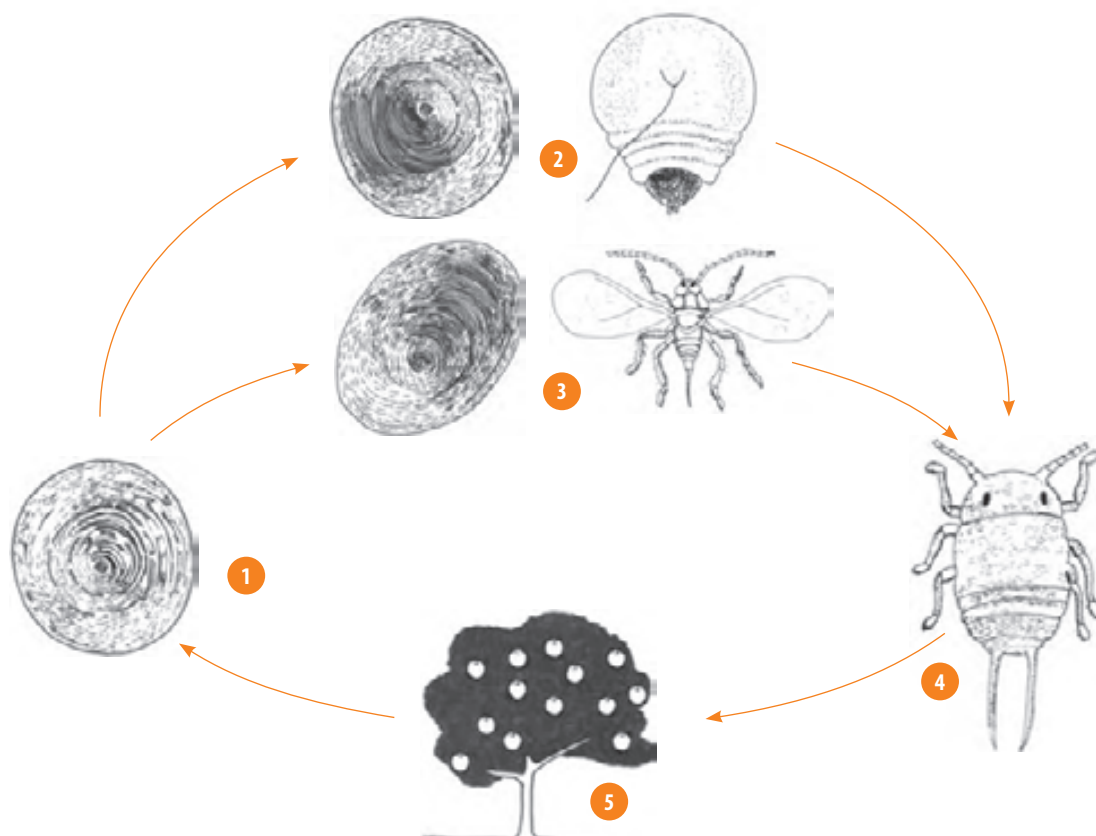
The pest and its impact

San José scale (*Diaspidiotus perniciosus*) infests a very wide range of mainly deciduous shrubs and trees, including apples, pears, stone fruits, grapes, kiwifruit, walnuts, willows, birches and elms. Their preferred habit is to form dense encrustations on the bark of their hosts, and at densities of over 100/cm² they have a gradual debilitating effect on branches. Branch death usually takes several years of continuous infestation. This has an effect on tree training. This, and an overall reduction in tree vigour and health, reduce fruit yields. The pests also feed directly on fruit and have a direct effect on fruit quality.

San José scale was once considered one of the most devastating pests of the apple and pear industries. The introduction of chlorinated hydrocarbon insecticides such as DDT led to a reduction in their importance, and this was maintained through the subsequent use of other broad-spectrum insecticides. With increasing use of more specific insecticides this pest is making a comeback in commercial plantings. San José scale can be found in all mainland Australian apple- and pear-growing regions and has recently been found in Tasmania.

Life cycle

The insect survives through winter in an immature state attached to the larger branches of trees. During this time it is around one-third grown. As temperature increases in spring the insect resumes growth ❶. This usually coincides with the beginning of blossom, but because development is dependent on temperatures the timing can vary. Although both begin the season as identical small scales, males and females develop differently and become distinct from one another. The body of the female is yellow, circular and flattened. It is hidden under a circular scale that is grey to black and has a raised light knob in the centre. This scale is around 0.9 to 1.4 mm long ❷. Males are covered by a smaller, oval-shaped scale that also has a raised knob. Males emerge as minute (1 mm long) yellow, two-winged insects ❸. Females remain under their scale and do not move throughout their entire lives.



Life cycle of San José scale © I&I NSW

Following mating females give birth to live young; they do not lay eggs. The developing young remain under the cover of the scale until they emerge as well-formed, mite-like insects. Their major distinction from mites is that they are bright yellow. These emerging insects are called crawlers **4**. They are highly mobile and disperse throughout the tree. They can also disperse to nearby trees at this stage **5**. Crawlers find a suitable feeding site within 24-hours; they insert their slender thread-like mouthparts through the bark, or the surface of the fruit or leaf, and begin to suck sap. Soon after settling down to feed, crawlers shed their skin, legs and antennae and appear as flattened, yellow sacks. As they continue to grow, their body secretes wax that hardens to form a scale. Development depends on temperature, but typically they reach maturity in 6 to 8 weeks and there are two or three generations a year.

Scales are often not completely dormant during winter, and all stages (except males) can be found throughout the colder months. Populations can build up during mild winters, requiring extra vigilance in spring.

Damage

Fruit

While feeding, San José scale injects a toxin that results in a distinctive red halo around the feeding site on the fruit. These halos can also be seen on younger, green, tender shoots and twigs. Apple, and particularly pear, fruit can become bumpy and may be misshapen and stunted where infestations are severe. Canning pears can be rejected because the sunken areas cannot be removed by peeling.

Limbs and branches

The toxin injected by San José scale during feeding results in the death of twigs and limbs and, over a series of seasons, an overall decline in tree vigour, growth and productivity. If infestations are unmanaged over a series of seasons, tree death can occur. Damage is usually more severe and occurs more rapidly on younger trees, which give easier access to succulent green tissues and have thinner bark. Young trees can be killed in 1 to 3 years.



Fruit symptoms of San José scale on pear (left) and apple (right)
French National Institute for Agricultural Research, © I&I NSW

Infested trees appear water stressed and the bark may crack and exude gum. Damage to branches affects tree training and hence may have secondary effects on the future productivity of blocks, even after infestations are controlled.



Symptoms of San José scale infestation on an apple twig Anne-Sophie Roy, Europe and Mediterranean Plant Protection Organisation

Similar damage

The red halos associated with San José scale infestations and the presence of grey scurfy scale infestations make them quite distinctive from other pests and diseases. Superficial examination may result in the fruit pitting symptom being mistaken for boron deficiency or apple dimpling bug.

Prevention and good orchard management

Pruning

Once an infestation is detected it is unlikely to go away and will most likely become worse. In blocks where San José scale has been a problem in the past, careful inspection and removal of infested wood during winter pruning will help to control the pest. Burn all infested prunings.

Monitoring

For San José scale, monitoring is targeted at detecting the crawler stage of the life cycle. This is because:

- it is one of the few stages of the scale's development when it is not protected by its waxy scale and can be effectively killed using insecticides
- it is a mobile stage that is responsible for spreading infestations. Controlling crawlers effectively stops infestations spreading in the orchard.

Monitoring by using pheromone traps (associated with phenology models) and/or sticky traps that use double-sided tape is used overseas, but these are not widely used in Australia. This may be because Australian orchards tend to be dusty, and double-sided tape quickly becomes dirty.

In Australia, careful monitoring of trees during pruning is a useful way to determine the level and location of San José scale infestations. The best place to look for scale is in sheltered spots such as in the forks of branches or in tiny cracks and crevices in the bark, or between the bud and stem of young branches. Even older, established scale colonies can be difficult to detect because their colour becomes very closely matched to the bark of older trees.

Management

Responsible use of pesticides

Where careful monitoring of the crop indicates that application of dormant oil and use of other management strategies have failed to control San José scale, it may be necessary to apply an insecticide. Almost all of the registered products available for use against San José scale in-season have an adverse effect on predators of orchard pests. These products should be applied only as a last resort, and if they are used orchardists should expect problems with other pests.

Fenoxycarb (Insegar®) is registered as a product that will suppress San José scale when applied to control codling moth and/or lightbrown apple moth. It is relatively benign to predators.

Biological control, biorational pesticides and organics

Oils sprays

In areas where San José scale is a regular problem, annual application of horticultural mineral oils during dormancy should be a standard practice. Oils should be applied as very-high-volume drenching sprays for best effect. If heavy infestations have been encountered, and because the scale can be difficult to detect and heavy infestations can come from relatively low starting populations, consider applying a spray even if no scale has been seen recently. Oil sprays during dormancy are particularly effective, as most of the scale population will consist of younger individuals that are particularly susceptible to this management.

This becomes more difficult for orchardists who also have a regular European red mite problem. For European red mites the recommendation is to delay oil application for as long as possible (delayed dormancy). This spray is not as effective in controlling scale, and two applications of oil are not recommended because they may harm the trees. Orchardists in this situation are advised to carefully monitor trees during dormancy for signs of European red mite and San José scale. Using this information as well as records from previous seasons, orchardists will need to decide which pest is likely to cause the most serious problem and apply oil accordingly.

Lime sulfur

Dormant application of lime sulfur in combination with oil sprays will help to control San José scale. This product is registered for use on apples but not on pears. Note the warnings and application timings on the product label. Incorrect application of lime sulfur can damage trees.

Biological control

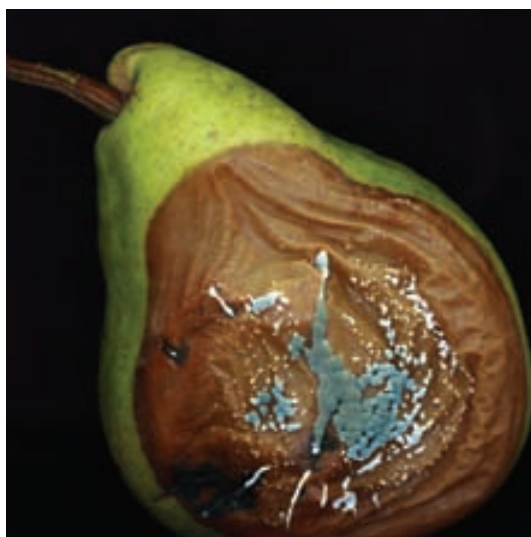
As with many of the insect pests of orchards, a range of predators feed on immature and adult scales. The native ladybird beetle *Rhyzobius lindi* is an important predator of immature stages of San José scale.

Several attempts have been made to introduce the tiny parasitoid wasp *Encarsia perniciosi* into Australia as a biological control agent. To date, the introduced strains have not sufficiently controlled the pest.

Storage rots

IPM quick facts

- A large number of fungi cause postharvest rots of apples and pears. The most common rots are blue rot, *Alternaria* rot and *Mucor* rot.
- Management begins in the orchard with a thorough pest control program.
- Fruit should be treated carefully to avoid bruising and cutting.
- Harvest and shed hygiene is crucial in minimising the spread of any storage rots.



© I&I NSW

Blue mould rot



The pests and their impacts

A wide range of fungi are responsible for storage rots of apples and pears. In the majority of cases they are opportunistic, requiring some form of wounding to enter the fruit and cause rots. Fruit with large, open calyces are often the exception to this rule. Apple varieties such as Jonathon and Delicious are more susceptible for this reason. Losses in storage can be very significant.



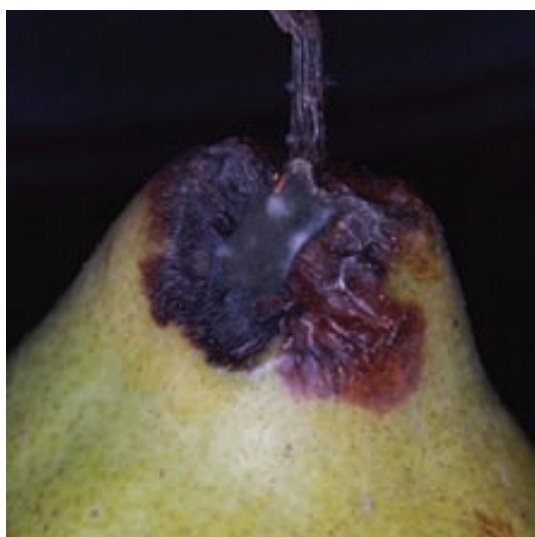
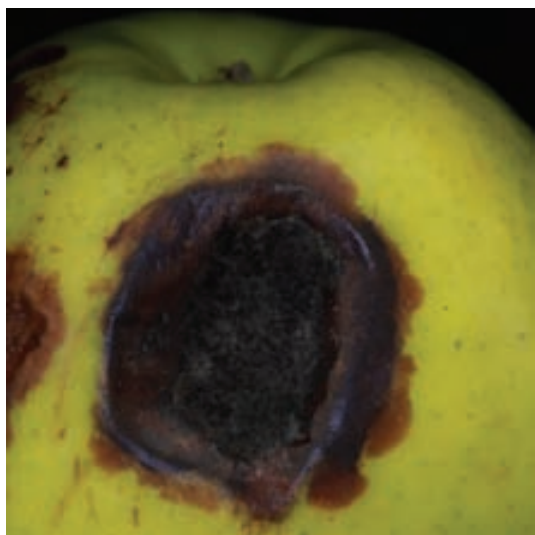
*Symptoms of *Penicillium* or blue mould on pear fruit (top) and apple fruit (above)* © I&I NSW

Blue mould or wet rot, caused by the fungus *Penicillium* (usually *P. expansum*), is the most common rot of apple fruit in Australia. Under modern CA storage conditions, losses due to this rot should be less than 1%, but if storage problems occur, or conditions are less than optimal, losses can be 50% or more. The disease is characterised by:

- soft brown tissue rot occurring beneath translucent, papery skin. This soft rot breaks up easily on the grading and packing line. Subsequent movement of this diseased flesh allows the disease to move quickly, infecting previously healthy fruit in the shed.
- tufts of bluish or blue-green spores that appear as the disease develops.

Blue mould infections originate from stem-end infections or wounds or as core rots in varieties with open calyces.

Alternaria rot



Symptoms of *Alternaria* rot on apple fruit (top) and pear fruit (above) © I&I NSW

Alternaria rot of apples and pears is caused by the fungus *Alternaria alternata*. It is important to realise that this rot is distinct from the disease *Alternaria* leaf spot, caused by *Alternaria mali*. (see 'Alternaria leaf blotch and fruit spot' p. 30). *Alternaria mali* causes small, red-haloed lesions centred on the lenticels, but these do not develop into serious rots. It is unlikely that *A. mali* causes any significant fruit injury in Australia, and damage previously attributed to *A. mali* may have been the result of bitter pit (see 'Bitter pit' p. 146).

Alternaria fruit rot is characterised by:

- round, brown to black dry, firm, shallow lesions that often occur around skin breaks
- a slowly progressing stem-end lesion on pears
- dark-coloured fungal material (mycelium) visible on the surface under wet conditions.

The rot caused by *Alternaria* is drier and firmer than that associated with other rots (including blue rot), and the infected fruit is less likely to break up on the grading and packing line.

Mucor rot

Mucor rot is often associated with fruit that has been wounded (by hail, insects or rough handling) and has subsequently been placed in storage. Flesh breakdown is more complete than with other rots, and after a period of months all that is left is the skin and large quantities of juice. During the early stages of breakdown the disease is characterised by infected tissue becoming soft, watery and brown. Secondary spread in cold storage is common in pears but not in apples.



Mucor rot © I&I NSW

Other rots

Many other fungi can cause storage rots if conditions suit their development. Often rots appear similar, particularly early in their development, and it may be necessary to obtain a diagnosis to determine the specific disease affecting the crop.

Bitter rot, caused by the fungus *Glomerella cingulata*, has been dealt with elsewhere in this manual (see 'Bitter rot' p. 51).

Grey rot (also known as spot rot; caused by the fungus *Botrytis cinerea*) affects both apples and pears but is more serious on the latter. This rot is favoured by cool, moist weather before and during harvest. Although the fungus often enters fruit through wounds, the most common invasion point is through the calyx or stem-end. This rot is often difficult to identify because its symptoms vary with fruit age and variety. The rot tends to start as a small brown spot with diffuse margins. As the rot progresses older portions of the decay darken, whereas the edges remain lighter. Under high humidity a white or grey-white fungal growth occurs. In storage this growth expands quickly and the rot rapidly overtakes neighbouring fruit. At 0°C fruit are completely destroyed in 3 to 4 months.

Other fruit rots are less common and include target rot (also called ripe spot; caused by *Neofabraea alba*), Cladosporium rot, Fusarium rot, Phoma rot, sprinkler rot (caused by *Phytophthora* spp.), transit rot (caused by the fungus *Rhizopus* spp.) and Stemphyllium rot. Management of these diseases is broadly similar to that of other storage rots.

Prevention and good orchard management

Prevention of storage rots begins in the orchard and continues until the fruit is eaten by your customers. Almost everything that you do while producing fruit has an impact on the fruit's quality and shelf-life.

In the orchard

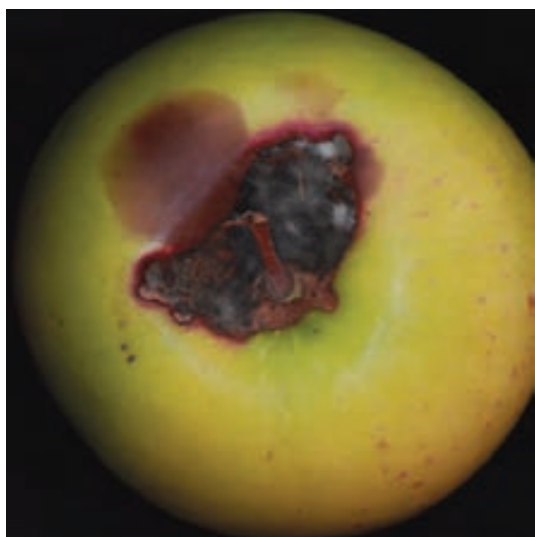
Insect pests must be controlled. Rots are able to gain ingress where the fruit's skin is damaged by pests. Control of codling moth and lightbrown apple moth is particularly important, as rots frequently originate from their damage. Millions of fungal spores are formed on a single piece of hanging rotten fruit. These spores are spread on the wind through the orchard, infecting other fruit and spreading the problem. Where fruit rots develop (even after sprays) it is important to remove diseased fruits from the orchard and destroy them. Typically, the fungi responsible for fruit rots produce copious, light spores that move easily on the wind. Rotting fruit are best removed early in the morning when the air is humid and the wind light. Rotten fruit should be picked directly in to bags to minimise the chance of spores spreading to other fruit.

Wounds caused by birds are also an important source of postharvest rots, and bird-damaged fruit should be removed as soon as possible. Be careful not to damage fruit during routine orchard operations, particularly around headlands and where there are hanging branches between rows.

Maintaining good control of diseases such as black spot and powdery mildew has coincidental benefits in controlling storage rots. Many of the fungicides that are effective against other diseases will also reduce the impact of storage rots. If storage rots are a serious problem this coincidental effect can be enhanced by including more protectant, broad-spectrum fungicides in your disease control program.

It is particularly important to monitor for fruit rots and to maintain good spray coverage close to harvest.

Overly dense clusters of fruit also pose a risk for the development of storage rots. Clusters provide sheltered positions for insects such as lightbrown apple moth that wound fruit, and it is difficult to get adequate spray penetration to protect fruit. Rots are common under these circumstances, and the disease can spread to effect entire clusters. These infected clusters become a source of infection for other fruit in the orchard.



Fruit damaged by lightbrown apple moth often develops rots that can spread to other fruit in storage. © I&I NSW

Harvest

Bins—particularly wooden bins—must be managed carefully during harvest. Before harvest begins the bins should be disinfected. They should be carefully inspected for protrusions and debris that could damage fruit. Damaged bins should be repaired or discarded. Plastic bins are preferable to wooden bins as they are more easily disinfected.

Extra care should be taken with late varieties if the bins are likely to have had repeated use during the season. Check and treat bins at regular intervals as harvest progresses.

Harvesting presents pickers with lots of opportunities to damage fruit. Training and supervision of the harvest is vital:

- Fruit should be handled gently, ensuring that all drops are no more than 10 to 15 cm.
- Wet fruit should be allowed to dry before picking.
- Tracks should be graded and trailers should have low tyre pressure.
- Fruit should be kept clean and bins should be kept off wet ground.
- Prevent machinery from carrying orchard soil on to the loading apron and handling areas.
- It is best not to disturb rotting hanging fruit during harvest. This fruit should be removed and destroyed as soon after harvest as is practicable.

Wounding of fruit by mechanical injury can happen at any time during the fruit production cycle, but harvesting, grading and packaging are periods of increased risk. Wounded fruit is likely to rot, because the sugary sap is a food source for the rot-causing fungi and the fruit's skin—a natural defence barrier—is compromised. Fruit wounding can be minimised by careful handling and making sure that the harvest equipment is padded and has few sharp edges.



Punctures, wounds and bruises allow rots to develop © I&I NSW

Postharvest

Each time fruit is handled in the shed the risk of damage is increased. Minimising the number of handling steps will reduce the likelihood of storage rots: plan for efficiency and minimise the risk.

Poor drenching practices can exacerbate storage rots. During drenching, fruit is likely to be exposed to rot spores in a wet environment—ideal conditions for rot to develop. It is important to follow the industry code of practice for postharvest drenching (see ‘More information: Storage rots’ p. 203), replace the drench frequently, and adhere to the label directions of any fungicides applied. Allow fruit to drain after drenching.

Sanitiser products such as Nylate® (bromo chloro dimethylhydantoin) and Tsunami on Farm® (Peroxyacetic acid + hydrogen peroxide) are also now widely used as dips or on-line sprays. These products are effective against fungal and bacterial organisms, as well as a range of human pathogens such as *Staphylococcus aureus* and *Salmonella kabla*, which pose risks to food safety. Instructions for the use of these products can be found on their labels and are also available for rural suppliers.

Inevitably, small fruit wounds will have occurred during harvest and postharvest handling. Allowing these wounds to seal by delaying cooling for 6 hours will reduce the likelihood of fruit becoming infected during storage. It is important to monitor and maintain strict CA and temperature tolerances. Rapid repair of any equipment failure is essential.

Packing

If rots have developed in storage they can be quickly spread in the dump tank water. Water should be regularly replaced and sanitised. Rotting fruit and other debris should be removed.

Maintaining hygiene during grading is very important. Spray fruit with fresh or sanitised water immediately after the inspection table. Wash down sorting equipment daily and ensure correct set-up and maintenance of the grading line to minimise bruising and wounding.

Fruit that is culled at this stage should be placed in a covered container that is emptied 2-hourly. Although time is often short during packing, it is good practice to keep a rough record of the percentage of fruit rejected and the reasons for rejection. This will allow you to refine your handling practices and reduce shed losses in subsequent seasons.

Monitoring

Many of the storage rots can appear in the orchard if wet or humid weather occurs close to harvest. Under these circumstances extra vigilance is required in the shed, as rots are likely to continue to develop during storage.

Harvest is a busy time. As far as is possible, a written record should be kept of the quantity of fruit that is rejected and the reasons for rejection during harvest, immediately post harvest and during packing. An investment in time at this point will allow you to identify specific problems, refine handling practices and reduce the time and money lost to fruit rejections in subsequent seasons.

Management

Responsible use of pesticides

Maintaining good disease control in the orchard is vital for control of storage rots. It is important that fungicides used in the orchard are not subsequently used postharvest. The fungicides recommended for postharvest application (carbendazim, thiabendazole, iprodione and imazalil) belong to activity groups prone to resistance. Their overuse increases the risk of storage rots developing resistance and subsequently destroying your stored crop. Where an effective, alternative fungicide is available for use in the orchard it should be used.

If DPA and/or calcium chloride are also applied to harvested fruit it is important to refer to the product label to determine compatibility. If fruit is to be exported, use only fungicides that are permitted by the importing country.

Biological control, biorational pesticides and organics

In most cases the most effective means of controlling storage rots is low-temperature CA storage. This also maintains other aspects of fruit quality (e.g. firmness, sugars). A comprehensive description of modern storage facilities is beyond the scope of this manual. Comprehensive information is available elsewhere (e.g. from the Sydney Postharvest Laboratory; www.postharvest.com.au/storage.htm).

Biological control

Although several products based on biological control agents (usually yeasts) are available overseas, there are no products registered in Australia. Given the fungicides commonly used for postharvest treatment of apples and pears in Australia, storage rots are likely to develop resistance at some stage. Further investigation of the effectiveness of postharvest application of biologicals may therefore be prudent.

Ozone

Ozone can be a valuable supplement to other storage rot management techniques. However, recall that storage rots occur following damage to the fruit's skin (by mechanical wounding, abrasion or insect damage) or by ingress to the fruit core via the calyx. Ozone works on the surface of the fruit as a sterilant. It effectively controls superficial spores associated with wounds but it is unlikely to have any effect on spores that have reached the fruit's core. Exclusive reliance on ozone is a dangerous practice.

Thrips: Western flower thrips, Plague thrips

IPM quick facts

- *Plague thrips* is a native species that infests flowers, causing fruit abortion.
- *Western flower thrips* (WFT) is an accidentally introduced pest that is becoming more widespread. WFT disfigures fruit when it lays eggs, causing a distinctive 'pansy spot'.
- Management of broad-leaved weeds, clovers and lucerne is critical to WFT management.
- If monitoring indicates that crop damage is likely, spray during blossom. Monitoring should be continued in case re-spraying is needed. Heed thrips resistance management strategies.



© I&I NSW

The pests and their impact

Two species of thrips can cause damage to Australian pome fruit. The biologies of these species are very similar, but the damage they cause and their management differs. Effective control of thrips can be undertaken only if you have identified which species of thrips is responsible for the problem. Accurate identification of thrips is a specialised skill; if thrips damage is suspected, samples should be submitted to State government agricultural departments for identification.

Plague thrips

Plague thrips (*Thrips imaginis*) is a very common native species that damages a range of crops, including stone fruit. Females of this species are 1.1 to 1.3 mm long and males are 0.8 to 1.0 mm. Plague thrips are almost always female, particularly early in the season. They are generally a dusky brown, and the last two portions of the body are darker. However, identification can be confused, because yellow forms exist in some regions.

Western flower thrips (WFT)

Western flower thrips (*Frankliniella occidentalis*) is slightly larger than plague thrips. Females are 1.4 to 1.8 mm long and males are 0.9 to 1.1 mm. WFT are predominantly male at low population densities (usually early in the season) and mostly female when numerous. Females have banded antennae and a pattern of darker spots on the top of their abdomen.



Plague thrips (top) and western flower thrips (above) © I&I NSW; Jack T Reed, Mississippi State University

Life cycle

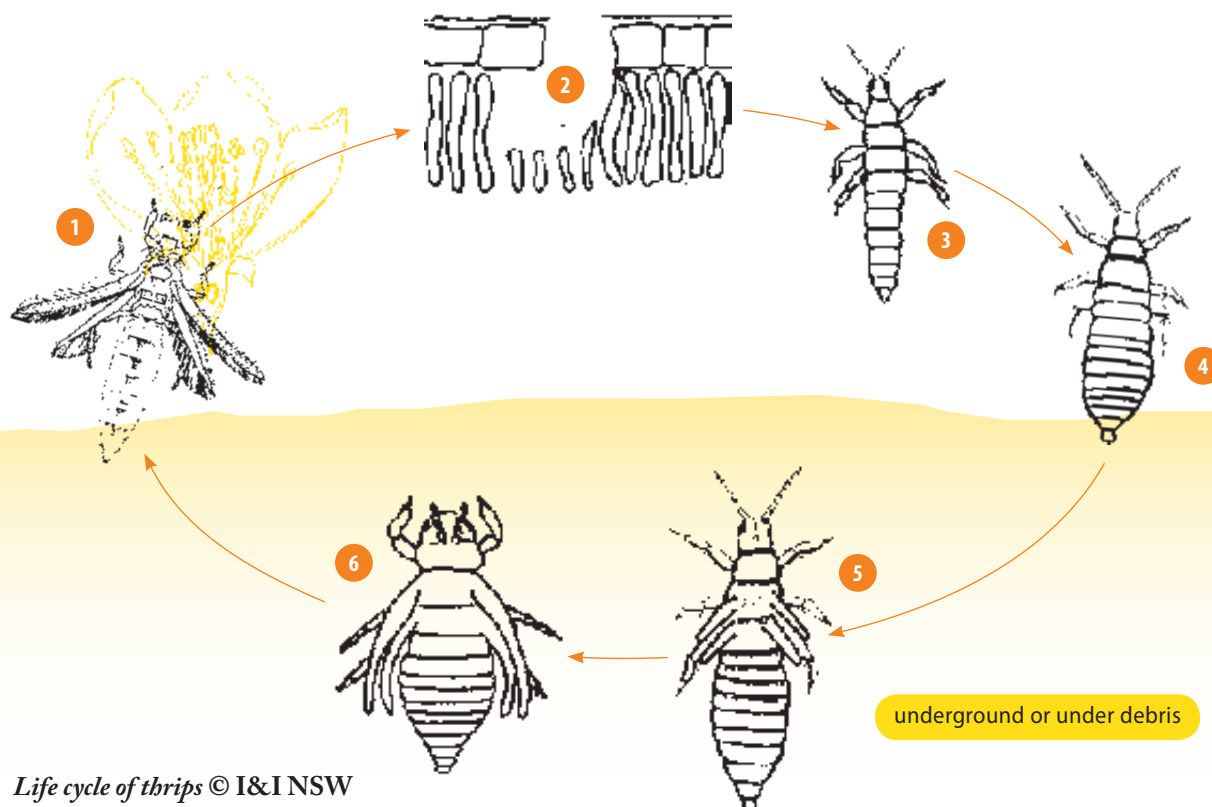
The various species of plant-feeding thrips (including plague thrips and WFT) have similar life cycles, but important differences do exist and are noted on this page.

Adult thrips are found mostly in flowers ❶.

They infest a wide range of plants, and many weed species harbour large numbers of these pests; clover is particularly favoured, as are other broad-leaved weeds such as capeweed, dock and sorrel.

In the orchard thrips begin to infest the crop as early as bud swell, when females lay eggs in sepals and other flower parts ❷. WFT may lay its eggs into the developing fruit later in the season. Plague thrips may migrate from some distance away, but WFT usually overwinters on weeds or garden plants close to the orchard. Plague thrips is usually the more common species during the flowering period. WFT is more common during summer on ripening fruit. Few thrips are found on the leaves. Eggs hatch into active, feeding larval or juvenile stages by late bloom. There are two larval stages (❸ and ❹), and these look like small wingless adults.

Larvae migrate to the ground, where they shelter under debris or soil and develop into inactive, non-feeding pupal stages (❺ and ❻). Winged adults then emerge and can live from 28 to 90 days.



Life cycle of thrips © I&I NSW

Damage

Both species of pest thrips can cause commercially significant damage to fruit. Although leaves are often infested, damage is usually limited to bronzing, which may be mistaken for mite infestation.

Adult female WFT cause damage when they lay their eggs into young fruit. Pansy spotting (also called ghost spotting) occurs around the site of egg-laying. Although all varieties are susceptible to WFT, damage is more obvious on light-skinned varieties and on lighter portions of the fruit.



Fruit damaged by western flower thrips
© I&I NSW

Plague thrips are native insects, and infestations often arise from surrounding bush. Adult insects feed on flower stamens and styles and can cause severe flower abortion. Often, if populations are low, this damage has a similar effect to flower thinning. However, heavy infestations can cause a large reduction in fruit set. The numbers of plague thrips are largely determined by what happens to their populations in the bush, and the severity of infestation is difficult to predict. Careful and frequent monitoring for damage is necessary.

Similar damage

Poor fruit set can be caused by many things, but plague thrips have been implicated in some cases. If plague thrips has been responsible then the thrips would have been present as tiny white larvae on stamen filaments in the flowers during very early petal fall.

Prevention and good orchard management

Weed management

Both WFT and plague thrips can be found on a wide range of broad-leaved weeds and flowering plants. Flowering plants are particularly attractive to WFT, with clover (particularly white clover) and lucerne hosting the highest thrips densities. WFT feeds on the pollen of these plants; therefore, preventing flowering can be an effective management strategy. Total removal of clovers and other broad-leaved weeds is one option, but if this is not possible then keep them mown short throughout the year to prevent flowering.

Managing your ground cover and weeds is critical to reducing thrips populations and preventing population carryover. As WFT does not feed on grasses, replace broad-leaved ground cover with grasses.

If ground covers/weeds have been left unmown, it is important **not** to mow them just before or during flowering, as this will send the thrips (if present) up into the flowers on the trees. Wait until well after petal fall, and then mow. Keep ground covers/weeds mown throughout the development of the fruit, especially close to harvest.

If thrips have been a problem in previous seasons and a decision is made to control weeds with a herbicide, it is advisable to treat for thrips at the same time. If thrips are not treated they will move to the trees as the weeds die.

Movement

Plague thrips can be carried into the orchard from considerable distances on the wind. There are very few practical measures that can be taken to restrict this movement. However, WFT spend winters on broad-leaved weeds or garden plants. Therefore, avoid moving from blocks that have been infested with WFT (in previous seasons) into 'clean' blocks. Plan your movements around the orchard so that blocks previously infested with WFT are the last to be visited.

WFT can be moved around the orchard on tools and clothes. Avoid wearing yellow, white or blue clothing, as this is attractive to WFT.

Monitoring

Monitor throughout the season from (budburst to harvest). The developmental stages of thrips are closely tied to the weather, and particularly temperature.

There are two methods of monitoring thrips.

Crop inspections

Thrips can be collected from buds or flowers. For each monitoring tree, tap 20 to 30 flowers over a yellow (not white) tray or sticky trap and collect any thrips in spirits (e.g. methylated spirits) for identification by your department of agriculture.

For plague thrips, all varieties are affected, but Granny Smith and Delicious are most readily damaged and should be kept under close observation.

For WFT, watch for symptoms on early-maturing varieties up until mid-summer. If symptoms are observed, treat the affected variety and prepare to also treat those that ripen subsequently.

By the time thrips are detected through monitoring it is often too late to eliminate their damage. Immediate management can reduce the severity of the damage and gives an early indication that action will need to be taken late in the season and early next season.

Yellow sticky traps

Monitoring with yellow sticky traps is useful for determining the presence or absence of thrips within an orchard:

- Varieties in which thrips are detected can be sprayed, minimising damage.
- Varieties that mature subsequently can be monitored more carefully following detection on early varieties.
- The number of beneficial organisms can be assessed.
- The information will help in management decisions the following season.

Locate the traps as follows:

- Hang some in the trees for the entire season. As a rough guide, use two traps in a block or five traps per hectare. Hang them in the lower third of the tree.
- Place extra traps in the ground cover from budburst to fruit set. Place the traps on a stake at a height of 0.25 to 0.5 m in the inter-row.

Replace the traps at intervals of 1 to 2 weeks, especially at peak times of likely activity. The yellow sticky traps in the trees are important in the pre-harvest period. Monitor them very carefully during the period from 1 month before harvest.

Identification can be done by your State government agricultural authority. Most agencies now charge fees for this service. Check with your local authority to determine what charges apply.

Management

Responsible use of pesticides

Insecticides are useful for control of thrips only when the insects are exposed. Sprays should be timed to coincide with the presence of adult or larval thrips. Both eggs and pupal stages are protected from sprays, and applying insecticides is likely to be futile unless the timing is correct. For this reason, three sprays are recommended to cover the time taken for eggs to hatch into larvae and for pupae to develop into adults. A series of three sprays of the same chemical several days apart will be effective for killing the majority of thrips.

The interval between applications varies with temperature. In cooler regions or at cooler times of the year (10 to 20°C) the length of the life cycle is 25 to 35 days. At 20°C to 30°C the life cycle is 15 to 25 days. Therefore, the higher the temperature the shorter the interval between sprays. Follow the product label directions for the minimum interval between successive applications

It is also **essential** that the type of thrips observed or collected during monitoring is correctly identified, because the type of pesticide that is effective varies among species.

For plague thrips, spray all varieties with endosulfan or bifenthrin as soon as monitoring indicates that thrips numbers have reached six to eight per blossom following warm dry weather during the pink to full-bloom period. Thrips occasionally occur in plagues and may invade flower buds as early as spurburst or early pink, causing serious damage. If thrips can be seen in large numbers in weed flowers and in early-flowering fruit varieties, be prepared to spray apples. Repeat spraying will be needed during plagues, as the residual action of endosulfan is short. Endosulfan should be applied only at times when bees are not actively working the blossoms, such as in the evening or early morning. Spraying at night has proved effective, but avoid frosty weather.

WFT activity can occur during flowering. If the pest is detected early, then apply spinosad at petal fall.

You should continue to monitor numbers of thrips so that you know whether there is a need to apply another series of sprays. If thrips are building up on sticky traps or you see many thrips on orchard plants (trees or weeds), or fresh damage is visible, then consider spraying again.

However, if the same insecticide is always used to control thrips, they will become resistant and the chemical will no longer be effective. Reduce the chance of thrips becoming resistant: apply three consecutive sprays of the same chemical and alternate to a different chemical group for the next series of sprays. There must be at least a 3-week break (when temperatures are lower than 20°C) or a 2-week break (when temperatures are greater than 20°C) before another series of sprays is applied. If monitoring indicates the need to spray earlier, then insecticide resistance, inappropriate spray application, or inadequate farm hygiene should be suspected and expert advice sought.

Biological control, biorational pesticides and organics

Very few options exist for organic growers facing thrips infestations. The preventive strategies mentioned earlier will minimise the impact of thrips but are unlikely to provide complete control during seasons in which thrips infestations are severe. Although predatory mites are used to control WFT in glasshouses, they do not persist in the orchard and will not give commercial control of the problem.

Weevils: Fuller's rose weevil, Garden weevil, Apple weevil, Fruit tree root weevil, Eucalyptus weevil

IPM quick facts

- Weevils are pests of apple and pear production because they damage fruit, leaves and roots and can also interfere with infrastructure such as irrigation. The Eucalyptus weevil (*Gonipterus scutellatus*) is a native weevil that can contaminate export consignments.
- Weevils are difficult to control once they are established. Therefore, effort needs to be put into preventing infestations. Orchard hygiene can reduce the chance of a serious weevil infestation. Weed control is important.
- A range of insecticides are registered for use against pest weevils. Always choose the pesticide that is likely to have least effect on natural enemies of weevils and other orchard pests.



Stewart Learmonth, WA Department of Food and Agriculture

There are five major pest species, and orchardists should learn to recognise those that are present in their regions.

Fuller's rose weevil (*Asynonychus cervinus*)

Adult Fuller's rose weevils are approximately 8 mm long. They are grey-brown and darker on the sides, with a distinguishing, short white line halfway down the body. They are flightless.

Garden weevil (*Phlyctinus callosus*)

Adult garden weevils are approximately 7 mm long. They are grey-brown with a prominent, pale V stripe at the base of the abdomen. They have a bulbous abdomen and are flightless.

Apple weevil (*Otiorynchus cribricollis*)

Adult apple weevils are dark brown to almost black and approximately 8 mm long. They have a slightly bulbous abdomen. The adult weevil is flightless and nocturnal, and all are females

Fruit tree root weevil (*Leptopius robustus*)

Adult weevils are approximately 10 mm long.

Eucalyptus weevil (*Gonipterus scutellatus*)

Eucalyptus weevils do not cause any damage to apples but can contaminate export shipments. They can be distinguished by their square shoulders. Adult weevils are approximately 10 mm long. They vary considerably in colour from grey to red-brown, with darker markings on the back. They are covered by small pale brown hairs that give a rough appearance to the body.

The pests and their impact

Various species of weevils are pests in all Australian apple production regions but are particularly serious in Western Australia, Victoria, Tasmania and South Australia. They cause direct damage to the fruit and leaves of apples. Some species also lay their egg masses in sprinkler heads, blocking them and disrupting irrigation. Most adult weevils are nocturnal and flightless and hide in cracks in the soil, under clods or between fruit during the day. The exception to this is Eucalyptus weevil, which can fly.

*Fuller's rose weevil**Garden weevil**Apple weevil**Fruit tree root weevil**Eucalyptus weevil*

Images courtesy of
Simon Hinkley and Ken Walker
(Museum Victoria)

Life cycle

The life cycle (p. 130) is simplified and generalised but will help orchardists to target IPM strategies at more susceptible phases of the pest's life. The exception to this generalised life cycle for weevils is that the larvae of *Eucalyptus* weevil feed on leaves.

Adult weevils emerge from the soil in late spring or early summer ❶. Most species of weevil are flightless (except *Eucalyptus* weevils), but are strong climbers. They make their way up into the canopies of apple trees and other vegetation and begin to feed on leaves and fruit ❷. When disturbed, most species drop to the ground and play dead. There is usually only one generation per year, but sometimes two.

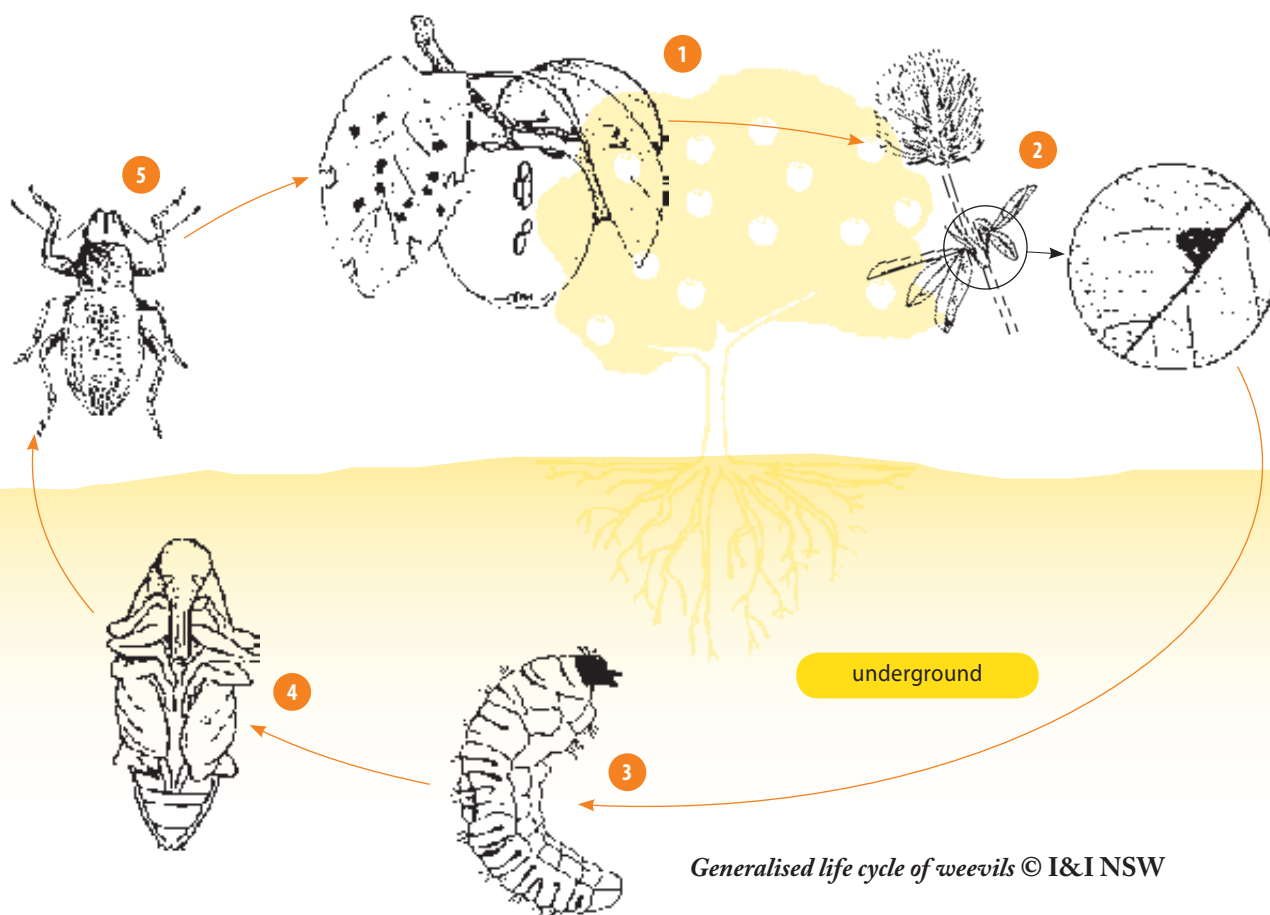
Eggs are oval-shaped, golden and laid in loose clusters or groups, with the exception of apple weevil eggs, which are laid singly ❸. They are laid in sheltered positions; common sites include the sheathing stipules of clover; new shoots of lucerne; splits in the bark of vines, shrubs and trees; and vegetable litter on the orchard floor. Fuller's rose weevils have a habit of laying egg masses in fine irrigation tubing and spray heads. The egg masses are resistant to drought and hatch when conditions become suitably moist.

The minimum length of time between laying and hatching varies between species but tends to be between 10 and 20 days.

Eucalyptus weevils lay their eggs in pods or capsules on the surfaces of newly expanded, mature eucalyptus leaves. The pods contain three to 16 pale yellow eggs arranged in vertical layers. These weevils particularly like *Eucalyptus globulus* (blue gum) and *E. viminalis* (manna gum). Both adults and larvae feed on foliage.

Upon hatching, young larvae of other species of weevils burrow immediately into the soil to a depth of 25 cm, where they feed on plant roots ❹. Initially larvae are yellow, but they become white as they mature. Fully mature larvae of most species are about 9 mm long. As spring approaches the mature larvae migrate closer to the surface and feed on shallow surface roots.

The larvae develop into pupae ❺. These pupae are essentially adult insects in a soft, fragile state, neatly folded and enclosed in a protective skin. This length of this pupal period varies between species. For Fuller's rose weevils it is typically 10 days before the adult emerges, whereas for garden weevils the length of the pupal stage is commonly 3 to 4 weeks.



Damage

Fruit

Garden weevil adults cause direct damage by feeding on young fruit. Scarring results and fruit is often unsuitable for the fresh market. Weevils feeding on leaves excrete around the stem-end of fruit, resulting in downgrading. Feeding by apple weevil adults on fruit stalks (pedicels) causes partial or complete ringbarking, sometimes leading to early fruit fall and reducing fruit size.

Leaves

Leaves infested by weevils have a ragged appearance. Initially damage may occur more at the edges of the leaves, giving them a notched or serrated appearance, but as the infestation worsens the damage spreads across the leaf surface. Foliage near the trunk or touching the ground is most likely to be damaged. In extreme cases the whole leaf (except the veins), as well as the soft bark on the twigs and pedicels, can be eaten. In turn this can lead to premature fruit drop, water stress and small fruit size. Damage tends to be more severe on younger trees.

Roots

Although larvae feed on plant roots they do not specifically target apple trees. Although some damage is likely, reports of significant losses are rare. Declining tree vigour is rare but has occasionally been reported. Root damage is apparent only when trees are removed and the severe root scalloping becomes apparent.

Similar damage

A number of other pests cause similar damage to apple leaves. Lightbrown apple moth (LBAM) feeds on the leaf surface, skeletonising it. If weevil infestation is responsible, the damage is more likely to be concentrated on the edges of the leaf. In any case, the pest itself is likely to be seen if sheltering leaves and fruit clusters are gently moved. Be aware that both weevils and LBAM larvae tend to fall to the ground when disturbed; care is needed to make the correct identification of the pest responsible.

Prevention and good orchard management

Eucalyptus weevil

Because of its ability to fly, the Eucalyptus weevil can enter orchards from reasonable distances. In a management sense this distinguishes it from other pest weevils and makes it extremely difficult to prevent and manage infestations. The Eucalyptus weevil is considered a relatively minor pest of plantation and ornamental Eucalypts. There are no relevant pesticide applications for use in pome fruit crops. Alpha-cypermethrin is registered for the control of eucalypt weevils on eucalypts. If an infestation is migrating from the adjoining bush or plantation properties, orchardists should contact the relevant managers and persuade them to control the pest.

Orchard hygiene

Once established in an orchard, weevils are difficult to control. The larvae of some species can survive in soil for up to 5 years, allowing re-infestation when conditions become suitable in apparently clean blocks. Prevention of establishment and spread is crucial to weevil control.

If weevil control has not been undertaken or has been poor, adults can be 'collected' during picking and other orchard activities. They also have the ability to cling tightly to rough surfaces. Carefully inspect any equipment, including ladders and bins that are being moved from infested areas to clean blocks. Preferably work in infested areas last. If bins are stored off farm, check them for weevils before they are unloaded. If any weevils are found, thoroughly pressure-wash the bins.

Weeds and rubbish on the orchard floor give weevils a place to lay eggs and alternative feeding sites. Numbers of weevils build up, and apple damage occurs more quickly in weedy rather than clean orchards. Maintaining a clean weed strip under the trees and a neatly mowed inter-row will reduce the numbers of weevils in the orchard. Removal of cape weed, sorrel, dandelion and dock will help to reduce weevil survival and abundance. However, if large numbers of weevils are seen on the weeds, care must be taken with mowing. In this situation mowing may drive the weevils into the apple-tree canopies.

Varieties

Some orchardists believe that the fruit of Pink Lady and Granny Smith is more likely to be damaged by weevils. It is likely that because of the lighter skin colour of these varieties, damage is more obvious.

Soil management

Weevils live underground for long periods of their lives and prefer lighter soils. They also benefit from cracks caused in the soil profile by drought. Addition of well-rotted compost or other organic material when blocks are established will reduce weevil numbers by reducing the rate at which soil dries out.

Choice of drippers

Fuller's rose weevil blocks irrigation components with its egg masses. Some products are less likely to be blocked than others. The Department of Primary Industries, Victoria (DPIV) has conducted research to determine the best irrigation equipment for use in areas where this problem occurs. Contact details for DPIV are provided in this manual (see 'Appendix 2: Useful contacts' p. 169).

Sticky bands

In some areas and for some species—particularly garden weevils—sticky bands can be used to limit the number of weevils that climb the trees. Sticky bands such as Tacgel® are less likely to work on dusty blocks, as they quickly get dirty and no longer trap crawling insects. Sticky bands used for garden weevil are not effective in preventing apple weevils from accessing the tree canopy. It is important to know which type of weevil is infesting your crop. Because apple weevil adults have spines over their bodies, some reduction in the numbers of weevils entering the tree canopy can be achieved by placing fibrous bands around trunks.

Monitoring

Larvae

When conditions are appropriate, larvae move toward the soil surface before emerging (see 'Life cycle' pp. 129–130). Examine a shovelful of soil at the base of the monitoring trees and in any known trouble spots in the block in late winter or early spring. The numbers of larvae actively feeding on the roots of trees or weeds provides an indication of the abundance of adult weevils that can be expected later on trees. For garden weevils in vineyards, the Department of Agriculture and Food, Western Australia, provides the following guidelines, which may be useful:

- If half of the shovelfuls have no weevil larva, whereas the other half of the soil samples have only one or two larvae, weevils are unlikely to be a problem.
- If weevil larvae are readily found—an average of five or more per shovel of soil—the potential for a weevil problem increases and control options should be considered.



Monitoring for weevils at the base of apple trees
Stewart Learmonth, WA Department of Food and Agriculture

Pupae

Although larvae are long-lived in the soil, the insect passes through its pupal stage relatively quickly. Nonetheless, monitoring for pupae should be done in a similar way to that for larvae. As pupae grow older they darken and become easier to spot, and this is a good indication of the imminent emergence of adults.

Adults

Adult garden weevils emerge between late October and late November, whereas Fuller's rose weevils and apple weevils emerge between late November and late December. Be aware that local variation in these emergence times will exist. Orchardists should be guided by their own experience, reinforced by accurate records of weevil monitoring from previous seasons. Weevil infestations tend to reasonably localised. Keep records of where in your blocks problems have occurred. Weevil infestations are more likely to recur in these areas, and they should be the focus of monitoring.

Weeds

As weevil adults emerge from the ground they move to the lowest vegetation first. Weeds are usually infested before trees. Careful monitoring of weeds and other vegetation (lucerne, clover) during early spring may give an early indication of weevil numbers.

Cardboard traps

Most weevils are nocturnal and seek out shelter during the day. Wrap corrugated cardboard around the tree trunk below the first branches, or place wooden plank traps on the ground. Traps should be numbered or placed in trees that are numbered so that weevil abundance can be recorded in specific locations. Alternatively, for young trees, tree guards will suffice. Check the traps fortnightly from November onwards and record weevil numbers.

Leaf damage

Look for the distinctive saw-tooth edges of leaves damaged in the early stage of weevil infestations—usually around the crotch of the tree. If damaged leaves are seen, verify the presence of weevils by inspecting the trees at night.



Corrugated cardboard for monitoring weevil numbers (top); weevil damage on leaves (above)
Stewart Learmonth, WA Department of Food and Agriculture

Management

Responsible use of pesticides

If preventive techniques have failed and an infestation has become established it may be necessary to make an insecticide application. Weevil infestations tend not to occur every season. They are also often restricted to known 'hot spots'. By carefully monitoring these hot spots it will be possible to spot-spray insecticides only when they are needed. This will minimise their off-target effect.

Indoxacarb (Avatar®) is registered for use against Fuller's rose weevil, garden weevil and apple weevil. It is relatively unlikely to be toxic to other insects in the orchard. Where an insecticide application is necessary its use should be preferred. Some of the pesticides registered for weevil control (alpha-cypermethrin and azinphos-methyl) are relatively broad spectrum and not desirable in the context of an IPM program. After application, orchardists should pay extra attention for subsequent infestations of mites.

Biological control, biorational pesticides and organics

For smaller orchards poultry may be a viable control option. Poultry will control a range of pests, including weevils. A maximum of 50 birds per hectare will be sufficient for small blocks. However, poultry should be carefully observed to make sure that their foraging does not damage roots or young tree butts.

A range of natural biological control agents also attack weevils. Birds can reduce the numbers of some species. Other natural enemies include wasps, assassin bugs, praying mantises and parasitic nematodes (such as *Heterorhabditis zealandica*). Unnecessary application of broad-spectrum insecticides should be avoided as it will have a detrimental effect on natural enemies.

Woolly aphid

IPM quick facts

- Woolly aphid causes damage to trees both above and below ground. Controlling infestations below ground is critical to successful management of this pest.
- Choose rootstocks carefully in areas prone to infestation.
- Monitor trees in late summer and autumn and flag any trees with fluffy white colonies. Be careful to examine pruning scars and rough bark as well as the axils of shoots and branches. Mark and document infested trees.
- Use an insecticidal soil drench between green tip and petal fall on trees marked during monitoring.
- Avoid spraying above-ground colonies if possible. Sprays are likely to kill *Aphelinus mali*, an effective biological control agent of woolly aphid.



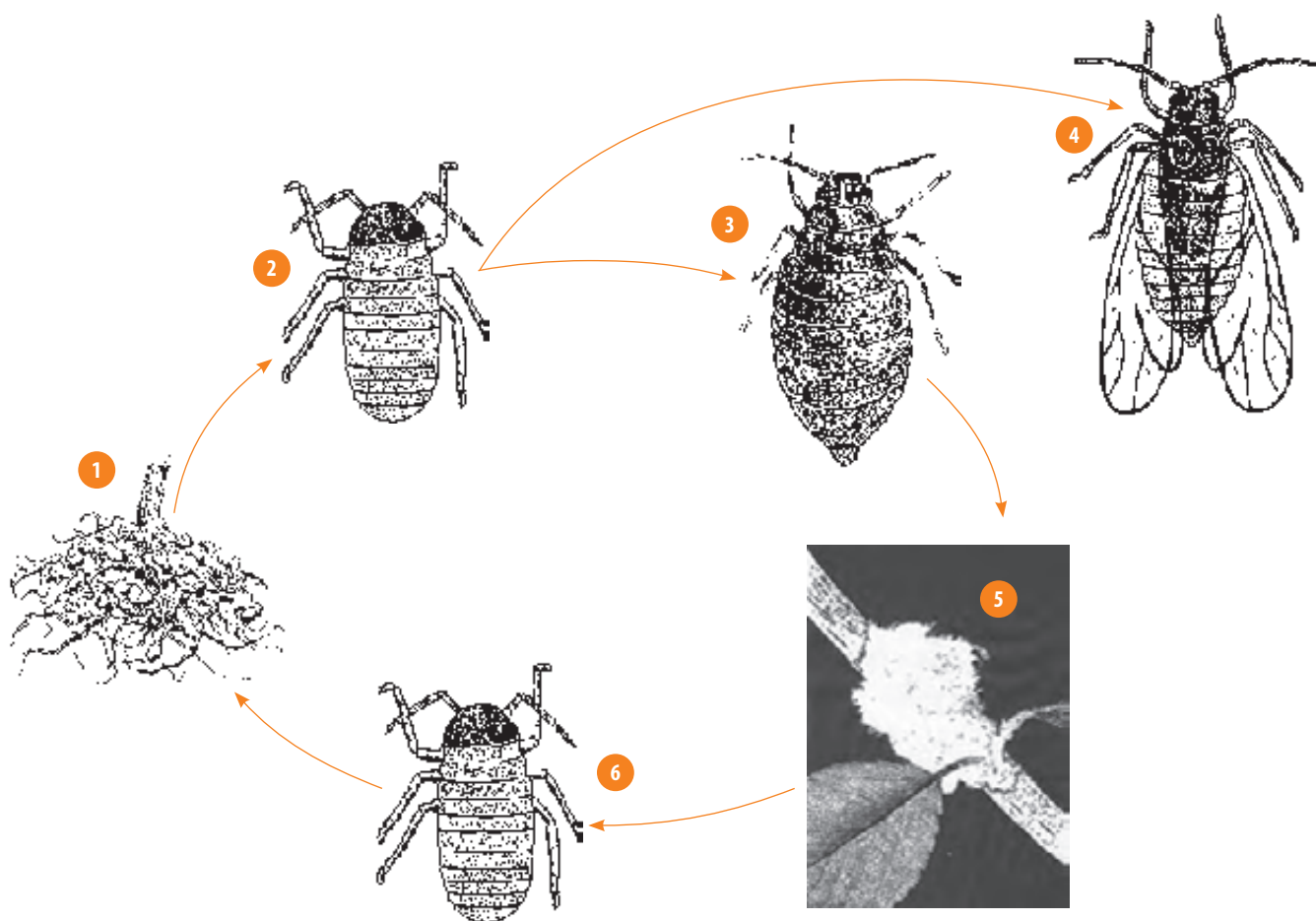
William M Ciesla, Forest Health Management International

The pest and its impact

The woolly aphid (*Eriosoma lanigerum*) is a serious pest of apple production in all Australian fruit-growing regions. This pest can infest apple trees and very occasionally pears. It can affect all parts of the tree, resulting in direct damage to fruit and limbs and a gradual decline in tree health. Because of its characteristic wool and stickiness it also has an effect on orchard operations—particularly summer pruning, thinning and harvesting.

Life cycle

Woolly aphid survives through winter as an early-stage nymph called a crawler. Crawlers are oblong, flattened, and a mealy grey to brown. These crawlers find sheltered positions in cracks and crevices in the bark; most disperse to the base of the tree and infest the roots. After finding a suitably sheltered feeding site, the crawler inserts its long feeding apparatus and settles. Crawlers feeding on the roots cause large galls to form ❶. These overwintering crawlers are long-lived and become dormant (i.e. they enter diapause) as temperatures decrease. As temperatures increase as spring approaches, crawlers become active and begin to disperse. Crawlers in root colonies ❷ may migrate into the tree canopy and vice-versa. Crawlers grow and moult four times before becoming adults. Later nymphal stages grow larger with each moult and



Life cycle of woolly aphid © I&I NSW

produce the characteristic white wool. There are two types of adult. The most common form has no wings and is asexual ③. The wingless adult aphid is about 2 mm long. It does not lay eggs but produces an average of 120 live young (all female) during its life. Woolly aphid can have 10 to 20 generations per season.

Toward the end of summer—particularly in warm regions winged adult female aphids appear ④. They are commonly found sitting on top of colonies of wingless individuals. They are a dull blue-grey to black and slightly larger than the wingless form. They produce live young, which are a mixture of male and female individuals. However, these males and females do not produce viable offspring and make no further contribution to the life cycle.

Woolly clusters or colonies ⑤ occur because, although dispersive, crawlers often settle close to their parent. Fluffy colonies are typically found in old pruning wounds and scars on major branches and on the trunk and water sprouts. Colonies begin at nodes and spread up and down the shoot. Woolly aphids are spread through the orchard by wind and by planting infested nursery stock.

Crawlers migrate between roots and shoots throughout the season, but as winter approaches those moving to the roots form dormant colonies ⑥.

Damage

Limbs and shoots

The most obvious sign of woolly aphid infestation is the presence of white woolly colonies. During summer, colonies form on actively growing terminals and water sprouts. These aphids produce copious quantities of sticky honeydew, which is released, falls on the fruit and shoots beneath, and fosters the development of sooty mould, resulting in fruit downgrading. In addition, brushing and crushing aphids during summer thinning, pruning or harvesting releases their body fluids, leaving purple stains on skin and clothing. This stickiness and the woolly filaments make orchard operations very uncomfortable.

Winter colonies do not produce the white wool commonly seen in summer. As winter approaches and colonies decline and lose their wool, galls become apparent. Galls occur when aphid feeding induces cell division and proliferation, resulting in the appearance of woody outgrowths. Galls in axils disrupt the production of fruit and vegetative buds. This may seriously disfigure young trees and nursery stock.

Overseas, woolly aphid has been implicated in the transmission of diseases such as perennial canker.

Roots

Feeding by woolly aphid also causes galls to form on the roots. Root galls can be very large, and continued feeding can kill roots, stunt tree growth and kill young trees. Because galls are prone to splitting at 0°C, they can predispose trees to infection by soil-borne diseases in colder areas.

Fruit

If aphids are in high numbers they produce a lot of sticky honeydew, which falls on to fruit. This becomes a food source for the fungus that causes sooty mould.

Occasionally, if numbers of the pest are particularly high, the aphid will infest the calyx end of the fruit. This is particularly the case in open-calyx varieties.



Woolly aphid colonies infesting the axils of apple leaves Joseph Berger



Galls on apple twigs University of Georgia



Galls formation caused on apple roots by woolly aphids
University of Georgia

Similar damage

Although other pests (e.g. lightbrown apple moth and mites) produce webbing or woolly shelters, it is difficult to mistake these for the aerial colonies of woolly aphid. Woolly aphid tends to infest axils, and its colonies are sticky with honeydew.

Root gallings is a little more difficult to distinguish from galling caused by nematodes or crown gall or a number of other pests. However, it is very rare for root infestations to occur without accompanying aerial infestations. Where root galls are found, the presence of aerial colonies is adequate confirmation that woolly aphid is responsible.

Prevention and good orchard management

Rootstocks

High-density plantings on dwarfing rootstocks return better yields; they result in better-quality fruit and are becoming the industry norm. However, modern dwarfing rootstocks are generally not as resistant to woolly aphid infestation as older rootstocks (see table on this page).

This problem is exacerbated in high-density plantings, because woolly aphid moves easily from tree to tree because canopies overlap.

The Merton-Malling (MM) series is resistant to woolly aphid. The least vigorous of these rootstocks is the semi-dwarfing variety MM102. MM102 provides an option for orchardists with high-density blocks where woolly aphid is likely to become a problem on more susceptible varieties. Experience in orchards has shown that MM102 is often suitable for replant soils, but note that this rootstock is susceptible to *Phytophthora* (see 'Phytophthora root and crown rot' p. 102) and there is limited information on its performance under Australian conditions. A breeding program is under way to develop woolly aphid-resistant dwarfing rootstocks based on the MM series, Northern Spy, the CG series from Geneva and *Malus seiboldii* (a crab apple). *Phytophthora* resistance will also be included in these rootstocks.

Susceptibilities of a range of rootstocks to infestation by woolly apple aphid (Campbell 2001)

Rootstock	Susceptibility to woolly aphid	
M27	Susceptible	
M9	Very susceptible	
P2	Susceptible	
Ott3	Susceptible	
M26	Moderately susceptible	
Mark (Mac 9)	Susceptible	
P1	Susceptible	
MM102	Resistant	
M7	Susceptible	
MM106	Resistant	
Bud490	Moderately susceptible	
Northern Spy	Resistant	
P18	Very susceptible	
MM111	Resistant	
MM104	Resistant	
Merton 793	Resistant	
M25	Moderately susceptible	
MM103	Resistant	
Merton 778	Resistant	
MM109	Resistant	
Merton 779	Resistant	

Remove suckers

Suckers or water shoots at the base of the tree and on major scaffold limbs are tender and become a favoured site for the development of early generations of the aphid as it migrates from the roots to the tree canopy. Removal of water shoots removes this convenient bridge.

Pruning

Most of the damage caused by woolly aphid occurs below ground; therefore, pruning can only help in the management of infestations. Nonetheless summer pruning to remove large colonies will help. Painting large pruning wounds also discourages woolly aphid from establishing colonies.

Because of the aphid's woolly, waxy coating it is difficult to wet colonies sufficiently for insecticides to be effective. Pruning will allow better penetration of canopies by insecticides.

Monitoring

In Australia, aerial colonies are often kept under control as a result of insecticides application for other pests such as codling moth. Root colonies are more likely to cause serious damage because they escape these insecticides. It's therefore necessary to monitor the orchard to determine which trees should be treated with a soil drench (see 'Responsible use of pesticides' on this page).

During late summer or autumn, apple trees with woolly aphid colonies or damage should be identified and marked for treatment early the following season. The presence of established aerial colonies is a good indication that root colonies are also present. Pay particular attention to old pruning wounds and damaged bark. Brightly coloured plastic flagging is useful for this purpose, but a written record of infested trees should also be kept. A written record ensures that where flagging is blown off or pulled off by birds the trees can still be found and treated. It also provides a useful historical record that can be used to determine the success of pest management.

Management

In Australia the key to good management of woolly aphid has proven to be control of the root-infesting phase of its life cycle (see 'Life cycle' p. 135). Applications of insecticides specifically to control aerial colonies of this pest are often unnecessary following effective application of a soil drench.



Aphid colonies on pruning wounds © I&I NSW

Responsible use of pesticides

Soil drench

Imidacloprid and clothianidin are registered for use as soil drenches for the control of woolly aphid, and the technique for application of these insecticides is similar. The product need be applied only to infested trees identified and marked during the previous season. Application to other trees wastes time and money.

A soil drench can be used on trees up to 7 years old. Timing is critical, and the application needs to be made between green tip and petal fall. Mix the product in a 1-L jug at the concentration prescribed on the label. Remove any weeds or mulch from around the base of the tree, leaving bare soil. Pour the contents of the jug to a distance of about 15 cm from the trunk. Penetration into the soil will be better if the soil is slightly moist. The insecticides become less effective after prolonged exposure to sunlight; therefore, running micro-sprinklers for an hour after the drench is helpful but not necessary.

In most cases application by hand or using a lance sprayer from the back of a four-wheel bike is sufficient. If a substantial percentage of trees are infested—particularly when they are in the same row—special rigs can be used for automated application of products to the bases of the trees.

Some orchardists have expressed concern at the cost of this technique. Depending on the soil type and moisture level and the age of the tree, it is likely that soil drenching need be done only every 3 years. Trees should be carefully monitored in the seasons following a soil drenching to determine when the next application is needed. Targeted application to infested trees also defrays costs.

Aerial colonies

At times it becomes necessary to apply an insecticide specifically for the control of aerial colonies of woolly aphid. Before making this application, consider:

- Is the problem restricted to one or two trees in a block? Spot sprays cost less money, are usually more effective, and will kill fewer predators of orchard pests.
- Is it likely that biological control agents (see 'Biological control, biorational pesticides and organics' on this page) will soon control woolly aphid without a pesticide application?



Butt drenching © I&I NSW

Biological control, biorational pesticides and organics

A number of native predators provide some control of woolly aphid; they include ladybird beetles (e.g. *Harmonia conformis*).

In 1923 the parasitoid wasp *Aphelinus mali* was introduced from New Zealand, and over a period of 15 years became established in all Australian apple-growing regions. Within a few years of its introduction, woolly aphid problems declined dramatically. The wasp is particularly effective in warmer areas and seasons. In cooler areas such as the NSW Tablelands, Tasmania and parts of Victoria, parasitoid activity may lag behind that of its host and infestations may require chemical control. Also note that the wasp cannot reach infestations on the roots.

Aphelinus mali lays more than one egg in each of its woolly aphid hosts. Eggs can be laid in all stages of aphid growth, but the parasitoid emerges from its host only as it approaches adulthood. Parasitised aphids become inflated, lose the ability to secrete their woolly covering, and turn into black mummies. The adult wasp emerges from the mummy through a large, irregular hole cut in the back of the aphid's abdomen.

Before making a decision to spray aerial colonies during the season it is important to check the level of activity of *Aphelinus mali*. Parasitised aphid colonies will have a sparse woolly coating and contain many blackened mummies. If parasitised colonies are widespread, it is probably best to delay insecticide application and carefully monitor aphid levels for the next few weeks.



Aphelinus mali is an effective parasitoid of woolly aphid. The parasitoid is a tiny wasp (left top). Parasitised colonies have sparse wool and black aphid mummies (left below). Close inspection of the mummies shows the exit hole from which *Aphelinus* emerged (above). © I&I NSW, © I&I NSW, Whitney Cranshaw, Colorado State University

Apple leafhopper (canary fly in Tasmania)



I&I NSW

The pest and its impact

The Australian apple leafhopper *Edwardsiana froggatti* irregularly infests apple and pear trees. Problems tend to be worse during dry years. The insect feeds by piercing and sucking juices from the leaves, resulting in chlorotic stippling, subsequent reduction in photosynthetic capacity, and (in extreme cases) premature leaf fall. If infestation is very severe, the insects foul the fruit with their excrement, giving the fruit a black, speckled appearance. Although this is superficial

it may necessitate extra washing. Leafhoppers fly quickly from their feeding or resting sites when disturbed. If they are present late in the season this behaviour irritates orchard workers and can slow harvest operations. *Edwardsiana froggatti*, which is also found in New Zealand, is known as the canary fly in Tasmania because of its bright yellow colouring. In the past, use of broad-spectrum insecticides for codling moth control has kept apple leafhopper in check, but the reduction in use of these insecticides in favour of more targeted IPM for control of major pests is leading to a resurgence of problems with secondary pests such as apple leafhoppers.

Description and life cycle

Adult apple leafhoppers are 3 to 4 mm long and pale to bright yellow. Leafhopper nymphs are whitish green, smaller, and wingless, and are usually found on the undersides of older leaves.



Apple leafhopper (Edwardsiana froggatti), adult (top) and nymph (above) © I&I NSW

During late autumn, female apple leafhoppers lay their eggs under the soft bark of the current season's twigs. These eggs remain dormant during the winter and begin to hatch in spring, at about the pink stage. Depending on the weather, hatching can extend over several weeks. The emerging nymphs feed on the undersides of leaves, gradually developing and becoming larger. Later the nymphs develop wings and finally become adult males and females. In warmer regions mating occurs in mid-summer and a second generation of eggs is laid in the veins of leaves. Where this occurs, the summer generation reaches adulthood in autumn.

Monitoring

No formal monitoring procedure or threshold levels have been developed for apple leafhopper, but if the insect has been a problem in previous seasons and the long-range forecast is for a largely dry season, problems should be expected.

Numbers of nymphs of the closely related species *Typhlocyba pomaria* (the white apple leaf hopper) are monitored in the USA as an indication of the severity of pending infestations and the need to apply insecticides. In this case, sprays are applied when nymphs are present on 30% of leaves. This may be a useful reference point in Australia, but until local experience is gained this rule should be used with caution. In any case, if large numbers of nymphs are seen during monitoring, pesticide application is likely to be warranted.

Management

Very little can be done to prevent leafhopper infestations, and often the only option available is application of an insecticide. Applications should be made only when necessary. Several biological control agents are likely to regulate apple leafhopper numbers (particularly in Tasmania), and premature application of insecticides is likely to kill biological control agents before they have had a chance to reduce pest numbers.

Responsible use of pesticides

Only two insecticides are registered for use against apple leaf hopper: maldison and azinphos-methyl. Both products are likely to kill beneficial organisms and may result in unintended consequences such as pest mite outbreaks. They should be used with caution and only when necessary.

Although not registered for apple leafhopper, applications of abamectin 2 weeks after petal fall for mite control will provide good control of apple leafhopper through until January.

Biological control

A parasitoid (*Anagrus armatus*) was introduced to Tasmania in 1935; it subsequently parasitised and killed 80% to 90% of overwintering eggs. By 1947, apple leafhopper was reported to no longer be a pest in some areas of Tasmania. The parasitoid was sent to South Australia and Western Australia during the 1940s but does not appear to have become established.

Apple mosaic virus



© I&I NSW

The disease and its impact

Apple mosaic virus is one of the most well-known diseases of apple production in Australia. It occurs commonly in all apple-producing regions and also infects quince, stone fruits, strawberries and hawthorn. Infected trees have pale to cream spots on expanding spring leaves. The number and severity of affected leaves depends on seasonal temperatures, with the symptoms being more severe in years with moderate spring temperatures. This reduction is caused by a severe reduction in bud set on infected trees.

There is some tenuous evidence that apple mosaic virus may predispose trees to infection by other diseases. Granny Smith is relatively resistant to *Alternaria* leaf spot unless infected by apple mosaic virus.

Biology and control

All varieties of apples are susceptible to this disease. Opinion is divided as to whether some varieties show a level of tolerance that is commercially viable. It is most likely that yields are similarly affected, but damage is more obvious on varieties such as Cripps Pink, Jonathan, Golden Delicious and Granny Smith.

The disease is transmitted by budding and grafting from infected stock. It is not transmitted by insects or other vectors. Transmission also occurs through naturally occurring root grafts, but this does not seem to be significant in commercial orchards. Once established, the disease cannot be cured. The only meaningful way of controlling this disease is to plant only virus-free material. If trees are infected it is usually not economical to tolerate yield losses. Remove infected trees and replace them with new stock.

Other viruses

A range of other viruses affect Australian apples and pears. Many of these viruses produce no obvious symptoms but affect yield. If trees perform poorly and there is no obvious physiological cause (e.g. nutrient deficiency), it is often best to replace the trees with virus-free stock and then closely monitor the yield when fruit is produced.

Pear stony pit is also relatively common in Australia. It is caused by a virus which is carried in the scion wood. The disease cannot be transmitted by insects and therefore only becomes a problem after diseased planting material is introduced in to the orchard. Symptoms of this disease include deformation of the fruit, development of stony growths in the fruits flesh, and roughened bark. Symptoms vary between pear varieties. 'Bosc' shows all types of symptoms. Cultivars showing mild symptoms include Comice, Bartlett, and Packham's Triumph.



Stony pit virus © I&I NSW

Armillaria root rot



Andrej Kunca, National Forest Centre,
Slovakia, Slovak Republic

The disease and its impact

In Australia, Armillaria root rot is caused mainly by a native fungal species, *Armillaria luteobubalina*, whereas overseas the most common cause of this disease is the closely related fungus *Armillaria mellea*. The fungus can infect at least 200 plant species and is also a significant pathogen of native forestry. Because of this, the disease is often seen where bush has been recently been cleared and an orchard block has been planted.



Felt-like fungus under the bark of a tree infected by Armillaria root rot (top). Shoelace-like rhizomorphs of the fungus can spread the disease from tree to tree (above). William Jacobi, Colorado State University; Joseph O'Brien, United States Department of Agriculture Forest Service

Symptoms and life cycle

Growers will notice the above-ground symptoms of the disease first. The symptoms are similar to those of other root rot diseases: leaves yellow and fall prematurely and the tree shows ill-thrift, the limbs die back, and the entire tree may die. Better diagnosis requires a closer look. Upon scraping away bark on the rotted stems and roots a white felt-like mat of fungus is revealed. This is often fan-shaped and smells like mushrooms. If the roots and soil around them are closely examined, shoelace-like rhizomorphs may be found. The fungus moves from tree to tree largely through root contact, but rhizomorphs can also be responsible for movement of the disease.

Olive-brown to yellow clusters of toadstools are sometimes seen growing from the bases of dead and rotting trees during the period from May to July. These toadstools can be up to 12 cm in diameter, with a stipe (stalk) of up to 15 cm high, although usually less.

The soil conditions that favour the development of the disease are not well understood. It is thought that the fungus prefers lighter soils or clays with reasonable drainage, and the disease can be very serious in the Stanthorpe region. Any form of stress is thought to predispose trees to infection, and both flood and drought have been implicated as contributing to disease severity. The fungus can survive in soil for extremely long periods (up to 20 years).

Control

(see Washington 2006 in 'More information: Armillaria root rot p. 204)

When clearing and planting new ground

- Ringbark native trees and leave them for at least 6 months before removing them, so that starch reserves in the tree are depleted. This lowers the chance of such trees becoming centres of infection. Note that permits may be required for clearing of native vegetation.

- Rip the area thoroughly, and remove and burn all stumps and large roots.
- Leave the area under pasture for at least 2 or 3 years to allow small roots to rot.

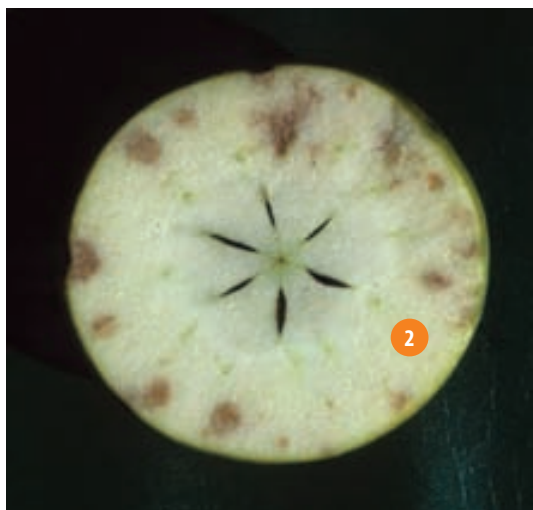
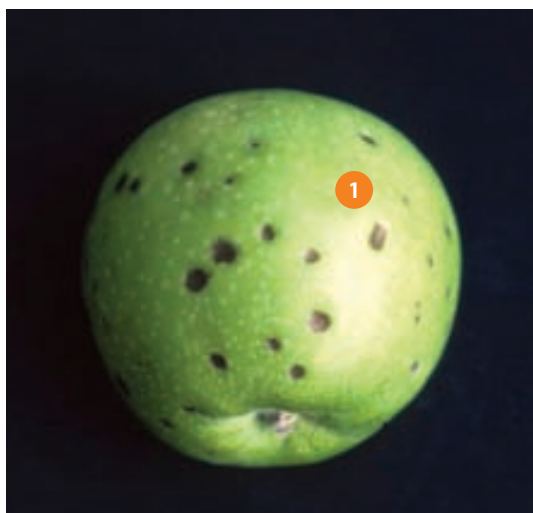
When treating slightly affected trees

- Remove soil from around the butt and main roots to a radius of about 750 mm. A high-pressure jet of water from a spray pump is a convenient way to remove soil from around affected trees. Cut out and burn diseased bark and roots, and paint cuts with a plastic paint. Leave the crown and roots permanently uncovered and do not replace the soil during cultivation. This will halt the disease, as exposure to air kills Armillaria.
- Remove and burn all badly affected trees, including roots.

Before replanting severely affected trees

- Map the affected area to find the extent of the infection within the orchard. Include all trees showing poor growth, all replants within the area, and two rows of apparently healthy trees adjacent to the affected area. Trees can be checked for infection by exposing the roots and butts, as described above, and by removing of a small piece of bark from this region. On infected trees this will reveal a creamy white mycelial fan. If rhizomorphs or mycelial fans are found on any apparently healthy trees, then adjacent trees should also be checked as well.
- Remove all of the affected trees within the area, and as many roots as possible, and burn them on the spot. Do not move this material from the site or cultivate outwards from the affected area, as the disease spreads readily through infected roots and stems.
- Plant a cover crop and allow time for any fine roots that remain in the soil to rot down completely before replanting.
- Monitor carefully for any signs that disease is reappearing.

Bitter pit



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The disorder and its impact

Bitter pit is a physiological disorder of apples that occurs when insufficient calcium is present in fruit. Symptoms of bitter pit include dark sunken pits on the surface of the fruit ❶ and corky brown tissue ❷.

This disorder is often associated with larger fruit, but a better understanding of the causes of calcium deficiency and how it relates to other factors in the orchard will help growers to treat the problem.

Fruit calcium levels can be influenced by many things, but a number of tree management issues exacerbate the problem. Trees with a high leaf to fruit ratio, and lightly cropped trees, are more prone to bitter pit.

Light cropping and bitter pit: causes

Poor pollination

Poor pollination can occur because of the presence of inappropriate pollinators, lack of bee activity because of rainy, windy or cold weather during bloom, or use of insecticides that are toxic to bees. The number of seeds in the fruit provides a rough index to the level of pollination; if fruit have only a small number of seeds, then beware of bitter pit.

Tree age

Young trees tend to have greater vigour and therefore a higher leaf to fruit ratio.

Excessive vigour

Over-fertilisation, overwatering and excessively hard pruning promote foliar growth at the expense of fruit production, thus boosting the leaf to fruit ratio.

Over-thinning

Over-thinning can occur as a result of poor management, or naturally because of hail or late frosts.

Other factors causing bitter pit

Variety and rootstock

Late in the season, as fruit finalises its maturation, it loses its connection to the tree's xylem. The xylem is the tube that passes calcium from the roots to the fruits. Varieties that lose this connection early accumulate less calcium and are prone to bitter pit. These varieties include Braeburn, Granny Smith, Gravenstein, Jonathan and Golden Delicious. Varieties less likely to suffer from bitter pit for this reason include Red Delicious.

Incompatibility between scions and rootstocks can also limit xylem flow and consequently affect calcium uptake.

Poor uptake of calcium by the roots

Anything that affects root health and function can be the primary cause of bitter pit. This includes dry or waterlogged soil, low soil calcium, a low calcium to magnesium ratio, a large amount of potassium fertiliser, heavy weed or grass growth, or competition between tree roots in a high-density planting.

Poor root function can also be caused by salinity, acidic soil, inadequate phosphorus, compaction, low oxygen, cold conditions, root disease, replanting or nematodes.

Preventive management

A soil analysis should be done on new blocks before planting, and suitable varieties and variety/rootstock combinations should be planted. If established blocks have been affected by bitter pit in the previous season, growers should determine the underlying cause (e.g. poor pollination) and treat it appropriately. Up to six foliar calcium applications per season can be made; details are included in Appendix 5: Using pesticides in IPM' p. 179). Late-season foliar calcium applications are particularly important. At this stage there is reduced transport of nutrients from the soil to the fruit and foliar applications are the most successful way of boosting calcium.

Pear leaf blister mite



Ontario Ministry of Agriculture, Food and Rural Affairs



Close-up of damage caused by pear leaf blister mite. Tiny mites can be seen in the lesion (above). A pear leaf blister mite magnified (inset). Norfolk Fruit Growers Association, Ontario, Canada

Damage

The pest and its impact

The pear leaf blister mite, *Eriophyes pyri*, is principally a pest of pears but also infests apples and some species of ash. Adult mites are tiny (0.2 to 2.5 mm long). Immature adults and young adults are white, and the body develops a pinkish hue later in the season. Their small size makes them more difficult to observe than other pest mites. They cannot be seen clearly with a 10× hand lens, and detection is likely to require a microscope.

Pear leaf blister mite has an elongated, tapering abdomen and two pairs of legs next to the head.

Adult mites survive through the winter in the bud scales. In spring these adults migrate to the bottoms of leaves and begin to feed. In warmer regions eggs are laid in the bud scales before migration. Alternatively, eggs are laid within the blisters that form as a result of feeding. The eggs hatch during spring and the immature mites continue feeding within the blisters until they reach maturity. There are often several generations per season, depending on the temperature.



Raised blisters as a result of pear leaf blister mite infestation on the underside of leaves Ontario Ministry of Agriculture, Food and Rural Affairs



Raised blisters as a result of pear leaf blister mite infestation on the top (top) of leaves. Infestations cause sunken russeted lesions on pear fruit (above). Ontario Ministry of Agriculture, Food and Rural Affairs

Damage occurs on leaves, fruit and stems. On leaves, damage first appears as small, green pimples on the underside of the leaf. These pimples develop into blisters and gradually take on a reddish appearance, eventually becoming brown dead spots. Blisters and spots can be seen on both leaf surfaces. Early feeding on fruits typically results in depressed, russeted spots, but if infestations are severe dwarfing and malformation can occur. Blisters on fruit stems often result in premature fruit drop.

Management

In deciding whether management is necessary, consider the level of damage caused by infestations in previous years and the likelihood of a warm spring that would increase the likelihood of damage this season. Management is rarely needed on mature, otherwise healthy trees, as the mites are unlikely to cause economically significant damage. Early-season infestation on young trees should be managed, as leaf damage can significantly reduce vigour. Management will also be necessary if significant fruit damage has occurred in previous seasons.

If the infestation has been severe, a postharvest application of paraffinic oil is recommended. Lime sulfur is also registered for dormant application until late budswell. If a miticide is required, in-season carbaryl is registered for this use.

Silver leaf



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The disease

Silver leaf is a disease caused by the fungus *Chondrostereum purpureum*. The disease occurs on both apples and pears. The same pathogen also causes silver leaf on stone fruit and other deciduous trees and shrubs, and infections pass easily among trees of different species.

The disease occurs in temperate regions throughout the world, but in Australia it is more common in cooler regions, particularly those that experience damp, humid conditions (e.g. the Adelaide Hills).



Symptoms and impact

The disease is characterised by the leaves developing a silvery sheen. This sheen is caused by light shining through leaf cells that are damaged by toxins exuded by the pathogen. Overall, the tree becomes unthrifty, with reduced leaf area, poor root growth and low yields of poor-quality fruit that does not store well. In storage, infected fruit is predisposed to infection by other fruit-rotting fungi. Apple and pear trees tolerate the disease better than stone fruit trees, which often die.

The disease is one of a number of factors that can lead to an increased incidence of water core.

External (top) and internal (above) symptoms of water core caused by the disease silver leaf
© I&I NSW

Management

The disease can be controlled by careful pruning, in conjunction with wound dressings.

Avoid winter pruning, particularly on calm, damp, overcast days when the greatest numbers of fungal spores will be present in the orchard. Aim to produce a wound that will heal quickly to produce a doughnut-shaped callus. Good technique and tools are important. Use good-quality, sharp pruning tools. Ragged wounds encourage the pathogen to colonise.

The disease is not easily transmitted on pruning tools, and it is not necessary to sterilise tools between cuts.

All prunings must be buried or burned. Also note that other forms of wounding (e.g. hail damage to limbs) may create infection sites for this disease.

Apply wound dressings as soon as possible after pruning—certainly on the same day. The pathogen produces more spores in the dark, and leaving wounds unprotected is a recipe for disaster. If for some reason wound dressings are not applied quickly, it is often best to leave wounds unprotected, as infection is likely to have already occurred. The pathogen is likely to have penetrated to some depth, and a surface dressing merely traps the fungus in the tree. Applying a late wound dressing is also likely to kill beneficial organisms that might otherwise kill the pathogen.



Painting large wounds prevents infection
© I&I NSW

Acrylic paints often form a physical barrier sufficient to stop the pathogen penetrating through wounds. Do not water the paints down; this reduces their effectiveness significantly and is false economy. Where wounds are particularly large, a second coat of paint may be required.

When applied at the wrong rates, many fungicides are toxic to trees. Therefore, avoid 'home-made' mixtures of paint and fungicides. Use of copper-based products is especially dangerous, as they may increase the tree's susceptibility to silver leaf. A commercial wound dressing formulation that contains the fungicides cyproconazole and iodocarb is available. Use this formulation if silver leaf has been a serious problem.

Snails



Paul James, Rural Solutions SA

Although several pest species are found in Australia, damage is usually caused by the common garden snail, *Helix aspersa*. Coincidentally this is also an edible species that is widely grown and used in European cookery. Some orchardists see control of garden snail to be an additional benefit to the presence of European fruit pickers, who collect and eat the snails.

Snails are hermaphroditic, meaning that each individual is both male and female. Mating involves a mutual exchange of sperm, and each partner stores fertilised eggs in its body until conditions are appropriate for laying. Eggs are laid into shallow depressions or crevices in moist earth, often in the moist soil beneath piles of leaves after they have fallen from trees. It usually takes emerging snails about 2 years to reach maturity.

As with all pests, control of snails is most effective when an integrated approach involving a number of techniques is used.

The pest and its impact

Snails are voracious feeders and can damage leaves and young fruit. Gala apples are particularly susceptible to infestation, with losses as high as 5% to 10% recorded in some Australian orchards. Damage is worst where trees are grown under nets. Orchards in Stanthorpe, the Goulburn Valley, Perth and the Adelaide Hills are often severely affected. Most damage occurs at night, as snails are largely nocturnal, although they will venture out if the weather is cool and rainy. During the day snails tend to cluster together in sheltered, humid places, such as under piles of leaves or prunings. Damage can also occur where large numbers of snails shelter in tree guards. Over a period of time the excrement from these snails builds up and can completely fill the guards with a rich, moist organic substrate. If this substrate builds up above the graft union adventitious roots can form from the scion. This also predisposes trees to diseases such as Phytophthora (see 'Phytophthora root and crown rot' p. 102).



Snail eggs on the orchard floor © I&I NSW

Cultural control

Snails are absolutely dependent on the presence of humid sheltering refuges, which they retreat to during the heat of the day. Any technique that makes it more difficult for snails to find these refuges will reduce their numbers.

Weeds and the orchard floor

It is important to keep the area under trees and the inter-row clean, tidy and free of weeds. Dense vegetation provides shelter for snails, and extra care should be taken for rows of trees near fence lines, where weed control may be difficult.

Snail eggs often survive through winter in moist soil under fallen leaves. Ground sprays of urea (see 'Apple scab (Black spot), Pear scab' p. 40) cause these leaves to break down quickly eliminating moist refuges. If serious damage has occurred over a series of seasons some orchardists have raked leaves out of the orchard.

Barriers

Snails do not like crawling on dry or abrasive surfaces. It may be possible to protect particularly badly infested trees with barriers, although this may not be practicable for large areas. This technique is also often used by orchardists who use organic techniques. Placing a ring of ash or sawdust around a tree forms a barrier across which snails are unable to travel. Superphosphate is also suitable. Rain or irrigation tends to disperse these barriers, and they require frequent reapplication.

Copper is an effective repellent of snails, and copper bands or wire placed around the butts of trees can be an effective barrier, but these need to be checked and renewed regularly as the tree butt expands. These techniques must be used in conjunction with effective pruning that stops branches—particularly fruit-laden branches—from touching the ground. If branches touch the ground snails will bypass the barriers.

Snails take refuge in tree guards. Guards should be removed as soon as is practicable. Snails don't like crawling on rough or abrasive surfaces and, where guards are necessary, surrounding them with a layer of fine straw mulch may reduce the rate of infestation.

Poultry in the orchard

Ducks, geese, chickens and guinea fowl are often kept in orchards to help to control pests. It is important to determine which type of birds are most suitable for the specific pests present in your orchard. Birds vary in their effectiveness against different pests. All birds must be managed properly. Unmanaged birds can cause more problems than they solve.

Ducks and geese are the most effective birds for the control of snails. Khaki Campbell and Indian Runner ducks are particularly good. Access to dams and waterways should be restricted to encourage foraging rather than resting on the water. A flock of two dozen birds can control snails over an area as large as 20 hectares.

Chickens are a good multi-purpose choice as they are more likely to control insects in addition to snails. Although guinea fowl do feed on snails they are not as effective as ducks or chickens, and they should principally be used where insects such as earwigs are the major concern.



Chickens in a Western Australian vineyard

The following points should be noted if birds are used to control orchard pests:

- Birds must be protected from predators, including foxes and feral cats.
- Certain pesticides, including diazinon, fenthion and azinphos methyl, are highly toxic to birds. A lockable pen or shelter must be available well away from the orchard when pesticides are being applied.

- Many birds will damage mature fruit.
- Foraging and dust baths during dry weather can predispose trees to mite infestation.
- Be very careful if eggs are harvested for human consumption. Testing should be undertaken, particularly if organochlorine insecticides are used or have been used in the past.

On mainland Australia foxes are often a problem. Birds must be kept in a fox-proof roost overnight. Daytime fox predation can also occur, particularly where human activity is low. Keeping vegetation within the orchard low makes it more difficult for foxes to stalk poultry.

Responsible use of pesticides

Copper

Copper is highly repellent to snails. Application of copper pesticides for the control of black spot and/or bitter rot at green tip will have some coincidental effect because of the product's deterrent qualities. The best effect is achieved when the application is very thorough and the trees are completely saturated.

Socutil® is a snail repellent based on a buffered copper complex; it is registered for use on deciduous fruit trees before flowering. It provides an option for early-season snail control, but—as with all copper products—care should be taken not to spray or overspray foliage or buds, as it will burn them.

Baits

Only one pesticide (Baysol, Mesurol), based on the active ingredient methiocarb, is registered for use as a bait in orchards.

This pesticide is very toxic, and improper application can result in poisoning; livestock and small children are at particular risk. Before using broad-scale snail baiting, make sure that alternative management techniques are ineffective and that the damage caused by snails warrants bait application. Baits are also expensive, and unnecessary application is a waste of money.

If it is necessary to apply baits, optimising application efficiency will reduce the volume required, save money and reduce the risk of accidental poisoning. Snail bait application can be optimised in the following ways:

- *Timing.* Do not apply baits in spring. Snail populations are at their greatest at this time, and greater numbers of snails are likely to survive a baiting program. Vegetation is also at its most lush, and fewer snails are likely to take baits when alternatives exist. Snail baits also get lost in long vegetation at this time of the year. In some regions rainfall can still be quite heavy in spring, reducing the effective life of baits.
- Baits are best applied in autumn, killing adult snails before they are able to lay eggs. This time also corresponds to a time when snails are hungriest, having spent the summer months inactive and having emerged when little alternative feed is available.
- Baits can be applied opportunistically in summer after thunderstorms initiate snail activity.
- *Other pesticides.* Do not apply copper-based pesticides when snail baits are present in the orchard. Copper is highly repellent to snails, and copper sprays are likely to taint baits and result in reduced snail feeding. For the same reason, mixing copper with baits in an attempt to increase their effectiveness does not work.
- Pesticides of any kind should be applied and allowed to dry before the application of baits, reducing the risk that the baits will be tainted.
- *Application.* Do not heap baits. A uniform spread of bait pellets in areas where snails are likely to converge or move will maximise the effectiveness of a given quantity of bait. Removal of overgrown vegetation and weeds along fence lines and along the tree row will increase the effectiveness of snail baiting.

White root rot



Christine Horlock, Biosecurity Queensland,
a service of DEEDI



The pest and its impact

The fungus *Rosellinia necatrix* (previously *Dematophora necatrix*) causes the disease white root rot. White root rot has been recorded only in the Granite Belt district of Queensland and the NSW Northern Tablelands, where it continues to cause serious tree losses. The disease is most severe in replanted orchards in which the previous apple trees were affected. In the past, serious losses have occurred in new orchards established in land cleared of native vegetation that was susceptible to the fungus. This disease will become more important as the numbers of medium- to high-density orchards increase.

Symptoms

Both apple and pear are hosts.

Trees develop an unthrifty appearance, with leaf yellowing, cessation of shoot growth, small leaves, premature leaf fall and small, shrivelled fruit. These symptoms are not distinctly different from those caused by other soil-borne pathogens (e.g. *Armillaria* root rot, crown rot and *Phytophthora* root rot) and root-lesion nematodes.



Above-ground symptoms of white root rot (top) are indistinguishable from those of other root-infecting diseases. Below-ground (above) the disease is characterised by almost complete destruction of primary and secondary roots and profuse growth of white fungal material. Christine Horlock, Biosecurity Queensland, a service of DEEDI

Crown

The bark of the crown roots and the base of the trunk can show a dark, wet rot. A distinct, sharp margin is evident between healthy and infected bark. A thin layer of white fungal growth occurs under the bark and is more prominent after wet weather.

Roots

This disease causes significant root damage in a relatively short period, with both fine and major roots equally affected. Infected roots appear to have a dark, wet surface rot, etching into the healthy internal wood. Affected roots can be covered with white strands of fungal growth, which can also grow into the soil and leaf litter in wet conditions. Hair-like growths of the fungus, called synnemata, can appear on the surfaces of the lower trunk at soil level and on the roots on undisturbed trees that have been infected for some time.

Sources of infection and spread

The fungus survives in the soil on old rotted roots and root debris left in the ground, on the roots of various native trees, and on the roots of weeds such as fleabane (*Conyza* spp.) and stinking roger (*Tagetes minuta*). Apple trees planted into infested soils become infected when their roots contact infected root material. The interconnected root zones in medium- and high-density orchard plantings greatly increase the distribution and rapidity of spread of this disease within orchards.

Management

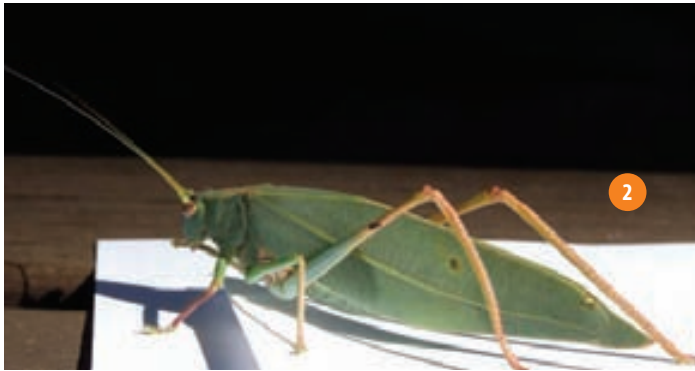
- Thoroughly remove infected roots from affected trees.
- Remove affected trees from the orchard as soon as possible, preferably while the trees are still alive, to make it easier to remove roots.
- Remove at least two, and preferably three, healthy-looking trees on either side of the affected trees. In high-density orchards, remove trees within 2 m from the root system of affected trees.

- Treat mature trees on either side of the vacant space, as well as the vacated soil, with a registered soil-sterilant fungicide.
- Take care before replanting young trees into spaces left by trees killed by white root rot in mature orchards. Planting young trees in the midst of a mature orchard may cause the replant trees significant stress, particularly in situations where the replant trees will be receiving the same amount of water and nutritional supplements as mature trees.
- Remove as many tree roots from as deep in the soil as possible when replanting a block where trees have been previously affected by white root rot.
- Clean machinery after use in a block affected by white root rot.
- Never pile up roots removed from blocks affected by white root rot on clean soil; instead, they should be carefully disposed of in an area well away from apple production blocks.
- Consider using a long-term (several years) crop rotation for severely affected blocks after a short-term (1-year) rotation of green manure crops. Anecdotally, successful rotation crops for the Granite Belt include stone fruit, grapes and vegetables.
- To facilitate short-term crop rotation, plant new trees in nursery blocks in a separate location for their first year, before planting them as 2-year-old trees into remediated blocks. Then crop these trees within 1 year of planting, instead of 2.

Acknowledgment

This chapter was written by Christine Horlock [Senior Plant Health Scientist, Biosecurity Queensland, a service of the Department of Employment, Economic Development and Innovation (DEEDI)].

Wingless grasshoppers and katydids



Wingless grasshopper (top) and Katydid (above)
Stewart Learmonth, WA Department of
Agriculture and Food; © I&I NSW

The pests and their impact

Wingless grasshoppers (*Phaulacridium vittatum*) are native to Australia and tend to be pests in areas such as the Granite Belt, Perth Hills, NSW Central West and Donnybrook/Manjimup.

Unlike locusts, grasshoppers don't form large migratory swarms. Therefore, the source of grasshoppers is likely to be close to the orchard (e.g. an adjacent orchard). This is borne out by Australian orchardists' observations that grasshoppers tend to turn up in the same spot every time there is an infestation. The orchard provides an alternative feeding source for grasshoppers as the grass and other food sources in paddocks starts to dry off in summer. Grasshoppers ① move in to orchards from December to February and feed on tender young shoots and leaves. The problem is worse along boundary rows, where they can completely defoliate trees. Young trees are particularly at risk.

Katydids ② are grasshopper-like insects with thin, long antennae (usually longer than the body). Stone fruit is more likely to suffer katydid damage than apples and pears. Adult insects are 40 to 50 mm long and green to brown. There is one generation per year; eggs are laid from January to April. Nymphs hatch in early spring.

Katydids feed on the surface of young fruit. As feeding wounds dry, a white-grey scar is formed; it expands as the fruit grows and matures. Katydids are active insects, and only a small number can result in substantial damage.

Nymphs also chew leaves, but this damage is relatively unimportant

Management

Grasshoppers like bare sandy ground for egg-laying. Look for emerging grasshoppers between September and November. If these egg beds can be found they can be cultivated and sown to tall pasture grasses such as rye grass; grasshoppers do not like these plants. Remove weeds such as capeweed and flatweed, as they provide for emerging and developing nymphs.

Poultry such as guinea fowl and chickens in the orchard can be an effective option for grasshopper control.

Pesticides should be seen as a last option if monitoring indicates the likelihood of significant damage. Pesticides can be applied to egg beds, the orchard floor or trees. As pesticides are likely to disrupt IPM for other pests, it is best to use them in an extremely targeted way by baiting, spot spraying or spraying only boundaries. Because grasshoppers infest only a portion of the orchard it should be possible to leave the majority of the orchard untreated. A commercial bait (David Gray's Cricket and Grasshopper Killer Bait) is registered for this application. Always read the label.

Pesticides should only be applied for katydids when there is potential for serious crop damage. The application should be targeted. Indoxacarb is the only pesticide registered for this use.

Both wingless grasshoppers and katydids are prey for a range of predators and parasites. For wingless grasshoppers, parasites—including nematodes and *Scelio* spp., bee flies and flesh flies—can have a substantial impact on egg survival. Parasites of katydid eggs include tachinid flies and wasps, whereas predators of nymph and adult katydids include assassin bugs, praying mantises, sphecid wasps and birds. Orchards in which IPM is practised are likely to contain more of these beneficial organisms.

Reducing the impacts of birds in horticulture



Birds



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Introduction

Many native and introduced birds in Australia can cause significant damage to cultivated fruits, nuts, olives and grapes. The main problem species are common starlings (*Sturnus vulgaris*), silvereyes, psittacines (cockatoos, corellas, galahs), honeyeaters (Meliphagidae), rosellas (*Platycercus* sp.) and corvids (crows and ravens).

There is a diverse range of management options for pest birds, with variable effectiveness, and no single solution is applicable to all situations. The greatest crop damage is usually caused late in the ripening season, which coincides with the busiest time for growers. As a result, bird management is often not initiated until after considerable damage has already occurred. IPM is a concept well understood for insects and disease problems, but birds are usually not managed in the same strategic way.

Rather than focusing on killing as many pests as possible, we now realise, as with most other aspects of agriculture, that bird management needs to be carefully planned and coordinated. Bird control is just one aspect of an integrated approach to production management. Many birds are highly mobile and can readily replace those that are killed in control programs. Unless actions are well planned and coordinated they are unlikely to have a lasting effect. When planning bird management, there are some important steps that should be considered.

What is the problem?

In the past the pest was usually seen as the only problem. Hence the solution was to kill as many birds as possible. We now know that the situation is more complex. First, determine what the problem is. It may be reduced crop yields, secondary losses causing downgrading of fruit, complaints from neighbours, or emotional stress from worrying about the next attack.

Several factors affect each of these problems, and control of birds is often only part of the solution. The following questions then help define the problem:

- Where is the problem?
- How severe is the problem?
- Will the problem change with time?

Identify the birds involved

Implementing an effective bird control program requires a basic understanding of the ecology and biology of the targeted species and, in some cases, the biology of other species affected directly (non-targets) or indirectly (prey species) by a control program. It is also essential to understand the impact created by the pest; that is, what is the problem? Control strategies can be targeted for particular birds.

For example, some species such as silvereyes and many honeyeaters are highly migratory, moving into orchards only during specific periods. Out-of-season control may therefore be inappropriate for these species.

Most birds are beneficial or desirable, and it is important that management does not affect these species. Some birds can be both beneficial and pests. Honeyeaters, for example, can become a serious problem in orchards during seasons of poor eucalypt flowering, but they also consume many damaging insects throughout the year. Other information sheets on pest bird identification, biology, movements, habitat, feeding behaviour and the damage they cause are available from your State government department of agriculture or primary industries.

Estimate the damage caused to production

Estimating the damage and calculating the cost will give you a basis for deciding how you can best reduce the damage and how much you can afford to invest in the control effort. The percentage of the crop damaged by birds in an orchard block can be estimated by randomly or systematically sampling rows, plants and individual fruit. Bird damage to individual fruit can be estimated by counting or weighing, or by visual estimate. Often sampling and calculating damage to the edges of a crop separately will increase the efficiency of your calculations.

Identify any key constraints

Consider legal, social and environmental issues. For example, will scare devices be acceptable to the local community? Are the techniques legally and/or environmentally responsible?

Decide on the most cost-effective time to implement the plan

Even when good information is available it is often not practicable to immediately respond to short-term fluctuations in bird numbers or the damage they cause. When damage becomes significant it is usually too late to implement control. For example, effective use of scaring often requires a 'start early' approach to prevent birds from establishing a feeding pattern. Likewise, investment in netting can't be simply withdrawn in those seasons in which damage is below the cost-benefit threshold. Instead, we may need to look at costs and benefits over a longer time frame and make decisions accordingly. If damage in your area is likely to be high, or if you have a history of high damage, you should be more inclined to invest in continuing management action. Measuring damage this year will help you to select the optimal management option next year and beyond.



Even relatively small bird pecks can mean that fruit is unsaleable and is liable to be infected by fruit rots © I&I NSW

Develop the most appropriate bird management plan

Importantly, the management plan must have details of what will be done, who will do it, when it will be done and how much it will cost. Options can include individual techniques or combinations, and different levels of application. The plan must have long-term, year-to-year strategies to cope with sudden increases in damage. For example, in the long term managers may net a small part of their crop every year, and in the short term, when damage is higher, they may also implement a scaring program.

Monitor and evaluate

Has your management been successful? Estimating damage is the most direct way you can measure the effectiveness of your management program. All costs and labour of implementing control should be considered. For example, nets might have significantly reduced bird damage, but they may have had to be repeatedly removed for maintenance and spraying the crop; this too, comes at a cost. What things worked; what things didn't; what can be improved for next year? Evaluating management will enable improved decision-making for future strategies. It allows you to modify your actions to maximise any economic return.

There is no one simple solution for managing birds effectively, but the following information may help you to decide on the most appropriate action for your situation.

Management options

Scaring

Many visual and sound devices have been used by managers in an attempt to scare birds. Some of these include acetylene and LPG gas guns, electronic devices, radio, flashing or rotating lights, scarecrows, reflective mirrors or tape, helium- or air-filled balloons, and predator models or kites.

Habituation is the main drawback of all types of scaring. Birds quickly become accustomed to noise or visual cues. Best results for scaring are achieved when:

- a combination of techniques is used
- scaring starts before the birds establish a feeding pattern
- the sound is reinforced by shooting or a threat to shoot
- the timing and placement of devices are changed frequently, but not at regular intervals.

The following suggestions may improve or prolong the effectiveness of scaring:

- Loud sounds are more of a deterrent than quiet sounds.
- Sounds with a wide frequency range are more of a deterrent than pure tones.
- Loud sounds produced by simple cheap methods are likely to be just as effective as sounds produced by expensive electronic devices.
- Devices are most effective when used for the shortest time necessary for a response.
- Adult birds are more easily scared than juveniles.
- All species habituate to nearly all sounds tested, so the effect of most sound-generating devices is short-term.
- Ultrasonic devices are ineffective, as most birds can't hear ultrasound (> 20 kHz).
- Broadcast alarm and distress calls can be effective but are subject to the same habituation as to other sounds, are species specific, and may cause a 'mobbing' rather than an escape response.
- Birds of prey rarely call when hunting; hence pre-recorded raptor calls are likely to represent something novel to birds rather than provoke an avoidance response from a predator.

Birds of prey

Attracting birds of prey or using falconry is often perceived to be of value in scaring birds or reducing pest numbers. However, although falconry has been used previously in airports to reduce bird strikes, it is impractical in most situations. Falconry is strictly regulated in Australia, requires skilled handlers and considerable training, and is labour intensive.

Encouraging raptors to specific areas is difficult, as different species occupy different niches. For example, sparrowhawks and goshawks prefer hunting among trees and tall shrubs to surprise prey; most falcons prefer open country; and Australian hobbies (*Falco longipennis*) prefer lightly timbered country along watercourses. The most effective predators of adult birds are also unlikely to be attracted by carrion or other food sources. Species that may be attracted (e.g. wedge-tailed eagles, little eagles, whistling kites) do not normally hunt birds in flight. Some studies have shown that providing perches increases the numbers of birds of prey. However, this has not yet been demonstrated to reduce the number of pest birds or the damage they cause. More investigation is required.

Lethal control

Many attempts to kill birds, despite alleviating frustration, do not reduce damage. The techniques used are usually labour intensive and may have legal, welfare and social concerns. Permits from national parks and wildlife agencies are required to kill most native species. Pest birds, particularly introduced species, have high population turnover rates and high rates of natural juvenile mortality. Attempts to reduce populations in the long term need to remove a greater number than are being replaced. Therefore, greater effectiveness may be achieved if the breeding population is targeted.

Traps require considerable labour and are therefore often cost prohibitive. However, trapping may be of benefit in situations where a single resident species is involved and a large proportion of the population can be trapped. A multitude of different trap designs are available, including remotely operated nets, cage and roost traps, funnel-entrance traps, modified Australian crow traps, and nest-box traps. The success of trapping varies according to the skill of the operator and the time of the year. For example, large numbers of starlings can be captured after the breeding season, between late December and March, when many juveniles are congregating. However, this may have little long-term effect on the population size owing to the breeding potential of starlings, which can produce an average of two clutches of four chicks each season. Hence removing birds during the breeding season (August to November) may result in fewer individuals captured but may create a greater reduction in population size for the summer and autumn.

Shooting is most beneficial when employed as part of a scaring program. If regarded as a training tool rather than a method of population control, it can educate birds to associate noise with a real threat. To reduce habituation, shooting should occur at the same time scaring devices are used. This establishes a connection between the scarer and danger.

Although some lethal poisons are registered for use in some States (see www.apvma.gov.au/PubcrisWebClient/welcome.do), their use is strictly regulated. For example, many products can be applied only for introduced species, in or around buildings, and by licensed pest control operators, and their use requires site permits from parks and wildlife agencies.

Reducing breeding success by removing eggs or nests or applying oils to eggs has not been adequately investigated. This method may be appropriate for species that reproduce quickly, and it has the advantage of reducing the need to kill large numbers of birds. Permits must be obtained for native species. Various fertility-control chemicals have been reviewed for birds, but none has been sufficiently field tested, nor is any commercially available.

Orchard management and habitat considerations

A range of landscape and habitat factors influence the number of pest birds and the damage they cause. These factors can be considered when attempting to minimise losses. The varieties grown and timing of maturity can be important. For example, growing varieties that mature simultaneously can help to alleviate the damage to individual growers. Depending on the birds involved, sites with adjacent roosting habitat or powerlines can have higher losses. The number of pest birds and the levels of damage will vary according to the preferred habitat of different species. For example, cockatoos and starlings are most abundant in cleared agricultural land and near cities and towns; and most native species prefer native vegetation. These factors can be considered before planting new crops.

Providing alternative food sources by decoy or sacrificial planting may be effective in some situations. This relies on knowledge of the feeding habits of the main birds involved. A decoy planting ideally will produce food of equivalent or enhanced nutritional requirements and attractiveness for birds; it should be available just before, and at the same time as, your crop is susceptible to damage. For honeyeaters and lorikeets, revegetating areas with local native trees and shrubs will increase the availability of their preferred food sources. This may offer a long-term solution in reducing damage and has obvious environmental benefits. Birds such as starlings that prefer insects may be attracted to irrigated areas where large numbers of insects are available. However, supplying alternative foods may also attract more pest birds to the area. Hence, for honeyeaters and lorikeets, a more regional approach to revegetation, rather than localised plantings, may be required. A scaring program is likely to be more effective if alternative food sources are available.

Netting

Exclusion by using throw-over or permanent nets has high up-front costs but may be appropriate where high value crops are grown and levels of damage are high. A variety of netting options are available. Machines can be used to install and remove drape-over nets of varying width. 'Lock-out' netting provides a continuous cover of netting by joining draped nets without the need for poles and cables. Nets can also be used on infrastructure to prevent bird roosting or nesting. If maintained, netting with ultra-violet stabiliser can provide between 5 and 10 years of protection.

Netting overcomes the legal, environmental, social and animal welfare concerns of other techniques. The decision to net is mainly an economic one. Will the increase in returns from excluding birds be beneficial over the life time of the netting? As an example, cost-benefit analysis of vineyard netting suggests that drape-over nets are cost effective when damage is consistently greater than 10%, and permanent nets are cost effective when damage is over 25%. The value of the crop and the practicalities of netting must be considered.

Roosting deterrents

There are a variety of spikes, coils, and wire products available to exclude birds from perching on buildings and infrastructure. Monofilament lines have been successful for deterring larger birds from fish farms but are ineffective for deterring smaller species from fruit crops.

Chemical deterrents

There are several chemical deterrent products commercially available in Australia. Check with the Agricultural Pesticides and Veterinary Medicines Authority for up-to-date registration information and appropriate applications. Some deterrents are based on polybutene, which is a tactile roosting repellent; aluminium ammonium sulfate, which acts on the senses of smell and taste; or methiocarb, which is an insecticide that causes conditioned aversion.

Polybutene is a sticky substance that irritates the birds' feet and can prevent the birds from roosting on infrastructure; hence it is applicable for buildings and urban areas. Aluminium ammonium sulfate may be applied to vegetables, nuts, fruit, orchard trees and vines, provided that the guidelines on the permit are adhered to (e.g. thorough washing before consumption). Methiocarb is a secondary repellent that causes birds to become ill, creating a learned aversion to food. This product can be applied to ornamental plants, but its use is not recommended on edible fruits or nuts. Garlic and chilli sprays have been used to deter birds from feeding, but these are unlikely to be effective.

Summary of the main points to consider:

- Identifying the bird species; consider behaviour, movement and legalities.
- Measure damage; How much are birds actually costing you?
- Use integrated control, with multiple techniques.
- For scaring, start early and use persistence, variation and reinforcement.
- Review your bird management strategy. Do the benefits outweigh the costs?

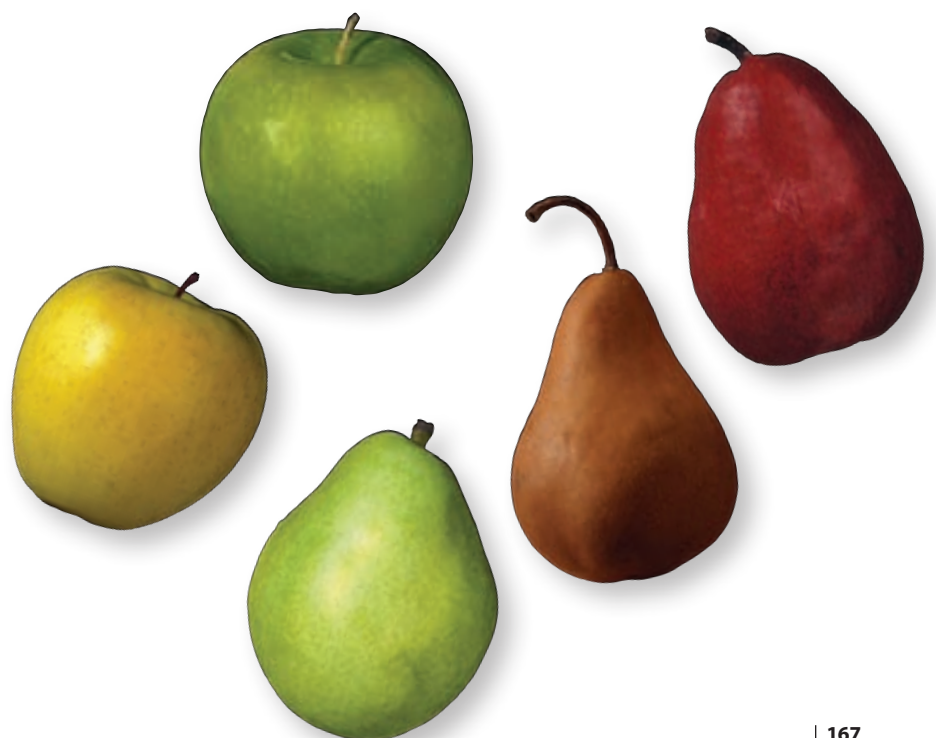
Acknowledgments

This chapter was written by John Tracey of the Vertebrate Pest Research Unit, Orange Agricultural Institute, Industry & Investment NSW.

The article originally appeared in Hetherington SD, Bright JD and Thwaite WG 2004. *Orchard Plant Protection Guide for Deciduous Fruits in NSW, 2004/05*. 14th edition. NSW Department of Primary Industries, Orange.

This information is based on national guidelines for managing pest birds, developed by the Bureau of Rural Sciences with help from the Natural Heritage Trust and the Australasian Pest Bird Network.

Forms, schedules and resources



Appendix 1. Pesticide application record sheet

Pesticide Application Record Sheet (To be completed within 24 hours of spraying and kept for 3 years)		
General Information		
Operator[†]		
Date of application:	Start time:	Finish time:
Crop details		
Crop sprayed:	Block/area name:	Size of block sprayed:
Product/Application details		
Pest targeted:	Equipment used:	
Product used (full trade name):		
Amount of concentrate used: (record either the label rate or total amount used)	Total quantity of spray applied:	Total area of application (in ha or m ²):
Weather conditions		
Wind speed:	Wind direction:	
Did weather conditions change during spraying?:	No	Yes (give details):
Other comments		
[†] If the operator is the property owner you need to record name, address and contact details; for an employee you need to record name and employer details; and for a contractor you need name, address and contact details. On this sheet record the name only, as long as you have the other details recorded elsewhere.		

Appendix 2. Useful contacts

New South Wales

Agricultural Scientific Collections Unit (ASCU)

The ASCU holds Australia's most complete collection of insect pests and diseases relevant to the agricultural industry. It offers a fee-for-service, NATA-accredited (ISO/IEC 17025 (1999)) diagnostic service.

Industry & Investment NSW
Orange Agricultural Institute
Forest Road, Orange NSW 2800
Telephone (02) 6391 3800
Fax (02) 6391 3899

Plant Health Diagnostic Services (PHDS)

PHDS are staffed by specialist pathologists, bacteriologists, mycologists and entomologists—experts in a wide range of horticultural pests and diseases—who can provide plant pathogen and insect identification of all insects, fungi and plant bacteria.

Telephone (02) 4640 6327
Fax (02) 4640 6400

Extension Horticulturists

Industry & Investment NSW offers a regional extension and advisory service to the apple and pear industry through its extension horticulturists, listed below.

Orange

Anne Mooney
Orange Agricultural Institute
Forest Road, Orange NSW 2800
Telephone (02) 6391 3873
Fax (02) 6391 3899
Mobile 0400 713 573

Sean Brindle
NSW Government Offices
27 Lynch Street, Young NSW 2594
Telephone (02) 6380 1701
Fax (02) 6382 2228
Mobile 0438 229 680

Peter Malcolm
Building M14, Castle Road
University of Western Sydney
Hawkesbury, Richmond NSW 2753
Telephone (02) 4588 2105
Fax (02) 4588 2159
Mobile 0412 424 628

Victoria

FruitCheque

FruitCheque is a Department of Primary Industries extension project working with fruit, olive and nut growers to achieve best practice in their businesses. For further information on FruitCheque please contact Cathy Mansfield at DPI Tatura on (03) 5833 5225 or cathy.mansfield@dpi.vic.gov.au.

Crop Health Services (CHS)

CHS offers a comprehensive range of diagnostic services on plant diseases and pests and will also provide management recommendations as appropriate. AS/NZS 9001:2000 quality assured, certified.

621 Burwood Highway, Knoxfield VIC 3180.
Telephone (03) 9210 9356
Fax (02) 9887 3166

Queensland

Grow Help Australia, Client Services Officer,
Queensland Primary Industries and Fisheries

Department of Employment, Economic
Development and Innovation
Entomology Building
80 Meiers Road, Indooroopilly QLD 4068
Telephone (07) 3896 9668
Fax (07) 3896 9446
Email growhelp@dpi.qld.gov.au
Web www.dpi.qld.gov.au/cps/rde/dpi/hs.xsl/26_12360_ENA_HTML.htm

Tasmania

Information and extension

Horticulture Branch, Grove Research Station,
99 Pages Road, Grove, TAS 7109.
Telephone (03) 6266 4305
Freecall 1300 368 550

Horticulture Branch,
Stoney Rise, Rundle Road, Devonport TAS
7310.

Penny Domeney, Horticulturist – IPM,
Department Primary Industries, Parks, Water
and Environment
Smithton Field Centre
151 Nelson St, Smithton
PO Box 61, Smithton TAS 7330
Telephone (03) 6452 1232
Mobile 0429 194 612
Email Penny.Domeney@dpiw.tas.gov.au
Web www.dpiw.tas.gov.au/ipmorchards

Entomology and plant pathology

TASAG ELISA Testing Services. Testing for a wide range of plant viruses, some viroids, and selected bacterial pathogens in a wide range of plants:

- *Entomology:*
Lionel Hill
Rundle Road, Devonport TAS 7310
Telephone (03) 6421 7636
Fax (03) 6424 5142
Mobile 0418 379 726
- *Plant Pathology:*
Dr Dean Metcalf
13 St Johns Avenue, Newtown TAS 7008
Telephone (03) 6233 6864
Fax (03) 6233 6864
Mobile 0417 387 370

Western Australia

AGWEST Plant Laboratories

Under Dr Hossein Golzar, AGWEST Plant Laboratories' horticultural disease diagnostics laboratory offers fee-for-service diagnostic services to the apple and pear industry.
Department of Agriculture and Food
AGWEST Plant Laboratories
Baron Hay Court, South Perth WA 6151
Telephone (08) 9368 3721
Fax (08) 9474 2658

South Australia

Primary Industries and Resources South Australia (PIRSA) provides horticultural advisory services through:

- Loxton Research Centre
Bookpurnong Road, Loxton
Telephone (08) 8595 9100
Fax (08) 8595 9199
- The PIRSA Lenswood Centre
Swamp Road, Lenswood
Telephone (08) 8389 8800
Fax (08) 8389 8899

Appendix 3. Suppliers of biological control agents

Beneficial	Used to control	Supplier								
		The Beneficial Bug Co. (NSW)	Bio-Protection (Vic)	BioWorks (NSW)	Biological Services (SA)	Bugs for Bugs (Qld)	BioResources (Qld)	Horticultural Crop Monitoring	IPM Technology (Vic)	Manchil IPM Services (WA)
<i>Phytoseiulus persimilis</i>	Two-spotted mite									
<i>Galendromus occidentalis</i>	Two-spotted mite									
<i>Euseius victoriensis</i>	Mites									
Trichogramma wasps	LBAM ¹ , OFM ²									
Lacewings	Aphids, two-spotted mite, scales, mealybugs, moth eggs and small caterpillars									
<i>Hippodamia variegata</i>	Aphids									

■ Beneficial available from this supplier. ¹ Lightbrown apple moth, ² Oriental fruit moth

The Beneficial Bug Co.

PO Box 436, Richmond NSW 2753
 Email info@beneficialbugs.com.au
 Web www.beneficialbugs.com.au
 Telephone (02) 4570 1331
 Fax (02) 4578 3979

Bio-Protection

PO Box 384, Kilmore Vic 3764
 Email rcoy@hyperlink.com.au
 Telephone (03) 5781 0033
 Fax (03) 5781 0044

BioWorks

PO Box 203, Nambucca Heads NSW 2448
 Email bioworks@tsn.cc
 Telephone (02) 6568 3555

Biological Services

PO Box 501, Loxton SA 5333
 Email info@biologicalservices.com.au
 Web www.biologicalservices.com.au
 Telephone (08) 8584 6977
 Fax (08) 8584 5057

Bugs for Bugs

Bowen Street, Mudubbera Qld 4626
 Email info@bugsforbugs.com.au
 Web www.bugsforbugs.com.au
 Telephone (07) 4165 4663
 Fax (07) 4165 4626

BioResources

PO Box 578, Samford Qld 4520
 Email richard@bioresources.com.au
 Web www.bioresources.com.au
 Telephone (07) 3289 4919
 Fax (07) 3289 4918

Horticultural Crop Monitoring

PO Box 3725, Caloundra Qld 4662

Email pjones@hotmail.net.au

Telephone (07) 5491 4662

Fax (07) 5491 4662

Manchil IPM Services

1/17 Batavia Place, Kallaroo WA 6025

Email lachlanchilman@hotmail.com

Telephone 0403 727 25

IPM Technologies

PO Box 600, Hurstbridge Vic 3099

Email ipmtechnologies@bigpond.com

Telephone (03) 9710 1554

Fax (03) 9710 1354

Appendix 4. Effect on beneficial arthropods of pesticides registered for use on apples and pears

Biological control agents vary in their susceptibility to the pesticides used in Australian apple and pear orchards. In general, biological control works best in orchards that have well established IPM practices such as mating disruption and monitoring. When you are deciding to introduce biological control agents to an orchard it is important to consider the pesticides that have been used and their residual effects, as well as the pesticides that are likely to be used in the future.

Very little is known about the effects of agricultural pesticides on some of the natural beneficial organisms present in orchards. However, more is known about the effects of pesticides on commercially available biological control agents.

Notes to tables A4.1, A4.2 and A4.3

The following tables contain information on the effects of nearly all of the pesticides registered for use on apples and pears (as at April 2009). Where pesticides are not included it is because there was insufficient information on their effect on beneficial organisms available. The information is colour-coded to reflect the toxicity towards common beneficial organisms in Australian apple and pear orchards:

1	Low toxicity; nil or low impact on beneficials
2	Moderately low toxicity; moderate impact on beneficials but populations recover quickly
3	Moderately high toxicity; moderate impact on beneficials; populations slow to recover
4	A high proportion of beneficials killed; populations may not recover

- 'Persistence' indicates the approximate period, in weeks, for which the effect of the pesticide lasts. For example, a persistence of 2 weeks means that biological control agents cannot be reintroduced during this period because of the harmful effect of the pesticide
- The symbol '–' means that the effects of this chemical on this beneficial are unknown.
- The information for these tables is drawn from:
 - » *The Good Bug Book (2nd ed.)* available from Bugs for Bugs Ltd www.bugsforbugs.com.au/product/good-bug-book
 - » Bright JD, Hetherington SD and Mooney AM. *The Orchard Plant Protection Guide for Deciduous Fruits in NSW*. Industry & Investment NSW, Orange (updated annually)
 - » Koppert Biological Systems, www.koppert.com
 - » Biobest Biological Systems, www.biobest.be



Pests used in the tables below. Green lacewings (left) are predators of aphids, two-spotted mites, scales, mealybugs, moth eggs and small caterpillars; Trichogramma wasps (centre) are parasitoids of lightbrown apple moth and oriental fruit moth; and Phytoseiulus persimilis (right; bottom of picture) is a predatory mite that eats pest mites. Richard Llewellyn, BioResources Pty Ltd

Occasionally the information available differed among sources. In cases where this occurred, the most harmful rating and longest persistence period are used in the tables.

Use the tables as a guide only. In some cases the specific information was unavailable, and that provided is for the interaction between the pesticide and a closely related species. The length of time for which a pesticide persists and is harmful to beneficials is also influenced by a range of factors, including climate.

- The lists of pesticides are separated into three tables according to the level of toxicity to beneficial organisms:
 - » *Table A4.1. IPM-friendly pesticides.* These pesticides are unlikely to harm beneficial organisms in your orchard and should not impede the introduction of commercial biological control agents. When pest management requires a pesticide application and an effective alternative is

present on this list, it should be preferred to those appearing in other tables. On rare occasions these pesticides may harm beneficial organisms, and orchardists should check the table before application.

- » *Table A4.2. Pesticides to be used with caution in IPM programs.* Because these chemicals are harmful to a number of different types of beneficial organisms, orchardists will need to know which beneficials are present in their orchards. Choose pesticides that are unlikely to cause secondary problems.
- » *Table A4.3. Pesticides that should be considered only in emergencies when no other effective alternative exists.* In some cases harsher chemicals will be required to treat pests (e.g. treatment of fruit fly). Where no 'soft' option exists, orchardists should be aware of the possible emergence of secondary pests and plan ahead for their management.

Table A4.1. Pesticides that – when used with care – will have very little impact on beneficials and are recommended in an IPM program.

			Predatory mite			Parasitoid		Predatory insect		
			<i>Phytoseiulus persimilis</i>			Trichogramma		Green lacewing		
Chemical name	Trade name	Egg	Nymph	Adult	Pupa	Adult	Larva	Adult		
Acaricides	Bifenazate	Acramite, Floramite	–		2	–		1	–	Non-systemic acaricide with contact action and long residual action. Group 2D.
			Persistence = 1 week					Persistence = 1 week		
	Clofentezine	Apollo	1	1	1	1	1	1	1	Specific acaricide with contact action and long residual activity. Group 10A.
			Persistence = 0 weeks			Persistence = 0 weeks		Persistence = 0 weeks		
	Fenbutatin oxide	Torque	1	1	1	1	1	1	1	Acaricide with contact and stomach action, controls motile stages. Group 12A.
			Persistence = 0 weeks			Persistence = 0 weeks		Persistence = 0 weeks		
	Hexythiazox	Calibre	1	1	1	1	1	1	1	Non-systemic acaricide with contact and stomach action. Group 10A.
			Persistence = 0 weeks			Persistence = 0 weeks		Persistence = 0 weeks		
	Tetradifon	Masta-Mite	1	1	1	1		1	1	Non-systemic acaricide. Contact action on eggs and all non-adult stages. Class 2B.
			Persistence = 0 weeks			Persistence = 0 weeks		Persistence = 0 weeks		

			Predatory mite			Parasitoid		Predatory insect		
			<i>Phytoseiulus persimilis</i>			Trichogramma		Green lacewing		
Chemical name	Trade name	Egg	Nymph	Adult	Pupa	Adult	Larva	Adult		
Fungicides	Boscalid	–			–		1		Foliar fungicide with protectant action. Group 7.	
		–			–		Persistence = 0 weeks			
	Bupirimate	Nimrod	1	2	2	–		1	1	Systemic fungicide with protectant and curative action. Group 8.
			Persistence = 0 weeks					Persistence = 0 weeks		
	Captan		1	1	1	–		1	1	Protectant fungicide. Group M4.
			Persistence = 0 weeks					Persistence = 0 weeks		
	Copper oxychloride		–		1	–		2	2	Protectant fungicide. Group M1.
			Persistence unknown					Persistence unknown		
	Cyproconazole	A component of Garrison	1	1	1	–		–	1	Garrison is a wound sealer containing curative and protectant fungicides. Group 3.
			Persistence = 0 weeks					Persistence = 0 weeks		
	Difenoconazole	Bogard	1	1	1	–		1	1	Systemic fungicide with protectant and curative action. Group 3.
			Persistence = 0 weeks					Persistence = 0 weeks		
	Dithianon	Delan	–	1	1	–	1	1	1	Fungicide with protectant and some curative action. Group M9.
			Persistence = 0 weeks			Persistence = 0 weeks		Persistence = 0 weeks		
	Fenarimol	Rubigan	1	1	1	1	1	–	2	Systemic fungicide with protectant and curative action. Group 3.
			Persistence = 0 weeks			Persistence = 0 weeks		Persistence unknown		
	Flusilazole	NuStar	1	1	1	–		–		Systemic fungicide with protectant and curative action. Group 3.
			Persistence = 0 weeks							
	Fosetyl-aluminium	Aliette	1	1	1	–		–		Systemic fungicide with protectant and curative action Group 33.
			Persistence = 0 weeks							
	Hexaconazole	Hex, Hexacon, Viva		1	1	–	1	1	1	Systemic fungicide with protectant and curative action. Group 3.
			Persistence = 0 weeks			Persistence = 0 weeks		Persistence = 0 weeks		
	Imazalil	Fungaflor etc.	3	1	1	–		–	1	Systemic fungicide with protectant and curative action. Group 3.
			Persistence = 0 weeks					Persistence = 0 weeks		
	Iprodione	Rovral etc.	1	1	1	1	1	1	1	Contact fungicide with protectant and curative action. Group 2.
			Persistence = 0 weeks			Persistence = 0 weeks		Persistence = 0 weeks		
	Kresoxim-methyl	Stroby	1	1	1	–		–		Systemic fungicide with protectant and curative action. Group 11.
			Persistence = 0 weeks							
	Myclobutanil	Systhane	1	1	1	–		1	–	Systemic fungicide with protectant and curative action. Group 3.
			Persistence = 0 weeks					Persistence = 0 weeks		

			Predatory mite			Parasitoid		Predatory insect		
			Phytoseiulus persimilis			Trichogramma		Green lacewing		
	Chemical name	Trade name	Egg	Nymph	Adult	Pupa	Adult	Larva	Adult	
Fungicides	Penconazole	Topas	1	1	1	–	2	–	1	Systemic fungicide with protectant and curative action. Group 3.
			Persistence = 0 weeks			Persistence unknown		Persistence = 0 weeks		
	Trifloxystrobin	Flint	–		1	–		–		Systemic fungicide with preventive and specific curative activity. Group 11.
			Persistence = 0 weeks							
	Triforine	Saprol	1	2	2	–	1	1	1	Systemic fungicide with preventive and specific curative activity. Group 3.
			Persistence = 0 weeks			Persistence = 0 weeks		Persistence = 0 weeks		
Zineb	Zineb	–	1	1	–	1	1	1	Protectant fungicide. Group M3.	
		Persistence = 0 weeks			Persistence = 0 weeks		Persistence = 0 weeks			
Insecticides	Buprofezin	Applaud	1	1	1	1	1	–		Persistent insecticide with contact and stomach action. Group 17A
			Persistence = 0 weeks			Persistence = 0 weeks				
	Fenoxycarb	Insegar	1	1	1	–	1	2	1	Insect growth regulator insecticide with ovicidal action. Group 7B.
			Persistence = 0 weeks			Persistence = 0 weeks		Persistence = 2 weeks		
	Indoxacarb	Avatar	–		1	–		–		Insecticide with both contact and stomach action, mainly against larvae. Group 22A.
			Persistence = 0 weeks							
Methoxyfenozide	Prodigy	–		1	–		–		Lethally accelerates the moulting process. Active primarily by ingestion. Group 16A	
		Persistence = 0 weeks								

Table A4.2. Pesticides that can be used in IPM programs, but growers must be aware of the beneficial organisms present in their orchards and spray appropriately

			Predatory mite			Parasitoid		Predatory insect		
			<i>Phytoseiulus persimilis</i>			Trichogramma		Green lacewing		
	Chemical name	Trade name	Egg	Nymph	Adult	Pupa	Adult	Larva	Adult	
Acaricides	Dicofol	Kelthane	3	4	4	3	3	1	2	Non-systemic acaricide with contact action. Group 2B.
			Persistence = 2 weeks			Persistence = 3 weeks		Persistence = 0 weeks		
	Propargite	Omite	4	3	3	1	1	1	1	Acaricide with contact action against active stages. Group 14A.
			Persistence = 0 weeks			Persistence = 0 weeks		Persistence = 0 weeks		
	Tebufenpyrad	Pyranica	—		4	—		—	2	Acaricide with contact action. Group 10A.
			Persistence = 1-2 weeks					Persistence unknown		
Fungicides	Carbendazim	Bavistin, etc.	3	4	4	1	1	1	1	Systemic fungicide with protectant and curative action. Group 1.
			Persistence = 1-2 weeks			Persistence = 0 weeks		Persistence = 0 weeks		
	Mancozeb	Dithane etc.	1	1	1	—	4	2		Protectant fungicide. Group M3.
			Persistence = 0 weeks			Persistence unknown		Persistence unknown		
	Metiram	Polyram	—	4	4	1	4	1	1	Protectant fungicide. Group M3.
			Persistence unknown			Persistence = 0 weeks		Persistence = 0 weeks		
Insecticides	Parathion-methyl	Folidol, Pennacap	—			—	1	3	3	Insecticide with contact, stomach and some respiratory action. Group 1B.
						Persistence = 0 weeks		Persistence unknown		
	Pirimicarb	Aphidex, Pirimor	2	2	2	1	4	2	2	Selective systemic aphicide with contact, respiratory and stomach action. Group 1A.
			Persistence = ½ week			Persistence = 0 weeks		Persistence unknown		
	Spinosad	Entrust, Success	—	4	4	—	1	1	4	Insecticide with contact and stomach action. Group 5A.
			Persistence = 1 week			Persistence = 0 weeks		Persistence = 0 weeks		
	Thiacloprid	Calypso	3	3	3	—		—		Systemic insecticide with contact and stomach activity. Class 4A.
			Persistence = 2 weeks			—		—		

Table A4.3. Pesticides that should be used only to control a specific pest when all other management options have failed. Orchardists should be aware that additional management (and expense) may be necessary to control secondary pests following the application of these pesticides.

			Predatory mite			Parasitoid		Predatory insect		
			<i>Phytoseiulus persimilis</i>			Trichogramma		Green lacewing		
			Egg	Nymph	Adult	Pupa	Adult	Larva	Adult	
Acaricides	Abamectin	Vertimec etc.	—	4	4	—		1	4	Acaricide with stomach action, some translaminar movement. Group 6A.
			Persistence = 2 weeks							
	Chlorfenapyr	Secure	—		4	—		—		Acaricide with stomach action. Group 13 A.
			Persistence > 1 week							
	Omethoate	Folimat, Sentinel	4	4	4	—		—		Systemic insecticide and acaricide with contact and stomach action. Group 1B.
	Etoxazole	Paramite	4	-		—		—		Acaricide with contact and residual activity against motile stages. Group 10A.
			Persistence unknown							
Tebufenpyrad	Pyranica	—		4	—		—		Non-systemic acaricide active by contact and ingestion. Group 21A.	
		Persistence = 1–2 weeks								
Insecticides	Alpha-cypermethrin	Dominex	4	4	4	—		—		Non-systemic insecticide with contact and stomach action. Group 3A.
			Persistence = 8 to 12 weeks							
	Azinphos-methyl	Gusathion, Benthion	3	3	3	—		4	4	Insecticide with contact and stomach action. Moderate persistence. Group 1B.
			Persistence = 2 weeks					P'tence = 6–8 weeks		
	Carbaryl	Bugmaster	—	4	4	4	4	3	4	Contact insecticide with stomach action. Group 1 A.
			Persistence = 2 weeks			Persistence unknown		Persistence = 4 weeks		
	Chlorpyrifos	Lorsban etc.	1	3	3	4	4	4	4	Contact insecticide with stomach and vapour action. Group 1B.
			Persistence = 0 weeks			Persistence > 4 weeks		P'tence = 8–12 weeks		
	Diazinon	Diazinon	2	2	2	4	4	4	4	Non-systemic insecticide and acaricide with contact, stomach and respiratory action. Group 1B.
			Persistence unknown			Persistence = 2 weeks		Persistence = 4 weeks		
	Dimethoate	Rogor etc.	4	4	4	4	4	4	4	Broad-spectrum contact and systemic insecticide. Group 1B.
			Persistence = 8 weeks			P'tence = 4–6 weeks		P'tence = 8–12 weeks		
	Endosulfan	Endosan, Thiodan	2	4	4	4	4	1	4	Broad-spectrum contact and stomach insecticide. Group 2A.
			Persistence = 2 weeks			P'tence = 6–8 weeks		Persistence = 0 weeks		
	Fenitrothion	Fenitrothion	—	4	4	4	4	3	4	Non-systemic insecticide with contact and stomach action. Group 1B.
			Persistence unknown			P'tence = 8–10 weeks		Persistence unknown		
	Imidacloprid	Confidor etc.	1	4	4	—	4	—	4	Systemic contact and stomach insecticide. Group 4A.
			Persistence = 0 weeks			Persistence unknown		Persistence = 4 weeks		
	Methidathion	Supracide etc.	4	4	4	4	4	4	4	Non-systemic insecticide with contact and stomach action. Group 1 B.
			Persistence = 3 weeks			Persistence > 4 weeks		Persistence unknown		
	Methomyl	Lannate, Nudrin etc.	4	4	4	4	4	4	4	Systemic insecticide with contact and stomach action. Group 1A.
			Persistence = 4 weeks			P'tence = 8–12 weeks		P'tence = 8–12 weeks		
	Tau-fluvalinate	Klartan, Mavrik	4	4	4	4	4	2	1	Insecticide and acaricide with contact and stomach action. Group 3A.
			Persistence = 6 weeks			P'tence = 4–6 weeks		Persistence unknown		

Appendix 5. Using pesticides in IPM

If monitoring shows that a problem exists, the most efficient and cost-effective management option is often a chemical pesticide application—even for organic growers, for whom the list of pesticides is more limited.

When a pesticide is needed, growers need to assess everything that is happening in the orchard to make sure that the spray is going to have maximum impact on pests, without off-target effects on beneficials, bees, the environment, or the health of orchard workers or consumers. (see ‘Appendix 4: Effect on beneficial arthropods of pesticides registered for use on apples and pears’ p. 173).

Apply a pesticide only when it’s needed

The pesticide application schedule presented in this Appendix tries to cater for the control of most of the pests that Australian orchardists are likely to encounter. At first glance it seems to be outlining a lot of pesticide applications. However, pesticides need only be applied to pests when monitoring indicates that they are present and experience has shown that they are likely to cause enough damage to warrant the cost of control. If a pest isn’t there or is causing only minor damage, it is usually a waste of time and money to apply a spray; maintain your preventive strategies and keep monitoring.

Can a spray be used against more than one pest?

The number of sprays can be reduced by carefully considering the type of pesticide and its timing and application. With good planning and technique it is usually possible to control more than one pest with a single application. Good examples include fungicides that are applied for apple scab and also control powdery mildew and a raft of other diseases, or insecticides applied for codling moth that control lightbrown apple moth and other moth pests.

Reduce off-target effects

Every time a pesticide is applied only a miniscule percentage of the spray contacts the pests that it is targeting. It’s important to make sure that the balance of the pesticide doesn’t cause problems. If there is a choice of effective pesticides, always choose the one with the most specific mode of action. Using cheap broad-spectrum pesticides is usually false economy. They damage beneficial organisms, and this in turn leads to an increase in the abundance of other pests and the need for more pesticide sprays. Do it once, and do it right!

Timing

All pesticide applications should be made on a ‘need only’ basis, as determined by some sort of monitoring. However, experience (and good record-keeping) should be used to determine when pests are most likely to be present in the orchard, when they are likely to cause damage and, most importantly, when pesticide applications are most likely to be effective. The following tables provide suggested timings for the application of pesticides. These timings are flexible and, within the constraints of the regulations prescribed on the pesticides label, other timings may be more effective under different individual circumstances. Experiment until you’re happy that you’re achieving the best possible results.

In a national manual it’s not possible to provide spray timing recommendations on a calendar basis. Trees, crops and pests develop at different times from region to region owing to changes in factors such as temperature, humidity and day-length. Within the same region timings will be influenced by the variety to which the pesticide is being applied. The pesticide schedule below gives an indication of pesticide timings with respect to crop development. The common terms describing the different stages of crop development vary among regions (and often between individual growers), and the panels of photographs of each stage will allow you to determine which crop stage is being described in the pesticide schedule.

Notes on the following tables

When choosing pesticides, always consider effectiveness, off-target impacts, and the likelihood of resistance developing. The pesticides in the following tables have been colour-coded so as to offer some guidance in making decisions about which pesticides offer effective control of pests and minimise damage to beneficial organisms.

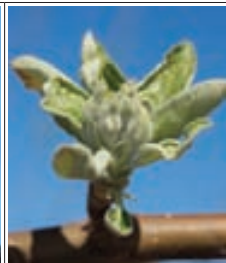
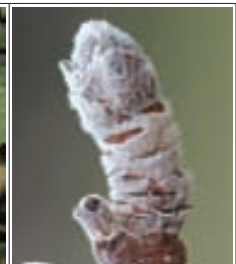
Pesticides written in green—when used with care—will have very little impact on beneficials and are recommended for use in an IPM program. Where they are available they should be your first choice.

Pesticides written in orange can be used in an IPM program. They will kill some beneficial organisms, and growers must be aware of which beneficial organisms are present in their orchard and spray accordingly.

Pesticides written in red should be used only to control a specific pest when all other management options have failed. They are a last resort, and orchardists should be aware that additional management (and expense) may be necessary to control secondary pests following the application of these pesticides. Also note that although specific information concerning the toxicity of clothianidin was not available, the Australian Pesticides and Veterinary Medicines Authority (APVMA) notes that there is significant mortality of bees and ‘effects on beneficial insects should be expected at the application rates proposed’. This pesticide is therefore written in red in the following tables.

Where a pesticide is written in black there is insufficient published evidence to make a judgment on its off-target effects. Spinetoram and chlorantraniliprole are widely regarded as being relatively soft on beneficial insects. They may be applied, but careful monitoring should be undertaken and orchardists should form their own conclusions about their effects.

Stages for timing of IPM scheduling in apples (all photos © I&I NSW)

				
Green tip	Green cluster	Blossom		
				
Petal fall	Fruit development		Harvest	Dormancy

	More information (page)	Green tip	Blossom	Mid season	Harvest	After harvest	Dormancy
Apple dimpling bug	35						
Apple leafhopper	141						
Apple scab	40						
Bitter pit	146						
Bitter rot	51						
Codling moth	55		MD				
Helicoverpa, loopers	68						
European red mite	83						
Lightbrown apple moth	73		MD				
Plague thrips	123						
Powdery mildew	108						
Fruit fly	62						
San José scale	113						
Sooty mould	81						
Two-spotted mite	83						
Western flower thrips	123						
Wingless grasshopper	157						
Woolly aphid	134						

■ Likely timing for monitoring and treatment, ■ soil treatment, MD Mating disruption

Apples – green tip			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Scab (spray 1)	Copper hydroxide (M1) or Copper oxychloride (M1) or Cuprous oxide (M1) or a proprietary mixture of mancozeb (M3) + copper hydroxide (M1)	All States	This is the first application of a schedule of sprays based on the protective method of control, which involves maintaining a protective cover of fungicide on newly exposed leaves, and later on blossoms, foliage and fruit until harvest. Do not use copper sprays after green tip, as russetting may occur. Apply a proprietary mixture of mancozeb + copper hydroxide no later than green tip if target spot, sooty blotch or fly speck have been a problem in previous seasons. This product is toxic to <i>Typhlodromus pyri</i> and cannot be used in conjunction with integrated mite control.
Bitter rot (Glomerella) (spray 1)	Copper oxychloride (M1)		
European red mite (ERM) San José scale	Horticultural mineral oil (HMO)	All States	European red mite eggs on spurs, laterals and main limbs are more susceptible to oil the closer the eggs are to hatching. This usually occurs around flowering. Most spray oil products are registered for use only up to green tip, generally at 2%. A small number of HMO products can be used later at 1%. The preferred timing is just after full bloom, when the spray will be a valuable component of the resistance management strategy for ERM. Do not apply oil sprays at both green tip and just after full bloom. Thorough coverage is essential at green tip to control both ERM and scale.
Alternaria leaf spot	Dithianon (M9) or metiram (M3)	NQW	A problem in the Granite Belt, Bilpin and Picton regions. An occasional problem in the Manjimup region.

Apples – green cluster			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Scab (spray 2) Powdery mildew (WA)	① Protective treatment: difenoconazole (3) or fenarimol (3) or flusilazole (3) or hexaconazole (3) or myclobutanil (3) or penconazole (3) or cyprodinil (9) or kresoxim-methyl (11) or trifloxystrobin (11) or dodine (M7) or captan (M4) or dithianon (M9) or mancozeb (M3) or metiram (M3) or thiram (M3) or ziram (M3) or a proprietary mixture of pyrimethanil (9) + fluquinconazole (3) or a proprietary mixture of boscalid (7) + pyraclostrobin (11)	All States	① Apply one of these sprays as the second protective fungicide application at spurburst. See label for use of protectant with difenoconazole. Fenarimol or penconazole should be mixed with a protectant chemical to increase the length of the protectant period. Note restrictions on the number of applications of some products – see labels. Do not use cyprodinil or pyrimethanil + fluquinconazole after petal fall. Do not apply kresoxim-methyl to apples if there is a chance of drift to cherries. Do not use dithianon after the beginning of December on apples to be cool-stored. This restriction does not apply to apples intended for controlled-atmosphere storage. Mancozeb, metiram and ziram are toxic to <i>Typhlodromus pyri</i> (but not to <i>T. occidentalis</i>).
	② Curative treatment: difenoconazole (3) or fenarimol (3) or flusilazole (3) or hexaconazole (3) or myclobutanil (3) or penconazole (3) or triforine (3) or dodine (M7) or a proprietary mixture of pyrimethanil (9) + fluquinconazole (3)	All States	② The curative or 'after infection' method of control involves spraying only after infection has taken place, in the spring. To be effective, curative sprays must be applied as soon as possible after infection has occurred. The effective periods for the fungicides recommended here are up to: • 1½ days – dodine • 3 days – pyrimethanil, triforine • 4 days – fenarimol, hexaconazole, penconazole • 5 days – difenoconazole, fluquinconazole, myclobutanil • 5 to 6 days – flusilazole. See manufacturers' labels for advice on mixing with protectant sprays, and restrictions on the number of applications. Neglect of scab on non-bearing trees can, in seasons favourable to its development, cause leaf drop, reduction in growth and eventual reduced cropping. The curative method of control can be employed to save unnecessary protective applications on young trees during spring and early summer.
Codling moth	Mating disruption agent	All States	Apply dispensers within the top 30 cm of the tree, before any adult codling moth activity starts. Do not use on blocks of less than 3 hectares or irregularly shaped blocks. No other codling moth control should be needed if infestation in the previous season was less than 0.3%. If more than 0.3%, partial or full supplementation with insecticide is recommended. Seek advice from reseller or consultant. Monitoring for codling moth activity throughout the season is important.
Lightbrown apple moth	Isomate + pheromone	All States	Twist dispenser in top third of the tree before first moths emerge in spring. Do not use in orchards smaller than 3 ha.

Apples – blossom (pink to petal fall)			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Powdery mildew (all States)	Bupirimate (8)	All States	Apply this third spray for scab 10 days after the spurburst spray (spray 2), at approximately pink stage.
Scab (spray 3) and Powdery mildew	Fenarimol (3) or flusilazole (3) or hexaconazole (3) or myclobutanil (3) or penconazole (3) or triforine (3) or kresoxim-methyl (11) or trifloxystrobin (11) or a proprietary mixture of fluquinconazole (3) + pyrimethanil (9) or a proprietary mixture of boscalid (7) + pyraclostrobin (11)		Apply a mildew fungicide on susceptible varieties. Include a wetting agent when recommended by manufacturer. Powdery mildew can be very damaging to non-bearing trees. A protective schedule should be followed. However, in blocks of young trees where spraying can be thorough and observations frequent, it is often possible to reduce the number of applications to below that usually required for older and larger trees. Powdery mildew control by chemicals is particularly important in young trees that are being trained as central leader or palmette types, where tipping is undesirable. See labels for restrictions on the number of applications of some products and instructions for mixing with a protectant. Do not apply kresoxim-methyl to apples if there is a risk of drift to cherries.
Woolly aphid	Imidacloprid (4A) or clothianidin (4A)	All States	Apply to soil around the bases of trees identified as infested in the previous autumn. See label for details.
Apple dimpling bug (ADB) (<i>Campylomma liebknehti</i>)	Thiacloprid (4A)	All States	Apply an initial spray from pink to petal fall when pest numbers reach accepted threshold levels, as indicated by monitoring. Spray thoroughly to ensure complete coverage of flowering parts and developing fruitlets, using dilute spraying equipment. A second spray may be necessary under high pressure.
	Chlorpyrifos (1B)		Apply at late pink to protect flowers if monitoring indicates that ADB numbers exceed the threshold for damage. Chlorpyrifos is very toxic to bees. Three days should elapse between spraying and start of bee activity. Do not apply to trees in flower.
	Endosulfan (2A)		Monitor for bug activity during flowering. An early application of chlorpyrifos should give adequate protection from bugs during the most susceptible stage of fruit development, but if reinfestation occurs apply endosulfan. Warning: Endosulfan should be applied only at times when bees are not actively working the blossoms, such as in the evening or early morning. Spraying at night has proved effective, but avoid frosty weather.
Apple dimpling bug (ADB) (<i>Niasstama punctatocollis</i>)	Chlorpyrifos (1B)	Tasmania	Spray macrocarpa hedges adjacent to orchards in late winter to early spring to prevent adults entering the orchard.

Apples – blossom (pink to petal fall)			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Plague thrips	Endosulfan (2A) or bifenthrin (3A)	QNSVW	All varieties are affected, but Granny Smith and Delicious are the most readily damaged and should be monitored carefully. Spray all varieties as soon as thrips numbers reach six to eight per blossom, following warm dry weather during the pink to full-bloom period. Thrips occasionally occur in plagues and may invade flower buds as early as spurburst or early pink, causing serious damage. If thrips can be seen in large numbers in weed flowers and in early-flowering fruit varieties, be prepared to spray apples. Repeat spraying will be needed during plagues, as the residual action of endosulfan is short. Warning: Endosulfan should be applied only when bees are not actively working the blossoms, such as in the evening or early morning. Spraying at night has proved effective, but avoid frosty weather.
Western flower thrips (WFT)	Spinosad (5A)	All States	WFT activity can occur during flowering. If the pest is detected early, then apply spinosad at petal fall. Do not confuse WFT with other thrips that also infest blossoms – the control measures are different. Have thrips identified if in doubt.
Helicoverpa and loopers	Endosulfan (2A)	All States	Endosulfan applied after petal fall will control early fruit caterpillars.
Scab (sprays 4 and 5) Powdery mildew	Scab fungicide or powdery mildew fungicide or scab and powdery mildew fungicide (see Scab spray 3)	All States	Apply the fourth protective spray 10 days after pink. This will be at approximately full bloom. The danger of scab infection at this stage is very great. Income for the year may depend upon the efficient operation of spray machinery and the maintenance of a close schedule of sprays. Aim to apply protective sprays every 10 days through October, or at even closer intervals if the weather is favourable for scab. Apply the fifth protective spray 10 days later. Include a mildew fungicide with the scab spray on susceptible varieties at each application. Take care not to exceed the total number of sprays for each group of fungicides, as recommended on the labels. Include a wetting agent for mildew control when recommended by the manufacturer.
European red mite	Horticultural mineral oil	All States	Apply 1% spray at high volume just after full bloom. Use only those formulations specifically registered for use at this time.

Apples – petal fall			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Alternaria leaf spot	Dithianon (M9)	All States	A problem in the Granite Belt, Bilpin and Picton regions. An occasional problem in the Manjimup region.
Helicoverpa, Loopers	Endosulfan (2A) or	All States	Apply after petal fall. There are restrictions on the supply and use of endosulfan.
	Indoxacarb (22A) or	All States	Application of the codling moth program of indoxacarb from petal fall will also control Helicoverpa and loopers.
	Bacillus thuringiensis Bt (11C)	All States	Apply at the first sign of activity. Bt is best used as a routine program. It is not suitable for emergency treatment.
	Chlorantraniliprole (28)	All States	Monitor for signs of activity of early-instar larvae. Where this is detected, an application should be made after petal fall.
Codling moth and lightbrown apple moth (first sprays)	Fenoxycarb (7B) 20 g/100 L	All States	Where possible use pest phenology models based on degree days to help you time the first spray. Some districts have commercial services that provide this information. Otherwise, apply the first application 7 to 10 days after complete petal fall. Thorough coverage is important. Follow with two further sprays at intervals of 7 days.
	Indoxacarb (22A)	All States	Use for the first half of the season only. See label for details of timing of sprays.
	Azinphos-methyl (1B) or parathion-methyl (1B) (micro-encapsulated)	NSTVW All States	Use phenology models where available (see fenoxycarb above). If phenology models are unavailable start applications 7 days after complete petal fall and continue at intervals not exceeding 14 days in blocks where codling moth was a problem last season. Alternatively, start the control program with indoxacarb, follow on with chlorantraniliprole or spinetoram, and use azinphos-methyl or parathion-methyl as a last resort. There are restrictions on the supply and use of parathion-methyl.
Codling moth (first sprays)	Thiacloprid (4A)	All States	Apply the first spray by the time 110 degree days after biofix has been reached (see 'Codling moth' p. 55). Continue applications (maximum of four) at 14-day intervals until four sprays have been used.
	Clothianidin (4A)	All States	Two sprays 14 days apart once pest monitoring indicates egg hatch. Follow with different chemical group.
	Chlorantraniliprole (28)	All States	Maximum of three applications 14 to 21 days apart, starting at petal fall (or before 110 degree days after codling moth detected in traps) and ending in late December. Program is also useful for control of budworm, oriental fruit moth and lightbrown apple moth.
	Spinetoram (5A)	All States	Use higher rates when adverse weather conditions may cause the spray interval to become greater than 14 days, or in high-pressure conditions or in orchards with a history of damage, or when mating disruption does not provide adequate protection.

Apples – fruit development (early)			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Bitter rot (spray 2)	Mancozeb (M3) or ziram (M3) or dithianon (M9)	All States	Bitter rot is normally troublesome only in hotter, more humid regions. Apply the first spray for its control during early fruit development. Continue sprays at intervals of 2 weeks during warm, humid weather. These sprays also control scab. Examine trees regularly. Remove infected fruits and burn or bury them. Warning: Mancozeb and ziram are toxic to <i>Typhlodromus pyri</i> .
Scab (sprays 6, 7), powdery mildew	See 'Scab (spray 2)'.		Apply a sixth protective fungicide spray 10 to 14 days after the fifth. Apply a seventh protective fungicide spray 14 days after the sixth. At this time include a mildew fungicide only on highly susceptible varieties, but ensure the choice of mildew fungicide does not exceed the maximum number of sprays for that group.
Codling moth Lightbrown apple moth (second sprays)	Azinphos-methyl (1B) or parathion-methyl (1B) (micro-encapsulated)	NSTVW All States	See earlier reference under 'Petal fall'. In all orchards except those where codling moth was prevalent last season, make the first application about 14 days after all petals are off the trees. Continue applications at 3-weekly (azinphos-methyl) of 2-weekly (parathion-methyl) intervals. Apply sufficient spray to ensure thorough coverage.
	Fenoxycarb (7B) (20 g/100 L)	All States	See earlier reference under 'Petal fall'. A total of four applications at weekly intervals is required, the first three at 20 g/100 L and the fourth at 40 g/100 L.
	Indoxacarb (22A)	All States	Continue applications at 10-day intervals.
Codling moth	Thiacloprid (4A) or clothianidin (4A)	All States All States	See earlier reference under 'Petal fall'. Continue applications at 14-day intervals.
Bitter pit	Calcium nitrate or calcium chloride, plus wetting agent	All States	Apply up to six sprays throughout the season. Calcium nitrate is recommended until the end of December and also provides a small amount of nitrogen nutrition. Calcium chloride is recommended from January to harvest. Avoid spraying when the temperature exceeds 28 °C and under slow drying conditions, as foliage and fruit injury can occur. The risk increases with the number of sprays.
Powdery mildew	Remove infected growth	—	Prompt removal of infected growth is most helpful in checking the disease. It should be seen as a valuable supplement to the application of mildew sprays.
Codling moth Lightbrown apple moth (third sprays)	Azinphos-methyl (1B) or parathion-methyl (1B) (micro-encapsulated)	NSTVW All States	Maintain schedule – see 'Codling moth, Lightbrown apple moth (second sprays)'.
	Fenoxycarb (7B) (40 g/100 L)	All States	When the 20 g/100 L applications have been completed, apply a fourth spray 1 week later at 40 g/100 L.
	Indoxacarb (22A)	All States	Maintain schedule – see 'Codling moth, Lightbrown apple moth (second sprays)', but stop after 6 applications.

Apples – fruit development (early)			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Codling moth	Thiacloprid (4A) or clothianidin (4A)	All States All States	Continue applications at 14-day intervals. Do not apply more than 4 sprays in one season. For the remainder of the season, use a different chemical if required.
San José scale	Chlorpyrifos (1B)	All States	If monitoring indicates that there is a need, apply thoroughly, especially to the tops of the trees, when crawlers are active. Will also give short-term control of woolly aphid. Fenoxycarb used for codling moth will suppress San José scale.
European red mite (ERM), Two-spotted mite (TSM)	Bifenazate (2D) or abamectin (6A) or tebufenpyrad (10A) or propargite (14A) or etoxazole (10A)	All States	If ERM or TRM is a problem early (rare under IPM), apply abamectin within 6 weeks of petal fall. The product must be mixed with horticultural mineral oil to assist leaf penetration. Follow the directions on the label. Warning: Avoid applying abamectin and dithianon within 7 to 10 days of each other, as some fruit russetting may occur. Check product labels for specific warnings. Bifenazate and propargite should be applied thoroughly. Resistance to tebufenpyrad in both TSM and ERM has been diagnosed. Etoxazole provides effective control of eggs and nymphs. Minimally effective against adult mites. Use only one application of abamectin, bifenazate or tebufenpyrad in a season. Consecutive applications between seasons must also be avoided. Monitoring will help you choose and time the treatment.
Lightbrown apple moth LBAM	Chlorpyrifos (1B) (WG or WP formulation) or spinosad (5A) or methoxyfenozide (16A)	All States	If mating disruption is the only management technique used for codling moth, fruit will be unprotected from LBAM. Check blocks regularly for infestation and apply treatment only if necessary. Apply at 14-day intervals from petal fall while LBAM is active. Target sprays of spinosad against mature eggs and newly hatched caterpillars. Indoxacarb, spinetoram, fenoxycarb or chlorantranilprole program for codling moth will help control LBAM.

Apples – fruit development (late)			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Scab (spray 8)	Scab fungicide. (See 'Scab spray 2'.)	All States	Apply a protective fungicide 21 days after the seventh spray. The length of this and subsequent spray intervals for scab control will depend on the weather and the development of any infection on either fruit or foliage. A shorter interval will be required on infected trees. Warning: Do not use dithianon after early December on clear-skinned varieties or on apples to be cool-stored, because of possible adverse effects on fruit finish. This restriction does not apply to apples intended for controlled-atmosphere storage. Some of the recommended fungicides have export intervals of up to 10 weeks. It is best to avoid using these chemicals if fruit is intended for export. Always read the label and, if unsure of the chemical's export harvest interval, contact your reseller.
Bitter rot (spray 3)	See 'Bitter rot (spray 2)'.		
Powdery mildew	See 'Scab (spray 3) and Powdery mildew'.		Protect new growth until the terminal bud has formed and leaves have hardened off. No further spraying for powdery mildew should be necessary until autumn.
Codling moth Lightbrown apple moth (fourth sprays)	Azinphos -methyl (1B)	All States	Continue applications at 2- to 3-week intervals. See earlier reference under 'Petal fall'. Lengthen the spray interval to 3 weeks as the season progresses. Five applications for the season should generally be sufficient, except in orchards with a heavy carry-over from the previous season. Thorough coverage is important in to maintain control of this pest. Apply sufficient spray to wet the foliage and fruit. If control fails, resistance is a possible cause. See section on resistance in the pesticides chapter of this manual. It should be possible to discontinue routine schedules 2 to 4 months before harvest, depending on the variety and region. Keep monitoring trees for signs of late infestation.
	Parathion-methyl (1B) (micro-encapsulated) or clothianidin (4A)	All States	Continue applications at 2-weekly intervals. Should also control San José scale and woolly aphid. It should be possible to discontinue routine schedules 2 to 4 months before harvest, depending on the variety and region. Keep monitoring trees for signs of late infestation.
	Fenoxycarb (7B) (20 g/100 L)	All States	See earlier reference under 'Mid-season'. The fifth application should be made 4 to 6 weeks after the fourth. Use sex pheromone traps to help in timing sprays. It should be possible to discontinue routine schedules 2 to 4 months before harvest, depending on the variety and region. Keep monitoring trees for signs of late infestation.
	Indoxacarb (22A)	All States	Change to alternative product after 6 applications. Azinphos-methyl (1B) or parathion-methyl (1B) are recommended to complete the season's program. It should be possible to discontinue routine schedules 2 to 4 months before harvest, depending on the variety and region. Keep monitoring trees for signs of late infestation.
Codling moth	Thiacloprid (4A)	All States	See earlier reference under 'Mid-season (early)'.
	Chlorantraniliprole (28)	All States	Limit to three applications, then continue with different mode of action.

Apples – fruit development (late)			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Two-spotted mite (spray 1)	Bifenazate (2D) or tebufenpyrad (10A) or chlorfenapyr (13A) or propargite (14A) or etoxazole (10A)	All States	Start regular checking of foliage, particularly in the centres of trees, for the presence of mites and predators. Use of an 8× to 10× hand-lens is recommended. Alternatively, use a commercial mite monitoring service. Make one thorough application of chlorfenapyr at the lower rate if two-spotted mite numbers are increasing and predators are scarce. If predators are absent, use the higher rate. Chlorfenapyr is toxic to <i>Phytoseiulus persimilis</i> . It is not effective against European red mite. Tebufenpyrad is not as effective against two-spotted mite as against European red mite. Use only one application of bifenazate, etoxazole, chlorfenapyr or tebufenpyrad in a season and avoid consecutive sprays between seasons.
Wingless grasshopper	Chlorpyrifos (1B) or Fenthion (1B)	All States All States	Blocks of young, non-bearing trees may be severely attacked in some localities as herbage dries out. Infestation may occur from December on, depending on the district and the nature of the season. Infestation may continue until February. In moist seasons, when there is ample green herbage, grasshoppers should not be a problem. Regularly mow grass both within and surrounding the block to reduce the numbers of host plants and keep grasshoppers away from trees. Spray infested herbage around trees and the trees themselves if they become infested. It is advisable to spray a strip of infested grassland at least 10 m wide around the margins of the block, especially if grasshoppers have not yet invaded the block. A further application may be needed in about 14 days, depending on the pressure of reinfestation from outside the block. Mowing might avoid the need to spray. For ground spraying use: Chlorpyrifos – 500 mL of 500 g/L product/ha. Warning: Stock should not be allowed to graze herbage for a period of 14 days after it has been sprayed.
Apple leaf hopper	Azinphos-methyl (1B) or parathion-methyl (1B) (micro-encapsulated)	All States	Usually occurs as a problem under a 'soft' program for codling moth (e.g. mating disruption). Treat only if necessary at the first sign of the pest; re-apply at intervals not less than 3 weeks. The pest can cause irritation to pickers at harvest. Only one formulation of micro-encapsulated parathion-methyl (Folidol® 450 CS) is registered for jassids (an obsolete name for leafhoppers). An abamectin spray for mite control during early fruit development has been shown to control leafhopper.
Woolly apple aphid	Chlorpyrifos (1B) Samuri is also registered for late season application.	All States	Infestations of new season's growth may not appear until well in to summer.
Bitter pit	Calcium chloride	All States	Apply up to three sprays during the late fruit development season (January to harvest in cooler growing regions). See warnings for Calcium nitrate under 'Mid-season (early)'.
Bitter rot (spray 4)	See 'Bitter rot (spray 2)'.	All States	Apply this spray 4 weeks after the previous bitter rot spray if the weather is hot and humid and the orchard has a history of bitter rot problems.

Apples – fruit development (late)			
Pest	Pesticide (pesticide grouping)	Registered	Comments
European red mite	Bifenazate (2D) or tebufenpyrad (10A) or propargite (14A)	All States	Maintain monitoring. Depending on the effectiveness of earlier sprays, a further one may be necessary. Use only one application of bifenazate or tebufenpyrad in a season and avoid consecutive sprays between seasons. Resistance to tebufenpyrad is known in some districts.
Two-spotted mite	See 'Two-spotted mite (spray 1)'.	All States	
Queensland fruit fly	❶ Hang male lures in orchard as an indicator of fly presence.	–	❶ In seasons of good summer rains, fly may be present from January in warmer regions. Three-quarter-developed fruit may be attacked.
	❷ Apply baits.	–	❷ See 'Fruit flies: Queensland fruit fly, Mediterranean fruit fly' p. 62.
	❸ Spray with fenthion (1B) or trichlorfon (1B)	All States	❸ For fenthion, spray thoroughly 6 weeks, 3 weeks and again 2 weeks before harvest maturity in susceptible districts or if lures indicate that fly is active. For trichlorfon, start spraying at the first sign of stings (use 500 mL/100 L), then weekly at 250 mL/100 L. Sprays may be substituted for, or complement, baiting and should be necessary only in warmer districts. In the interests of integrated pest management, avoid using sprays if possible. Fenthion will also control codling moth and LBAM. Warning: Fenthion is moderately toxic to <i>Typhlodromus pyri</i> and very harmful to <i>Phytoseiulus persimilis</i> . Trichlorfon is very toxic to <i>Phytoseiulus persimilis</i> .
Scab	See 'Scab (spray 2)'.	All States	If scab has been well controlled it should be possible to reduce or even cease scab sprays from Christmas onwards. However, keep in mind the influence of the weather and regularly monitor crops, particularly after infection periods. Consider the option of adopting a curative program at this time of the year.
Bitter rot (spray 5)	See 'Bitter rot (spray 2)'.	All States	Apply this spray 4 weeks after the previous bitter rot spray if the weather is hot and humid and the orchard has a history of bitter rot problems.
Codling moth Lightbrown apple moth	Azinphos-methyl (1B) or parathion-methyl (1B) (micro-encapsulated)	All States	It should be possible to discontinue routine schedules by late February, depending on variety and season. Careful monitoring should continue to look for signs of late season infestation.
	Fenoxycarb (7B)	All States	Apply seventh spray 4 to 6 weeks after the sixth on later-maturing varieties.
Woolly aphid	Pirimicarb (1A) or chlorpyrifos (1B) or clothianidin (4A)	All States	Infestation is most likely to occur in the centres of dense, vigorous trees and may not appear until late summer or early autumn. Monitor very closely for this, because woolly aphid should not be allowed to build up on bearing trees. Observe withholding periods.
Lightbrown apple moth	Chlorpyrifos (1B) or spinosad (5A)	All States	See spinosad label for restrictions on the number of sprays.

Apples – fruit development (late)			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Sooty blotch, fly speck	Mancozeb (M3)	All States	These diseases are troublesome in damp, humid areas, especially in coastal districts. The disease becomes apparent as fruit approaches maturity. Orchards where a minimum of cover sprays are applied for black spot control are more susceptible. In affected orchards apply sprays at 3-weekly intervals, starting in February. The fungicide will also control scab and bitter rot. Mancozeb is toxic to <i>Typhlodromus pyri</i> .
Scab	See 'Scab (spray 2)'. 	All States	Where the weather is war and humid and favours scab development in the lead-up to harvest, consider apply sprays at intervals not exceeding 3 weeks. Longer intervals may lead to late scab development either on the tree or in store. Include mildew sprays only on varieties highly susceptible to mildew. Always read the manufacturer's label and be extremely cautious to observe withholding periods.
Bitter rot	See 'Bitter rot (spray 2)'. 	All States	If bitter rot has caused losses at this time in past seasons, continue spraying late varieties at intervals of 3 weeks in the lead-up to harvest.
Sooty blotch and fly speck	Mancozeb (M3)	All States	Spray late-maturing varieties in districts where infection is common.
Apples – postharvest to leaf fall			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Scab	Urea	All States	This postharvest treatment is recommended for reducing the primary spore population that overwinters in leaves. It is a valuable supplement to scab control and should be used annually, but it is especially valuable after a bad scab year. Urea also has some nutritive value. Apply after picking, but well before leaf fall. It is essential to cover lower surfaces of leaves. If necessary, apply a light ground spray to contact all fallen leaves. No special attention to a ground spray will be necessary if dilute sprays by air-blast are used. Better results can be expected if the orchard floor is clean at the time of spraying. Any treatment, such as mowing or mulching, that hastens leaf breakdown will result in the reduction of overwintering scab. Beware: Some damage by urea to spurs and laterals has occurred in very dry seasons. Care should be taken to avoid overspraying with urea. This is most likely to occur on headland trees.
Woolly aphid	Chlorpyrifos (1B) or endosulfan (2A)	All States	Mark infested trees in late summer or autumn to help identify trees that should be treated with imidacloprid or clothianidin in the following spring. Alternatively, apply either chlorpyrifos or endosulfan (preferred) as a post-harvest spray when a lot of leaves have fallen. This may not obviate the need for a further application on infested trees during the following season.

Apples – dormancy			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Powdery mildew	Remove infected buds when pruning.	–	Removal of infected material when pruning is most important for good control of mildew. It is particularly important to tip-prune infected buds from Jonathan.
Bitter rot	Remove and burn mummified fruits and dead wood when pruning.	–	Remove all 'mummies' that failed to set but that are still attached to the trees. In areas where bitter rot occurs most of these will be infected.
San José scale	Dormant oil	All States	In orchards where scale is known to be present, apply oil at 2 to 3 L/100 L at any convenient time when trees are dormant. Spraying before pruning is preferable, as scale may survive on prunings on the ground. In districts where this pest is a problem, an annual oil spray may be necessary. Elsewhere, an oil spray every second year is advisable, even if scale is not apparent, because once scale becomes established on trees it is difficult to control. Sprays for San José scale should be applied dilute and very thoroughly, taking care to get good wetting of trunks, limbs and twigs and penetration of cracks and crevices in the bark. Warning: Only one full strength oil spray (3 L/100 L) should be applied in a season. An interval of at least 4 weeks between a full-strength oil spray and green-tip application is desirable.
	Sanitation: Spray with oils as above or cut down and burn.	–	Scale can build up heavily on neglected fruit tree seedlings around orchard areas, on many ornamental trees and shrubs related to apple, and on several unrelated hosts, e.g. tree lucerne, osage orange and willow. It can be spread from these species to apples by wind or birds. Such sources of infestation should not be overlooked in areas where scale is a problem. Infested deciduous ornamentals should be sprayed with oil. Neglected apple trees and other hosts should be cut down and burned.

Stages for timing of IPM scheduling in pears (all photos © I&I NSW)

				
Green tip	Green cluster	Blossom		
				
Petal fall	Fruit development		Harvest	Dormancy

	More information (page)	Green tip / budswell	Blossom	Mid season	Harvest	After harvest	Dormancy
Codling moth	55	MD					
Lightbrown apple moth	73						
Longtailed mealybug	79						
Pear slug	99						
Pear leaf blister mite	148						
Pear scab	40						
Queensland fruit fly	63						
San José scale	113						
Two-spotted and European red mite	83						

■ Likely timing for monitoring and treatment, MD Mating disruption

Pears – green tip / budswell			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Scab (spray 1)	Copper hydroxide (M1) or copper oxychloride (M1) or cuprous oxide (M1) or tribasic copper sulfate (M1)	All States	Apply first spray at green tip stage. Beware, Winter Cole and Josephine pears may be damaged by copper sprays.
Longtailed mealybug	Buprofezin (17A)	All States	Apply twice, 10 to 14 days apart, between budswell and the end of flowering in sufficient volume to ensure the bark is soaked with thorough coverage to the point of run-off.
Scab (spray 2–3)	Difenoconazole (3) or flusilazole (3) or hexaconazole (3) or myclobutanil (3) or cyprodinil (9) or kresoxim-methyl (11) or trifloxystrobin (11) or dodine (M7) or captan (M4) or dithianon (M9) or mancozeb (M3) or metiram (M3) or thiram (M3) or ziram (M3) or a proprietary mixture of pyrimethanil (9) + fluquinconazole (3)	All States	Apply one of these fungicides at spurburst and again 10 days later at approximately white bud stage (except with difenoconazole which is applied 10 days after spurburst). Note restrictions on the number of applications of some products and the need to mix some with protectants. Neglect of scab on non-bearing trees can, in seasons favourable for its development, cause leaf drop, reduction in growth and eventual reduced cropping. The curative or 'after infection' method of control can be employed to save unnecessary protective applications on young trees. Do not apply kresoxim-methyl to pears if there is a chance of drift to cherries. Curative sprays, to be effective, must be applied as soon as possible after infection has occurred. The effective periods for the fungicides recommended here are: • 1½ days: dodine • 4 days: hexaconazole • 5 days: difenoconazole, fluquinconazole, myclobutanil • 5–6 days: flusilazole. Beware: Do not use dodine at temperatures close to freezing from white stage onward, as fruit russetting may occur. Do not use cyprodinil or pyrimethanil + fluquinconazole after petal fall.

Pears – green cluster			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Codling moth	Mating disruption agent	All States	Apply dispensers within the top 30 cm of the tree, before any adult codling moth activity starts. Do not use on blocks of less than 3 hectares or on irregularly shaped blocks. No other codling moth control should be needed if infestation in the previous season was less than 0.3%. If more than 0.3%, partial or full supplementation with insecticide is recommended. Seek advice from reseller or consultant. Monitoring for codling moth activity throughout the season is important.
Pears – blossom			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Scab (spray 4)	See 'Scab (spray 2–3).	All States	Beware: The danger of scab infection tends to be very high during blossom. Income for the year may depend on the efficient operation of spray machinery and the maintenance of a close schedule of sprays. In weather that is conducive to scab infection, it may be necessary to spray every 10 days.
Longtailed mealybug	Clothianidin (4A)	All States	Monitor carefully and apply the first spray as soon as crawlers are seen but after petal fall. Two sprays 14 days apart will give significant knockdown, but continue to monitor and if reinfestation occurs further sprays with a pesticide from another activity group may be required.

Pears – fruit development (early)			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Scab (spray 5)	See 'Scab (spray 2–3).	All States	Spray intervals can be lengthened to 14 days
Codling moth, Lightbrown apple moth (LBAM)	Azinphos-methyl (1B) or parathion methyl (1B) (micro-encapsulated)	All States	See apples, October–November for timing the first spray. Otherwise, make the first application 2 weeks after petal fall. Continue applications at 3- weekly (azinphos-methyl) or 2-weekly (parathion-methyl) intervals. May be combined as needed with fungicides. There are restrictions on the supply and use of parathion-methyl.
	Fenoxycarb (7B) (20 g/ 100 L)		See under apples, 'Petal fall'. Otherwise apply three applications at weekly intervals, starting 7 to 10 days after complete petal fall.
	Indoxacarb (22A)		Maximum of six applications. See product label for details of timing of sprays.
Codling moth	Thiacloprid (4A)	All States	Apply the first spray by the time 110 degree-days after Biofix has been reached. Continue applications (maximum of four) at 14-day intervals until four sprays have been used.
Pear slug	Azinphos-methyl (1B) or spinosad (5A)	All States	Apply as soon as infestation is noticed.
Pear leaf blister mite	Carbaryl (1A)	All States	Apply only if monitoring indicates that economic damage (heavy foliar infestation or fruit damage) is likely. Apply as soon as infestation is noticed Carbaryl is toxic to <i>Typhlodromus occidentalis</i> .
Two-spotted mite	Bifenazate (2D)	All States	Keep foliage under observation, particularly in the centres of the trees (Use an 8× to 10× hand-lens). If mites appear in moderate numbers and predators are scarce, thorough application of one of the listed treatments is recommended. Abamectin must be mixed with a horticultural mineral oil to help leaf penetration. See label for details. Unlike with apples it is not necessary to apply abamectin to pears within the first 6 weeks after petal fall. Provided that predators are present, no further application should be necessary, but continue to keep trees under observation. Use only one application of chlorfenapyr on any one block in a season. Chlorfenapyr is toxic to <i>Phytoseiulus persimilis</i> . Use of bifenazate or tebufenpyrad is restricted to one application in a season. Avoid consecutive applications between seasons. Warning: Propargite should not be used on pears, except as a postharvest spray. Resistance to tebufenpyrad in two-spotted mites has been diagnosed in some districts.
	or abamectin (6A)	All States	
	or tebufenpyrad (10A)	Not in ACT	
	or fenbutatin oxide (12 A)	All States	
	or chlorfenapyr (13A)	All States	
European red mite	Bifenazate (2D)	All States	European red mite rarely occurs on pears. Fenbutatin oxide (at full rate) will control a moderate infestation. Alternatively, use abamectin or bifenazate or tebufenpyrad, but only one application of any of these should be used in a season, regardless of the pest, and consecutive applications between seasons must be avoided.
	or abamectin (6A)	All States	
	or tebufenpyrad (10A)	Not ACT	
	or fenbutatin oxide (12A)	QNVWS (Not ACT)	

Pears – fruit development (late)			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Codling moth, LBAM	Azinphos-methyl (1B) or parathion-methyl (1B) (micro-encapsulated)	All States	Continue applications. Monitor trees after the last spray in case of late season infestation. With early-maturing varieties, Be wary of the interval between spraying and harvest (14 days).
	Fenoxycarb (7B) (40 g /100 L)		Fourth and subsequent applications at this rate.
Codling moth	Thiacloprid (4A)	All States	Continue applications at 14-day intervals. Do not apply more than four sprays in one season. For the remainder of the season, use a different chemical as required.
Scab	See 'Scab spray 2, 3.'	All States	Frequency of application will depend on seasonal conditions and the amount of infection already present. Generally, monthly or even longer intervals will be satisfactory in clean orchards. However, if infection occurred in spring, a spray interval of 3 weeks should be maintained. Monitoring for infection is vital. Some of the recommended fungicides have export harvest intervals of up to 10 weeks. It is best to avoid these chemicals if fruit is intended for export. Always read the label and, if unsure of the chemical's export harvest interval, contact your reseller. On later-maturing varieties, apply spray approximately 3 weeks before picking is due to start.
Queensland fruit fly	See under Apples	All States	
Scab	See 'Scab (spray 2, 3).'	All States	On later-maturing varieties, apply spray approximately 3 weeks before picking is due to start.
Pears – postharvest to leaf fall			
Pest	Pesticide (pesticide grouping)	Registered	Comments
Two-spotted mite	Propargite (14A)	All States	Apply immediately after harvest if required. Use high volume. Continue to monitor for predators.
Scab	Urea	All States	See under 'Apples'.
Pears – dormancy			
Pest	Pesticide (pesticide grouping)	Registered	Comments
San José scale	Dormant oil and sanitation	All States	See under 'Apples'.

More information and index



More information

Some of the information provided in the following references (marked †) comes from other countries. Always remember that the biology of pests and the tactics used to control them vary subtly from country to country and will change with time. Be particularly cautious with pesticide recommendations. If a pesticide is not recommended in this manual you must check that it has current registration in your State and abide by the conditions of that registration, as specified on the pesticide's label.

ALWAYS READ THE LABEL.

Alternaria leaf blotch and fruit spot (p. 30)

Horlock C and Hetherington S 2008. Alternaria leaf blotch and fruit spot of apple. In *Orchard Plant Protection Guide for Deciduous Fruits in NSW 2009–10*, NSW Department of Primary Industries, Orange. Available in pdf format on the I&I NSW website at www.dpi.nsw.gov.au/agriculture/horticulture/pests-diseases-hort/multiple/orchard-plant-protection-guide pp. 118–119

Horlock C 2007. *Alternaria fruit spot: New Directions*. Final Report, HAL Project AP05002. 53 pp.

Persley D 2008. *Diseases of Field Crops. Apple and Pear*. Queensland Department of Primary Industries and Fisheries, Brisbane

Apple dimpling bug (p. 35)

Bower C, Page FD, William DG and Woods W 1993. *Management of Apple Dimpling Bug*. Final Report HRDC Project A/003/R1. 93 pp.

Ellis MD, Baxendale FP and Keith DL 1998. *Protecting Bees when using Insecticides*. University of Nebraska. G98-1347-A

Mayer DF and Burgett M 2009. Honeybee. Washington State University Tree Fruit Research and Extension Center, Orchard Pest Management Online

Mayer DF, Johansen CA and Baird CR 1999. *How to Reduce Bee Poisoning from Pesticides*. PNW518. A Pacific Northwest Extension Publication. 14 pp.

Sivyer M and Learmonth S 2005. Fact Sheet Note 178. *Apple Dimpling Bug*. Department of Agriculture and Food, Government of Western Australia. 2 pp.

Williams M 1995. Dimpling bug. Agdex 212/622. Number 374. In *Insect Pests and Diseases of Apple in Tasmania*. Department of Primary Industries and Fisheries Tasmania. 2 pp.

Apple leafhopper (canary fly in Tasmania) (p. 141)

Beers EH and Elsner EA 1993. *White Apple Leafhopper*. Tree Fruit Research & Extension Center, Orchard Pest Management, Washington State University. <http://jenny.tfrec.wsu.edu:16080/opm/> †

Apple mosaic virus (p. 143)

Podeckis EV and Welliver R 2008. *Apple Mosaic Virus*. Kearneysville Tree Fruit Research and Education Center, West Virginia University. www.caf.wvu.edu/Kearneysville/disease_descriptions/omvirus.html

Apple scab (Black spot), Pear scab (p. 40)

Anonymous 1996. Apple scab management in British Columbia. www.agf.gov.bc.ca/cropprot/tfpm/applescb.htm †

Domeney P. Black spot Autumn monitoring. IPM postcards. Department of Primary Industries and Water Tasmania

Draper MA, Burrows R and Maxson-Stein K 2007. *Apple Scab. A Disease of Apple and Crabapple*. South Dakota State University FS939

Eyres N and Kumar S 2004. *Apple Scab*. Government of Western Australia. Department of Agriculture. Farmnote No. 78/2003

Manktelow D and Beresford R 1993. Improved management of apple black spot. *The Orchardist* 66, 59 †

Percy H 1996. HortFACT – Black spot (*Venturia inaequalis*) in apples and pears. An introduction to the disease. www.hortnet.co.nz/publications/hortfacts/hf205001.htm †

Penrose L 2004. *Apple and Pear Scab*. NSW Department of Primary Industries, Orange. Agfact H4.AB.4

Solymár B 2005. Apple scab. Ministry of Agriculture, Food and Rural Affairs, Ontario. www.omafr.gov.on.ca/english/crops/facts/apscab.htm †

Triloff P 1997. Bulletin OILB/SROP. 20(9), 229–240

Vaillancourt L and Hartman JR 2000. Apple Scab. APSnet Education Center. Plant Disease Lessons. Apple Scab. www.apsnet.org/education/lessonsPlantPath/AppleScab/ [†]

Washington WS and Villata O 2006. *Apple Scab*. Department of Primary Industries Victoria. AG0167

Washington WS and Villata O 2006. *Pear Scab*. Department of Primary Industries Victoria. AG0159

Withnall M 2008. Organic gala grower masters scab control. *The Fruit Grower* October, pp. 16–18

Armillaria root rot (p. 144)

DECC. *Armillaria Root Rot Fact Sheet*. Botanic Gardens Trust, Department of Environment and Climate Change, Sydney. www.rbgsyd.nsw.gov.au/plant_info/pests_diseases/fact_sheets/armillaria_root_rot

Washington WS 2006. *Armillaria Root Rot*. State of Victoria, Department of Primary Industries Agriculture Notes. AG0155. [www.dpi.vic.gov.au/dpi/nreninf.nsf/v/33959CB2ED9A9E42CA257412001311E6/\\$file/Armillaria_Root_Rot.pdf](http://www.dpi.vic.gov.au/dpi/nreninf.nsf/v/33959CB2ED9A9E42CA257412001311E6/$file/Armillaria_Root_Rot.pdf)

Bitter pit (p. 146)

Warner G 2008. Bitter pit causes are complex. *Good Fruit Grower* April p.15 [†]

Bitter rot (p. 64)

Ellis MA 2008. *Bitter Rot of Apples*. Factsheet, Agriculture and Natural Resources HYG-3302-08. Ohio State University Extension [†]

Sutton TB 1990. Bitter rot. In *Compendium of Apple and Pear Diseases*. The American Phytopathological Society, pp. 15–16 [†]

Codling moth (p. 51)

Addison MF 2008. Monitoring of codling moth in apple and pear orchards: What is it worth? *South African Fruit Journal* August–September, pp. 66–67 [†]

Botha J, Davis P, Woods B and Power G 2006. *Codling Moth (Cydia pomonella). Exotic Threat to Western Australia*. Department of Agriculture and Food Western Australia. ISSN 1443-7783 no. 44/2000

Michaels F 2008. Organic codling moth control. Green Harvest. www.greenharvest.com.au/fact_sheets/fs_codling.html

Sexton S 2008. Managing codling moth. *Tree Fruit* August, p. 24

Solymár B 2005. Codling moth. Ministry of Agriculture Food and Rural Affairs, Ontario. www.omafra.gov.on.ca/crops/facts/codling.htm [†]

University of California 2008. How to Manage Pests. UC Pest Management Guidelines. Pear Codling Moth. www.ipm.ucdavis.edu/PMG/r603300111.html#printpage

Williams D 2000. Codling moth. *Agriculture Notes*. AG0095. ISSN 1329-8062. State of Victoria, Department of Primary Industries

Woods B, Trend B and Black T 1998. *Codling Moth*. Department of Agriculture and Food Western Australia. Farmnote 52/1988

Fruit flies: Queensland fruit fly, Mediterranean fruit fly (p. 58)

Frances Michaels 2009. Organic fruit fly control. Greenharvest. www.greenharvest.com.au/pestcontrol/fruit_fly_info.html

Anonymous 2009. About fruit flies. Bugs for Bugs. www.bugsforbugs.com.au/library/fruit-fly-info

Broughton S and De Lima F. *Control of Mediterranean Fruit Fly (Medfly) in backyards*. Department of Agriculture and Food Western Australia

Broughton S and De Lima F 2006. *Recognizing exotic fruit flies likely to enter Western Australia*. Farmnote 63/99. Department of Agriculture and Food Western Australia

Dominiak B 2007. *Control of Queensland Fruit Fly in New South Wales*. Primefact 518. NSW Department of Primary Industries, Orange

Dominiak B 2007. *Queensland Fruit Fly*. Primefact 520. NSW Department of Primary Industries, Orange

DPI Victoria 2009. *Queensland Fruit Fly*. Department of Primary Industries Victoria

Heaven D 2006. *Fruit flies*. Fact Sheet FS 21/77/07. Government of South Australia. Primary Industries and Resources SA, Adelaide

Helicoverpa and loopers (p. 68)

Goodyer GJ 1987. *Heliothis caterpillars*. Agfact, Department of Agriculture New South Wales, Sydney. Agdex 622

Lightbrown apple moth (p. 73)

Anonymous. *Isomate. Pheromone Mating Disruption Dispensers. Organic Pest Control*. HortResearch Rangahau Ahumāra[†]

Baker G 2005. *Lightbrown Apple Moth*. Government of South Australia, Primary Industries and Resources. Fact Sheet No: 07/04

Thomas WP 1998. *HortFACT Lightbrown Apple Moth Life Cycle*. The Horticulture and Food Research Institute of New Zealand Limited[†]

Williams D 2000. *Lightbrown Apple Moth in Orchards*. AG0093 (ISSN 1329-8062)

Longtailed mealybug (p. 79)

Anonymous, *Mealybugs – Fact Sheet*. Plant Disease Diagnostic Unit, Royal Botanic Gardens Trust, Sydney

Cox J 1998. *HortFACT. Longtailed Mealybug Life Cycle*. The Horticulture and Food Research Institute of New Zealand Ltd. www.hortnet.co.nz/publications/hortfacts/hf401032.htm[†]

Furness GO 1976. The dispersal, age-structure and natural enemies of the longtailed mealybug, *Pseudococcus longispinus* (Targioni-Tozzetti), in relation to sampling and control. *Australian Journal of Zoology* 24, 237–247.

Mo J 2005. *Long tailed mealy bug*. New South Wales Department of Primary Industries. www.dpi.nsw.gov.au/agriculture/horticulture/citrus/health/pests/long-tailed-mealy-bug

Varela LG, Elkins RB, Van Steenwyk RA and Ingels C 2008. *Pear Mealybugs*. Statewide IPM Program, Agriculture and Natural Resources, University of California, Davis, CA. www.ipm.ucdavis.edu/PMG/r603301211.html[†]

Mites: Two-spotted mites, European red mites, Bryobia mites (p. 83)

Botha J and Learmonth S 2005. *Management of European Red Mite in Western Australia*. Government of Western Australia, Department of Agriculture. Farmnote No. 40/2005

Bower CC and Thwaite WG 1995. *Management Manual: A practical guide to integrated mite control in apples*. NSW Agriculture, Orange

Bower CC and Thwaite WG 1995. *The Mite Management Manual*. NSW Agriculture, Orange

Collyer E 1998. HortFACT. *European Red Mite Life Cycle*. www.hortnet.co.nz/publications/hortfacts/hf401005.htm[†]

Collyer E 1998. HortFACT. *Two-spotted Mite Life Cycle*. www.hortnet.co.nz/publications/hortfacts/hf401024.htm[†]

Solymár B 2008. *Mite Pests and Their Predators*. Ontario Ministry of Agriculture, Food and Rural Affairs. www.omafra.gov.on.ca/english/crops/facts/mite.htm[†]

Thwaite WG 2003. Coping with European red mite resistance. *FruitWise*, Winter, 51, pp. 6–7

Williams D 2000. *Integrated Control of Two-spotted Mite in Orchards*. Department of Primary Industries, Victoria. AG0157

Pear leaf blister mite (p. 148)

Fraser H and Carter N 2007. *Don't Get Burned by Pear Leaf Blister Mite*. Ontario Ministry of Agriculture, Food and Rural Affairs[†]

Howitt AH 1999. *Pear Leaf Blister Mite*. Michigan State University Extension, Van Buren County. Fruit IPM Fact Sheet. www.canr.msu.edu/vanburen/fplbm.htm[†]

Williams D 2000. *The Bryobia Mite and Pear-leaf Blister Mite*. State of Victoria, Department of Primary Industries. AG0094

Pear blossom blast (p. 96)

Carter N 2005. *Pear Blossom Blast*. Ontario Ministry of Agriculture Food and Rural Affairs. www.omafra.gov.on.ca/english/crops/hort/news/hortmatt/2005/12hrt05a1.htm[†]

Guerana M and Born H 2003. *Organic Pear Production. Horticulture Production Guide*. Appropriate Technology Transfer for Rural Areas (ATTRA). www.attra.ncat.org[†]

Scheidt JW 2008. *Pear – Pseudomonas Blossom Blast and Dieback*. An online guide to plant disease control. Oregon State University Extension http://plant-disease.ippc.orst.edu/factsheet.cfm?RecordID=807&rec_type=disease[†]

Whitesides SK and Spotts RA 2006. Susceptibility of pear cultivars to blossom blast caused by *Pseudomonas syringae*. *HortScience*

Pear slug, Pear sawfly (p. 99)

Michigan State University Extension. *Fruit IPM Fact Sheet. Pear Sawfly (Pear Slug)*. www.canr.msu.edu/vanburen/fpsawfly.htm [†]

University of California Statewide Integrated Pest Management Program. *Pear Slug*. University of California, Davis. www.ipm.ucdavis.edu/PMG/r603302211.html [†]

Utah State University Extension. *Pear Sawfly*. Fact Sheet number 55. Utah State University [†]

Washington State University Extension. *Insect Answers. Pear Slug*. Washington State University. <https://cru84.cahe.wsu.edu/ListItems.aspx?Keyword=pear%20slug> [†]

Phytophthora root and crown rot (p.102)

Alexander BJR 1999. *Studies on Biological Control of Phytophthora cactorum on Apple* <http://researchspace.auckland.ac.nz/handle/2292/874> [†]

Gubler WD and Teviotdale BL 2006. *Apple. Phytophthora Root and Crown Rot*. UC Pest Management Guidelines. UC ANR Publication 3432. www.ipm.ucdavis.edu/PMG/r4100511.html [†]

Lim TL 1997. *Phytophthora Root and Trunk Rot of Pome and Stone Fruits*. Agriculture Notes. State of Victoria, Department of Primary Industries. AG0191 ISSN1329–8062

Powdery mildew (p. 108)

Penrose L 1998. *Powdery mildew of apples*. Second edition, Agfact H4.AB.8. NSW Department of Primary Industries, Orange

Turechek WW, Carroll JE and Rosenberger DA 2004. *Powdery Mildew of Apple*. Cornell University. www.nysipm.cornell.edu/factsheets/treefruit/diseases/pm/apple_pm.pdf [†]

Washington WS 2006. *Powdery Mildew of Apples*. Department of Primary Industries Victoria. AG0161

Yoder KS, Hickey KD and Biggs AR. *Plant Disease Fact Sheet. Powdery mildew, Podosphaera leucotricha*. Kearneysville Tree Fruit Research and Education Centre, West Virginia University. www.caf.wvu.edu/Kearneysville/disease_descriptions/ompowmil.html [†]

Reducing the impacts of birds in horticulture (p. 159)

Bomford M and O'Brien P 1990. Sonic deterrents in bird damage control: a review of device tests and effectiveness. *Wildlife Society Bulletin* 18, 411–422

Bomford M and Sinclair R 2002. Australian research on bird pests: impact, management and future directions. *Emu* 102, 29–45

Braysher M 1993. *Managing Vertebrate Pests: Principles and Strategies*. Australian Government Printing Service, Canberra

Braysher M and Saunders G 2002. *Best Practice Pest Animal Management*. Agnote DAI 279. NSW Department of Primary Industries, Orange

San José scale (p.113)

Wearing CH. HortFACT. *San José Scale Life Cycle*. The Horticulture and Food Research Institute of New Zealand. www.hortnet.co.nz/publications/hortfacts/hf401021.htm [†]

Welty C 2003. *San José Scale on Fruit Trees*. Chelan County Pest and Disease Control Board. www.co.chelan.wa.us/pc/pc_scale.htm [†]

Silver leaf (p. 150)

Spiers A 1996. *HortFACT – Silverleaf (Chondrostereum purpureum)*, an introduction to the disease. The Horticulture and Food Research Institute of New Zealand Limited. www.hortnet.co.nz/publications/hortfacts/hf205015.htm [†]

Spiers A 1996. *HortFACT – Silverleaf – How does the Disease Affect Tree Productivity and Fruit Quality?* The Horticulture and Food Research Institute of New Zealand Limited. www.hortnet.co.nz/publications/science/asexpt2.htm [†]

Spiers A 1997. *HortFACT – Pruning to Prevent Silverleaf*. The Horticulture and Food Research Institute of New Zealand Limited. www.hortnet.co.nz/publications/hortfacts/hf205016.htm [†]

Six steps to controlling diseases of apples and pears (p. 1)

Dart J 2008. *Intensive apple orchard systems*. Primefact 815. New South Wales Department of Primary Industries. www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/238191/intensive-apple-orchard-systems.pdf

Furness G 2006. *Orchard & Vineyard Spraying handbook for Australia and New Zealand*. Department of Primary Industries and Resources SA, Adelaide

James P and Cambell J. *Successfully Replanting Orchards, Five Easy Steps. A Best Practice Guide*. Apple and Pear Growers Association of South Australia, Cavan SA

Ohlendorf BLP 1999. *Integrated Pest Management for Apples and Pears*. Second Edition. University of California publication 3340⁺

Tracey J, Bomford M, Hart Q, Saunders G and Sinclair R 2007. *Managing Bird Damage to Fruit and Other Horticultural Crops*. Bureau of Rural Sciences, Canberra

I&I NSW (various dates) *Spray Sense* (information on pesticide issues). www.dpi.nsw.gov.au/agriculture/farm/chemicals/general/spray-sense-leaflet-series

Snails (p. 152)

Davis P, Widmer M and Craven T 2004. *Control of Pest Snails and Slugs*. Government of Western Australia, Department of Agriculture. Garden note No. 12 (formerly Farmnote 113/94 and 100/99)

Davis P, Widmer M and Craven T 2004. *Pest Snails and Slugs of Western Australia*. Government of Western Australia, Department of Agriculture. Garden note No. 11 (formerly Farmnote 112/94)

Storage rots (p. 117)

Holmes R and Washington B 2007. *Guidelines for Postharvest Drenching of Apples and Pears*. Apple and Pear Australia Limited. www.apal.org.au/assets/content/3213/DPA%20use%20guidelines%20Revised%20April07.pdf

Thrips: Western flower thrips, Plague thrips (p. 123)

Medhurst A 2002. *WFT Insecticide Management Plan: Stone Fruit*. National strategy for the management of western flower thrips and tomato spotted wilt virus. Horticulture Australia Limited

Moran J and Miller J 1997. *Western Flower Thrips – Information for Industry*. State of Victoria, Department of Primary Industries. Available through DPIV website, www.dpi.vic.gov.au/dpi/index.htm

Steiner M 2004. Which Thrips is That? A Guide to the Key Species Damaging Stone and Pome Fruit in NSW. NSW Department of Primary Industries

Swanson B 1997. *Western Flower Thrips in Victoria*. State of Victoria, Department of Primary Industries. Available through DPIV website, www.dpi.vic.gov.au/dpi/index.htm

Thwaite G, Hardy S and Steiner M 2007. In: *Orchard Plant Protection Guide for Deciduous fruits in NSW 2007/08*. 17th edition pp.116–116

Persley D, Sharman M, Thomas J, Kay I, Heisswolf S and McMichael L 2007. *Thrips and Tospovirus. A Management Guide*. Cooperative Centre for Tropical Plant Protection. The state of Queensland, Department of Primary Industries and Fisheries

Weevils: Fuller's rose weevil, Garden weevil, Apple weevil, Fruit tree root weevil, Eucalyptus weevil (p. 128)

Caprile JL, Wunderlich LR, Vossen PM, Coates WW, Andris HL, Varela LG and Bentley WJ 2006. *UC Pest Management Guidelines. Apple Cribrate Weevil*. University of California Online Statewide Integrated Pest Management Program. www.ipm.ucdavis.edu⁺

Domeney P. *Weevils*. www.dpiw.tas.gov.au/ipm

DPI Tasmania. *IPM Strategies for Combating Weevils in Apple Orchards*. FarmPoint. Department of Primary Industries and Water, Tasmania. www.farmpoint.tas.gov.au/farmpoint.nsf

Fisher D and Learmonth S 2004. *Garden Weevil in Vineyards*. Farmnote No. 60/203. Department of Agriculture, Government of Western Australia

Fisher D and Learmonth S 2007. *Apple weevil (Otiorynchus cribricollis) – Pest of Viticulture*. Department of Agriculture and Food, Government of Western Australia

May BM 1998. *HortFACT. Fuller's Rose Weevil Life Cycle*. The Horticulture and Food Research Institute of New Zealand Limited. www.hortnet.co.nz/publications/hortfacts/hf401030.htm⁺

Mo J and Hardy S 2005. *Fuller's Rose Weevil*. NSW Department of Primary Industries, Orange

Phillips C 1992. *Eucalyptus weevil*. Primary Industries and Resources SA. Government of South Australia. www.pir.sa.gov.au/_data/assets/pdf_file/0014/32900/Number_7_Eucalyptus_Weevil.pdf

White root rot (p. 155)

Horlock CM, Haselgrove L and Cameron D 2007. *Sustainable Management of White Root Rot of Apple in Queensland*. Final Report, HAL project AP03026, 61 pp.

Pérez-Jiménez RM 2006. A review of the biology and pathogenicity of *Rosellinia necatrix* – the cause of white root rot disease of fruit trees and other plants. *Journal of Phytopathology* 154, 257–266[†]

Wingless grasshoppers and katydids (p. 157)

Emery R 1990. *Wingless Grasshoppers and their Control*. Farmnote No. 62/90, Agdex 622, Agriculture Western Australia, Perth

Oliver S and Croft D 2007. *Wingless Grasshoppers*. NSW Department of Primary Industries, Orange. Primefact 631 (Fourth Edition)

Walker P, Hunter D and Elder R 2008. *Wingless Grasshoppers*. Queensland Department of Primary Industries and Fisheries

Mo J 2002. *Katydid*. NSW Department of Primary Industries, Orange

Woolly aphid (p. 134)

Beers EH, Hoyt SC and Willett MJ 1993. *Woolly Apple Aphid*. Washington State University Tree Fruit Research and Extension Center. Orchard Pest Management Online. <http://jenny.tfrec.wsu.edu/opm/displaySpecies.php?pn=410>[†]

Campbell J 2001. Apple rootstock identification. Agfact H4.1.10 (second edition). Industry & Investment NSW. www.dpi.nsw.gov.au/agriculture/horticulture/pomes/apples/rootstock

Schooley K 2005. *Woolly Apple Aphid*. Ministry of Agriculture Food and Rural Affairs, Government of Ontario. www.omafr.gov.on.ca/english/crops/facts/wooph.htm[†]

Seaman AJ and Riedl H 1988. *Woolly Apple Aphid*. Cornell University, New York State. Tree Fruit Fact Sheet 102 GFSTF-I 16. www.nysipm.cornell.edu/factsheets/treefruit/pests/waa/waa.asp[†]

Welty C and Murphy J. *Woolly Apple Aphid*. Extension factsheet. Ohio State University. <http://ohioline.osu.edu/hyg-fact/2000/2208.html>

Kay BJ, Twigg LE, Nicol HI and Korn TJ 1994. The use of artificial perches to increase predation on house mice (*Mus domesticus*) by raptors. *Wildlife Research* 21, 95–106

Sinclair R 2000. Guidelines to best practice bird control to minimise losses in vineyards. *Australian Viticulture* Mar/Apr, pp.60–85

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