Integrated Pest Disease and Weed Management manual for Australian Apple and Pears

Disclaimer:

Funding statement:

Levy funds – R&D projects

This Manual is an output of project AP16007 "An Integrated Pest, Disease and Weed Management Program for the Australian Apple and Pear Industry" funded by Hort Innovation, using the Apple and Pear industry research and development levy and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Additional funding, not managed by Hort Innovation, was provided by the Victorian Government through the Agriculture Victoria group in the Department of Jobs Precincts and Regions; the New South Wales Government through the Department of Primary Industries; the Queensland Government through the Department of Agriculture Food and Fisheries; the Western Australian Government through the Department of Primary Industries and Regional Development; and the Tasmanian Institute of Agriculture within the University of Tasmania.

Edition information:

This is the second edition of the manual, the first having been produced as "Integrated Pest Management for Australian Apples & Pears" in 2009 by Shane Hetherington and edited by Ann Munroe on behalf of Apple and Pear Australia Ltd. Many of the photographs and images from that edition have been retained in this second edition. Additional photographs were sourced from Plant Health Australia, NSW DPI, TIA, WA DPIRD, Agriculture Victoria, and private individuals with acknowledgement embedded with the image.

This edition was prepared by David Williams[1] and Oscar Villalta[1] with contributions by Stephen Quarrell[2], Kevin Dodds[3], Paul James[4], Alison Mathews[5] and Stewart Learmonth[5]. Jennifer Sexton[1] undertook the mammoth task of correcting formatting and other errors.

[1] Agriculture Victoria; [2] TIA; [3] NSW DPI; [4] Lenswood Cooperative, [5] DPIRD WA

Publishing details:

Published and distributed by: Hort Innovation

Level 8
1 Chifley Square
Sydney NSW 2000

Telephone: (02) 8295 2300

www.horticulture.com.au

Supported by APAL and Lenswood Apples

Table of Contents

About this manual

This second edition of the manual revises the Australian apple and pear IPM strategy developed in 2007-08. Development of the original strategy involved collaboration between Australian apple and pear growers, researchers and extension specialists to create a strategy that gave practical pest management options instead of 'warm fuzzy' philosophy.

Australian pome fruit is grown in a range of climatic zones which means that the pest problems experienced by orchards in our regions are diverse. This revised edition of the manual includes updated pest management knowledge, an increased emphasis on cultural and biological control options that help reduce reliance on pesticides and help to slow development of resistance in pests, diseases and weeds to chemical treatments. Readers will also notice that the manual is now called an IPDM manual to recognise the advances in integrating disease management. The new manual is being delivered in conjunction with training opportunities for growers, agronomists, pest management scouts and consultants, and extension officers.

Many markets require growers to demonstrate that they are growing their crops in ways that are safe to the environment, consumers, farm workers and the general community. Any claims by growers are expected to stand up to the scrutiny of an audit. This means that growers need to document what they do and why they do it, which is why Australian growers have adopted Quality Assurance (QA) systems that identify, document, and control food safety issues. QA systems require justification of pest management decisions to be based on the results of monitoring pest populations. This is integral to IPM but in the past IPM often focussed on integrating biological control of an individual pest species into the pesticide-dominated program for controlling the broader pest complexes attacking crops. An example is integrated mite control in which predator mites resistant to the broad-spectrum pesticides used against codling moth were introduced to control spider mite outbreaks caused by those same pesticides killing other non-target species that had previously exerted control over the pest mites. The Australian apple and pear industry supports a sustained program of pest management research and development that generates a better understanding of the interactions occurring in the orchard and how they impact on crop quality and productivity. Growers now have a suite of biological, agronomic, and decision-support tools available to help them deal with the interactive biological web of pests, diseases, weeds, and biological control agents that influence their economic and ecological sustainability. Many of these are covered in the revised manual. Updates and new tools are also available on the Australian Apple and Pear IPDM Webpage www.extensionaus.com.au/ozapplepearipdm and on facebook OzApplePearIPDM.

Apple and Pear IPDM

Chapter 1: Introduction to IPDM

IPDM quick facts

- Orchardists are in the business of growing quality fruit and not timber
- Pests, diseases and weeds are not problems until they start to cause economic losses
- Biocontrol agents are good long-term investments
- Soil biodiversity is important for plant health and nutrition, and supporting biocontrol agents
- Improving biosecurity is more cost-effective than attempting to eradicate all pests and diseases
- Cultural practices are effective preventative measures
- Pesticides have a role in IPDM strategies but must be chosen with care and only used when really needed
- Conservation agriculture relies on minimal mechanical soil disturbance, at least 30% permanent soil organic cover, and species diversification to improve soil health and habitat for biocontrol agents
- Regenerative agriculture is an evolution of conservation agriculture
- Functional diversity recognises that species can each perform more than one role in an ecosystem
- Conservation biocontrol is provision of habitat to support biocontrol agents
- Use of IPDM is a personal choice
- IPDM involves identification of objectives and implementing planned strategies, tactics, monitoring and evaluation

What is IPDM?

IPDM is integrated pest and disease management. It is defined by the Food and Agriculture Organisation (FAO) as meaning "*the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. (IPDM) emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms."* In short IPDM involves evaluating your pest problems and then developing a systems approach to manage the problems in a crop production context. It may initially appear complicated because consideration must be given to impact on the entire block and side effects on biocontrol agents working "behind the scenes" preventing other pests from becoming problems. Generally, a well-run IPDM program will result in reduced usage of synthetic pesticides although in some cases they may be substituted by bio-pesticides. This is a natural consequence of considering the entire range of control options available, starting with orchard hygiene and other cultural aspects such as pest or disease resistant rootstocks, encouraging biocontrol agents, use of technology that disrupts pest communication systems (pheromones), and use of appropriate pesticides when required.

Although IPDM systems generally have a common theme behind the way they run, even within a single crop system such as apples or pears the details depend on the geographical area in which the crop is located. Apple and pear IPDM systems developed in Germany, North America, or even New Zealand will be dealing with pest complexes and host-pest-predator-climate interactions that are different to those in Australia and therefore cannot be adopted "off the shelf" without modification. Different growing regions in Australia also have differences in pest complexes and climate that need to be considered as part of the challenge in developing a national IPDM system. The decision to implement IPDM is very much a personal decision driven by the historical context and current aspirations of the orchardist. Therefore, a single recipe for IPDM will not work for all growers. The manual addresses this by providing strategies rather than prescriptive recipes.

Orchardists using IPDM choose management options from within a strategic plan that recognises that:

- The orchardist is in the business of growing high-quality fruit
- Presence of pests and diseases is natural and does not present a problem until they start to create economic losses
- If application of a pesticide results in a pest resurgence, or development of a secondary pest outbreak, then that's a cost associated with putting on the initial pesticide application.

- Some biocontrol agents will persist for a long time in the orchard after being released (often depending on what chemical are subsequently used) and so may provide benefits throughout the season and in years to come, resulting in the cost being spread across seasons
- The cost of releasing biocontrol agents is a very small component of the total cost of producing fruit. Access to markets and gaining a higher price for fruit produced under a system that doesn't use hard chemicals can outweigh the costs.
- Soil biodiversity is an important indicator of soil health.
- Weeds are plants that are growing where they are not wanted. Weeds take advantage of bare soil and bacterially dominated soil microbiota. Plants that compete with crop plants for water and nutrients without providing off-set benefits to the crop plants are weeds. However, many "weeds" stimulate nitrogen-fixing soil microbes, improve soil health, and/or provide nectar that sustains parasitoid wasps and other biocontrol agents that in turn reduce pest and disease pressure.
- Completely eradicating pests and diseases is almost impossible but preventing their establishment is feasible by improving farm biosecurity.
- Cultural techniques, including crop hygiene, are preventative measures that limit initial pest and disease population size
- Biological control agents are beneficial species that provide cost-effective pest and disease management but may require occasional help in extreme conditions
- Pesticides have a place in the strategy but should be chosen using knowledge of their target range, how they impact beneficial species such as pollinators and biocontrol agents, their approval and MRLs in target markets, resistance management strategies and re-entry periods.

Conservation agriculture promotes the use of no-tillage techniques that generate minimum soil disturbance, maintenance of a permanent organic soil cover, and plant species diversity to improve farm biodiversity and the ecosystem functions above and below ground that lead to greater water and nutrient use efficiency for improved sustainable crop production. There are three principles driving conservation agriculture:

- **Minimum mechanical soil disturbance** achieved through direct seeding and fertilizer placement. Land preparation for seeding in this approach involves slashing, rolling, or spraying existing weeds and crop residue to create a mulch layer and direct seeding through the mulch to maintain soil cover. In modern moderate-high density perennial tree crops soil beneath the trees is usually maintained weed-free by spraying so that the tree roots are not disturbed.

- **Permanent soil organic cover of at least 30%** maintained with cover crops or crop residues. Cover crops are used to improve soil fertility between crops and in annual cropping systems their growth is interrupted before they compete with the commercial crop. In perennial deciduous tree crops such as pome fruit a common practice is to maintain a grass/clover inter-row sward and a narrow weed free tree-line that is mulched by use of a side-discharge mower to maintain the inter-row at a low height. The inter-row provides about 55% soil organic cover and the mulched area completes the coverage. If a side discharge mower is not used to provide mulch the "weeds" growing in the tree-line can be sprayed with a dessicant type herbicide that leaves standing plant residue to provide soil cover.
- **Species diversification** achieved through crop rotations involving at least three different crop types is not feasible in a perennial tree orchard unless the inter-row is used for "crop" rotations. An alternative way to improve species diversification is to plant a mixed species inter-row using a range of perennial and/or annual plants that withstand mowing and traffic. Such a sward could be designed to improve soil health and also provide habitat and alternative food sources for beneficial predatory and parasitic biocontrol agents useful for pest management.

Regenerative agriculture is both a new name for an old philosophy and an evolution of conservation agriculture whereby many of the external inputs are replaced when natural systems are allowed to move toward greater complexity (biodiversity) in response to disturbance. It is occurring in tandem with development of systems approaches in science that acknowledge the traditional reductionist approach to problem solving takes too long to explain the complex adaptive interactions between species, substrates and disturbance within an agroecosystem. Biodiversity related to an agroecosystem can be crop-associated biodiversity consisting of the range of organisms above and below ground (such as pests, diseases, weeds, biological control agents, pollinators, and mycorrhizal fungi) that positively or negatively impact on agriculture. Planned biodiversity in an agroecosystem includes all the organisms, including crop species, introduced by the farmer. Unplanned biodiversity are all other organisms that exist in or colonise the agroecosystem.

Functional diversity is a measure of the number of species and the number of different roles those species perform in the ecosystem. A single species can provide more than one role or function.

Classical biocontrol and augmentative biocontrol both involve release of predators, parasitoids, or pathogens that attack crop pests. These biocontrol agents are usually imported specialists from the home range of the pest and in Australia must undergo intensive testing for host specificity before approval can be given to release them from quarantine.

Conservation biocontrol is the practice of providing habitat to support populations of naturally occurring predators and parasitoids that attack crop pests. Conservation biocontrol supports the wide range of generalist native predators and parasitoids but also has potential to enhance survival and performance of introduced specialist biocontrol agents released under classical and augmentative biocontrol programs. Practices that increase wildflower abundance and habitat structure are important components of conservation biocontrol.

One of the many challenges facing Australian apple and pear growers in adopting regenerative agriculture approaches is that the crop, an introduced species, is by definition a disturbance in the ecosystem and triggers an adaptive response from the unplanned biodiversity. This happens at the same time that the introduced species may require supplements unless there is sufficient functional diversity in the soil biota to provide for its needs. The application of supplements may then have a negative impact on the native unplanned biodiversity and set off a treadmill effect.

The goal of IPDM is to reduce pest populations while minimizing risk to the environment and beneficial species such as predators, parasitoids, pollinators, and earthworms. This can be achieved by integrating aspects of conservation agriculture, regenerative agriculture, and conservation biocontrol to improve functional diversity through increased biodiversity within the production system.

Making the decision to use IPDM requires personal choices

Australian pome fruit orchardists operate under a production system that requires a high degree of financial risk and large amounts of annual expenditure to achieve production that may generate low rates of return. Bad and damaged fruit costs money in lost marketable yield but there are also significant costs associated with preventing yield loss. If the costs of preventing loss are higher than the value of the potential loss, the threshold damage levels are too low. The level of damage considered acceptable varies between orchardists and is context dependent. Some want to produce 'perfect' fruit and are willing to pay to do this while others will tolerate some damage. IPDM involves making personal choices about what is an acceptable level of damage and what level of risk is acceptable. There are no firm rules and regulations.

A well run IPDM program involves no reduction in pack-out. However, during the first few seasons of transition while the system beds down and beneficial biodiversity establishes, inexperience means that some mistakes may happen. The information in this manual provides a way of minimising that risk:

Farm management practices

Professional pest monitoring services are available for growers who:

- Do not have staff trained in pest, disease and weed identification
- Do not have time to conduct regular monitoring
- Prefer to have independent monitoring conducted

Many of the larger orchards employ their own trained agronomists to oversee farm operations. Staff conducting farm management activities such as mowing, pruning, thinning, irrigation, and harvesting should be given basic instruction in identification of symptoms that trees or fruit may be infected. This forms the basis of situational awareness that allows orchard staff to detect unusual pests or damage that can be referred to the agronomist, crop consultant, or government agencies for identification as part of the orchard biosecurity program. The additional observers in the orchard provide a means of passive surveillance that may detect early signs of a problem that can then be addressed before it becomes a hotspot.

Decisions on the need for pest management intervention, and which tools to use, depend on a range of factors:

- The pest, disease or weed being targeted
- The size of the problem, as indicated by results from monitoring
- Presence of biocontrol agents that could manage the problem before a spray is required
- Weather forecasts
- Whether multiple species are being treated at the same time
- The stage of growth of the crop and the pest, disease or weed
- Non-target effects of pesticides, including implications for IPDM
- Presence of resistant pests, diseases or weeds
- Cost of alternative products, including consideration of costs resulting from non-target impacts (such as additional chemical applications to control mite flare, or the cost of purchasing biological control agents to replace those killed by a pesticide application)
- Compatibility with other products that may be proposed in the tank mix, including the need for adjuvants

Spray equipment should be well maintained and calibrated, and all use documented. Spray operators should be appropriately trained and accredited.

Legislation

All orchards must comply with relevant national, state and territory pest and disease control legislation. All pesticides supplied and sold in Australia must be registered by the Australian Pesticides and Veterinary Medicines Authority (APVMA). The control of use of pesticides is governed by State and Territory regulations. Label directions must be followed to ensure that maximum residue limits (MRLs) are not exceeded and that bees, other non-target organisms, the environment, and humans are not adversely affected. It is outside the scope of this manual to provide details of the State and Territory regulations, which may vary regarding definitions of “off-label” uses, and it is the responsibility of individual businesses to ensure they are compliant with current regulations.

Market requirements

Each market has detailed quality assurance requirements to ensure that food safety and other quality standards are met. Export markets, and some interstate markets, have additional phytosanitary (biosecurity) requirements that may stipulate particular monitoring standards and /or post-harvest disinfestation protocols. Export markets also vary in which pesticides can be used to produce the crop and the permitted MRLs. These change frequently and are outside the scope of this manual.

Developing a strategy to transition to IPDM

- Summarise the current situation, providing some historical context and how your current aspirations (long term objectives) will drive adoption of IPDM.
- Identify your key pest and disease risks and the tactics that have worked and those that were not successful.
- Identify one or more strategies to achieve the objective
- Plan for potential changes in pest or disease pressure as you make changes in management or the climatic conditions change.
- Seek knowledge on the positive and negative side-effects of changes that you intend to implement.
- Document the tactics you will use within each strategy
- Develop and implement a monitoring program to track performance of these tactics so that you can intervene with corrective actions (biological or chemical) to keep damage within acceptable levels.
- Evaluate the impact of your tactics and strategies each season then record any subsequent changes and the reasons for those changes.
- This is no different to the process (identifying risks, implementing appropriate risk mitigation strategies, and assessing the results) that you use for your quality assurance program.

The key to IPDM success is to monitor activities, keep good records of what has been done and the results of those actions. Records should be used to analyse current strategies and to honestly evaluate whether the chosen tactics are the best options. This allows constant refinement of the management strategy to cope with new threats.

Some IPDM terms defined

IPDM 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 the relationship between them.

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

- ***Establishing and checking traps*** to capture mobile stages of pests (typically adults) or diseases (typically spores) to assess population levels and/or to generate data used in predictive models that forecast critical times in the pest or disease lifecycle. Keep records for each individual trap.
- ***Checking trees for signs of infestation***. It is preferable to select trees at random each time these checks are undertaken. Record results for each individual tree so that you get a feel for variability between trees rather than just responding to total or average infestation levels. A good practice is encouragement of situational awareness in staff who are regularly mowing, or conducting other activities in the orchard, so that they detect early signs of infestations or other problems. It is often tempting to monitor the same trees (indicator, static or sentinel trees) throughout the season but this is usually counterproductive since they are often in hotspots (particular trees prone to problems) and can lead to over-estimation of severity or lead to you missing development of infestations in other parts of the block.
- ***Carefully checking weather forecasts*** for conditions such as temperatures, rainfall, leaf wetness and wind speed that are likely to favour pests or diseases or affect spray application.
- ***Checking fruit damage at critical stages of pest and disease development and again at harvest*** to measure the success of your management efforts.
- ***Maintaining database records of results*** from trapping, tree inspections, weather stations, data loggers, and fruit inspections.

2. Sample unit 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 tree or soil at the base of the tree
- If black spot is being monitored, the sample units are fruit and leaf.
- An insect trap.

3. **Action threshold (or Economic Threshold)** is the pest or disease level at which you may need to intervene to prevent economic damage from occurring. The economic injury level is reached when the value of damage caused by pest population equals the cost of control. Action thresholds include:

- Pest numbers per sample unit reach a certain level (e.g. 10 mites/leaf, 5 moths/trap)
- The proportion of infested sample units reaches a certain level (e.g. 80% leaves infested with mites)
- An accumulation of either of the above over time (e.g. 5 moths/trap/week, or 500 cumulative leaf infested days for mites)
- The weather is so favourable to a pest that it is almost certain that damage will follow (e.g. a scab warning has been issued and you have a block with history of scab)

Action thresholds are not "magic numbers" that must be reached exactly; they can be varied with experience, value of the crop, and ability to respond in time to avoid adverse outcomes. Because economic injury level varies due to a range of factors such as seasonal conditions, crop susceptibility, weather, rate of pest population increase, side effects of specific treatments, and value of the crop it is almost impossible to determine in advance. The usual practice is to set an economic injury level that the grower is comfortable with, and an action threshold that has enough margin of safety that the economic injury level is not exceeded. As the grower gains more experience and confidence in the approach the action threshold can be increased.

4. **Appropriate action** when the action threshold has been reached must:

- Be effective over a relatively long period
- Not cause secondary problems such as an outbreak of an otherwise minor pest, or, if a disruptive treatment must be applied, supplementary releases of biocontrol agents can be made to counteract the disruption

5. **Cultural control methods** manipulate the crop environment to:

- Reduce susceptibility to pests by improving plant health or using varieties and rootstocks resistant to the pest
- Make the environment unfavourable to pest population build up by opening the tree canopy to improve light penetration and air flow
- Increasing soil health and orchard floor biodiversity

6. Biological control is the suppression of pest damage through the action of natural enemies, which could be pathogens, predators, or parasitoids. Biological control can be achieved by:

- **Importation and establishment** of specialised natural enemies from the region in which a pest originated. An example is Mastrus ridens, the parasitoid wasp natural enemy of codling moth imported into Australia and New Zealand from Kazakhstan via California and Argentina
- **Augmentation by localised releases** of natural enemies purchased from commercial suppliers of biological control agents.
- **Conservation by modifying the crop environment** to increase biodiversity that in turn enhances performance of natural enemies.

7. Behaviour modification is the manipulation of pest communication systems to alter the behaviour of the pest in ways that reduce its population by reducing either its ability to mate or lay eggs on the host. This can be achieved through use of:

- **Pheromones** used to attract insects to traps
- **Pheromone-mediated mating disruption** by reducing the ability to find mates and thereby delay mating and oviposition resulting in lower pest populations
- **Combination of pheromones and host plant volatiles** to improve sensitivity of monitoring traps and mass-trapping of both sexes
- **Herbivore-induced plant volatiles**, released by plants attacked by pests, to attract natural enemies of the pests

Apple and Pear IPDM

Chapter 2: Developing an IPDM Plan

IPDM Quick Facts

IPDM starts well before problems are observed. A well-developed IPDM plan involves 4 major steps:

1. Prevention by strategic planning to avoid problems
    - Identify short, medium and long-term objectives
    - Develop strategies to achieve the objectives
    - Determine resources required to undertake the strategies
    - Identify suitable tactics to employ to allow flexible delivery of the strategies
    - Identify milestones needed to track performance of tactics
    - Identify criteria to confirm achievement of milestones
    - Document a work plan
2. Preparation to counter adverse conditions
    - Identify existing issues
    - Identify and evaluate potential solutions to existing issues
    - Consider possible side effects that could generate new issues
    - Identify and evaluate potential solutions to the possible new issues
    - Include the solutions you have identified into your strategic plan as tactics
3. Planting healthy quality trees into well prepared sites
    - Determine the health and quality parameters you want
    - Specify those parameters in your contract with the nursery
    - Reject trees that do not meet your specifications
    - Planting substandard trees costs you in lost productivity
4. Pest, disease and weed management planning
    - Assess previous season damage

- Develop an Action Plan
- Identify suitable thresholds for interventions
- Identify suitable interventions based on your thresholds
- Plan monitoring program
- Plan damage assessments
- Establish a monitoring database
- Train staff or contract a pest management scout
- Ensure you get a written report after each visit by scout

Step 1: Prevention

Plan strategically

- **Establishing new blocks**
    - **Identify constraints to productivity related to the proposed site.**
    - **Identify proposed tree training method**
    - **Review history of pests, diseases, weeds and climate**
    - **Determine varieties and rootstocks to suit the site, its pest and disease history and your business plan**
    - **Contract a reputable nursery to provide healthy, certified pathogen-tested trees to your specifications.**
- **Site preparation**
    - **Existing blocks**
    - **Assess damage levels from previous season**
    - **Identify pest, disease, and weed hotspots**
    - **Identify corrective measures**
    - **General maintenance**
        - **Pruning and tree training**
        - **Irrigation system**
        - **Machinery service, replacement and calibration**

Planning to set up new blocks on old orchard land or virgin land

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.

Check local advice. All production areas vary in their soil type, micro-climate, soil problems and nutritional status. Obtain advice about any local issues you may need to consider.

Accurately map the old area (or use an aerial photograph). Using a map or photograph allows you to accurately locate problems areas (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 adjust irrigation systems. Accurately mapping the old tree rows allows you to rearrange row positions and minimise the number of trees planted in an old tree row.

Soil test for pH, soil nutrients, salinity, organic matter, and soil biology. These tests identify if 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 specific apple replant syndrome, other soil borne problems and nematodes. Bioassay tests of soils show how much affect 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 e.g. White Root Rot (*Rosellinia necatrix*) in Queensland, Phytophthora and Armillaria.
- 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 lime, gypsum and/or dolomite requirements for the site. It is extremely important that if soil amendments (and phosphorous fertilisers) are required, they 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 have any beneficial effect. Do not use dolomite in soils with high magnesium levels. Use calcium carbonate lime if acidity is an issue. Be aware that phosphorus fertilisers may have negative effects on beneficial fungi in the soil.

Consider site rotation and possible cover crops. Preparatory planning may show that it is inappropriate to replant the orchard. A change of crop or longer-term approach to replanting may be necessary. Orchards are expensive to establish, don't waste money on a problem site by taking shortcuts.

Select and order the varieties and rootstocks. Selecting the right variety determines how much money you can make. Selecting the right rootstock determines how much you minimise production costs, 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 (10-12 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. Small, not big 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.

Planning to prepare established blocks for a new season

Assess damage levels from the previous season

- Review results of pest and disease monitoring and identify hotspots and potential control problems.
- Assess outputs from pest and disease models to identify gaps in management strategies used last season and plan improvements for the coming season.
- Consider the need to purchase biological control agents to re-introduce or top-up populations that were affected by chemicals used last season.
- Develop a strategic plan involving appropriate use of alternative pesticides that will provide a back-up for the biocontrol agents without harmful side-effects.

General maintenance

Pest carry-over in hotspots

Pests and diseases survive through winter in various ways without fruit, leaves or succulent shoots for nutrition. Some migrate, but most pests never leave the orchard or its nearby surrounds. Destroying these overwintering sites will reduce pest and disease problems in the upcoming season.

- Remove and destroy all fallen and hanging fruit.
- 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.
- Know what biocontrol agents (predators, parasitoids and entomopathogens) could be working in your orchard to reduce your pest populations over winter and avoid use of pesticides that may kill or sterilise them.

Training, pruning, thinning and fertilisers.

Training systems that provide open canopies result in greater air flow and shorter drying times. Consequently, incidence of diseases and soft-bodied sap-sucking insects such as aphids and mealybugs tends to be lower.

- Training systems that minimise pruning and, subsequently, pruning cuts (disease entry points) result in fewer problems from diseases such as silver leaf and pests such as woolly apple aphid.
- Although benefits can be gained from opening 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.
- Fertiliser use should meet tree and crop requirements, be based on soil and/or leaf tests, and be applied at appropriate times to maximise crop benefits and minimise excessive growth.

Pruning should:

- remove water shoots
- remove diseased tissue
- open the canopy to allow air movement and better spray penetration.
- Allow for renewal of fruiting wood

Thinning is not just about crop load. It should also help to reduce pest and disease problems. Clusters of fruit are prone to pests and diseases 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.

Irrigation system

- Inspect and repair irrigation lines, sprinklers and emitters to prevent excessive periods of leaf wetness caused by broken or poorly orientated irrigation equipment.
- Emitters and microjets are prone to blockage by insects such as weevils laying eggs in the orifice.

Machinery

- Service all tractors and sprayers well before they're needed.

- Sprayers must be calibrated properly to apply the correct volume of spray onto the right locations on the trees or weeds.
- For diseases such as black spot and powdery mildew you will need sufficient, well-maintained equipment to spray the entire orchard within 3-4 days after rain.

Pest and disease monitoring

- Insect traps require regular maintenance and should be cleaned before each season
- Weather stations and other sensors need regular calibration to ensure they are providing accurate data.

Netting

- Full exclusion netting must be inspected regularly, and damage repaired to prevent pest incursion.

Step 2: Prepare land for planting

- **If you are replanting an existing block survey the trees and mark on a map the location of diseased trees, areas of poor drainage, frost pockets, and soil types. Remove the old trees and their root systems when soil conditions are suitable. If removed trees are to be destroyed by burning on site consider the effects of high temperatures on soil biology, structure and quality, and develop a mitigation plan. Mark burn sites on the block map. Burning may also require a permit from Local Government or appropriate Fire agency or both.**
- **Conduct soil tests and repair drainage, soil structure, salinity, soil biology and soil fertility problems. Destroy weeds and plant suitable cover crops. Plan location of infrastructure (water mains, valves and sub-mains, power, trellis poles and netting supports).**
- **Work in the cover crops, hill up the rows, establish infrastructure, and plant suitable orchard floor species in the inter-rows.**

Remove the old Orchard or virgin bush and tree roots

- **Remove trees when soil conditions enable easy removal of trees and roots.** It is important to remove as many roots as possible, so avoid dry periods or wet soils when removing trees.
- **Timing and removal method** (bulldozing, excavator or stumping) will depend on the soil conditions, slope (safety and erosion) and permanent fixtures in the orchard.
- **Collect and dispose of as many roots as possible.** Old roots harbour pathogens that can reduce new tree performance. Decaying roots can be toxic to young trees.
- Where practical remove all root pieces longer than 30-40 cm and/or larger than 4-5 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 off the planting site. If trees must be burned on site, several small heaps are better than one large one. Burn before spring to avoid emergence of overwintered codling moths from under the bark of removed trees.
- **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, temporary contour grades or roughly plough the block to slow the speed of

any water running down the block. Establish a cover crop if land is to be left bare for any length of time, particularly in winter.

Prepare the site

- **Rip the site to improve soil aeration, drainage, 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 hard pans and compacted areas, to improve aeration and root penetration and to bring old roots to the surface.
- On steep sites minimise the erosion risk by leaving the soil in a rough condition until ready to further prepare the site. Interceptor drains, grade furrows and/or contour banks may also be necessary.
- Erosion can be minimised in some situations by only ripping 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 site and remove any visible roots.** Each preparatory activity unearths old roots. The more roots that are removed (especially large roots), the better.
- **Even-out the site if required (and practical).** Even out any rough or shallow areas (especially along the planting row) to develop a uniform block. This is a high erosion risk activity, therefore 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 rip lines.** Prior to mounding and/or final soil preparation, broadcast any fertilisers and soil amendments (lime, gypsum etc.) and incorporate by cultivation.
- Where 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.
- **Mark out new rows – minimising planting in old tree rows.** The replanted block will usually involve new training systems and different planting densities. Using your orchard plan accurately mark out the new block. Minimise the number of rows in old row positions.
- **Recultivate – preparing for planting or mounding.** Where soil depth or drainage is an issue the site can be mounded by moving topsoils from the centre of the row into raised mounds along the planting row. This increases the depth of topsoil for tree roots and ensures the root crown is above the water table. The inter-row space also acts as a surface drain. Mounding is

particularly valuable in replanted blocks which have previously had problems with root diseases such as Phytophthora, Armillaria or white root rot.

- In 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 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 prior to winter and to provide a firm surface during the winter/spring planting. When choosing a cover crop pay attention to the pests which are likely to occur in the block, the requirements for nectar and shelter of predators and parasitoids that may prey on the pests, trafficability and other inter-row management issues, and plant appropriately. For example, Western flower thrips can build to large numbers in an inter-row which contains white clover before moving in to – and damaging – the crop.

Step 3: Planting and establishment

- **Assess quality of trees delivered by the nursery and reject any that do not meet the contracted specifications. Sort trees so that you can plant similar sized and shaped trees within a row.**
- **If you cannot plant when the trees arrive do not let them dry out in storage.**
- **Inoculate the roots against crown gall before planting. Plant at the correct depth and do not stress the young trees**

Store nursery trees correctly before planting. Nursery trees (especially their root systems) should never be allowed to dry out. Trees should be planted on arrival from the nursery or 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 only suitable for short-term storage.
- Putting them in cool storage – place trees upright in a bin, 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 (Sept/Oct) affects first year performance due to stress on young trees because after mid-August they need to produce roots and shoots at the same time. Shoot growth is retarded, desiccation maybe a problem and tree losses can increase.

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.

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 nurseryman and consider regrading. Orchard uniformity is improved if similar sized and shaped trees are planted in the same row.

- 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 put fertiliser in the planting hole. Mono-ammonium phosphate (MAP) is often used as a planting hole amendment in replant orchards. If placed incorrectly, young root systems can be burnt and tree performance affected – trees can even die.

- If fertiliser requirements are correctly determined and 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.

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. A consistent height influences the uniformity of tree growth in the orchard. Hand planting provides more consistency in planting depth than machine planting.
- Up to two weeks after planting, trees planted too low should be carefully raised.

Ensure trees are adequately watered-in at planting (hand, rain or irrigated). 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 improves the chance 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 to prevent the rapidly growing new trees experiencing any moisture stress.

- Dwarfing apple rootstocks especially M9, Ottawa 3 and M26 have smaller, finer root systems and are susceptible to moisture stress during establishment.
- It is therefore critical to have an irrigation system installed and operational as soon as possible after planting.

Install support systems, especially for dwarfing rootstocks. Wind plays havoc with newly planted trees.

- Movement of treetops will rock and break new roots.
- Provide support for trees soon after planting to minimise root damage.

Use tender loving care for your trees. 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.
- Nitrogen 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 over emphasised.

- Small trees have small root systems so light frequent irrigations are required to avoid excessive soil wetting and drying.

Keep young trees healthy rather than "weed and vermin free". The concept of a "weed"-free treeline creates several problems because bare earth is not healthy soil and fruit trees perform better in healthy soils. Conventional wisdom suggests weeds compete with the trees for moisture and nutrients and must be removed. However, most herbaceous weeds are colonisers of disturbed or impoverished soil that is dominated by bacteria instead of beneficial mycorrhizal fungi. These colonisers stimulate nitrogen fixing soil biota that assist recovery of the fungal biomass. Mycorrhizal fungi and the tree roots form symbiotic relationships that enhance uptake of nutrients and water by the tree. The 'weeds" that encourage mycorrhizal fungi improve the overall soil biodiversity and provide nectar that enhances performance of parasitoid wasps preying on pests, should therefore be considered as beneficial species rather than weeds.

- Be careful with herbicide applications, they can kill young trees and some have unintended side-effects on beneficial insects and fungi.
- Tree guards reduce damage caused by rabbits, hares and wallabies, and they protect young green stems from herbicide but should be inspected for sheltering slugs, snails, and harlequin bugs.
- Don't bury tree guards as moisture trapped around the tree stem induces problems with Phytophthora.
- Pay careful attention to the type of tree guard used with M26 rootstock to avoid burr knotting.
- Prevent establishment of aqricultural and environmental weeds such as mallows, fat hen, dock, thistles, bridal creeper, ivy, wireweed, and morning glory that provide "ladders" used by weevils and harlequin bugs to bypass the tree trunk to access the canopy and therefore avoid butt treatments designed to trap, deter, or kill the pests,
- Lower-growing herbaceous plants with nectar producing flowers encourage predators and parasitoids that prey on pest species. Consider local native plants adapted to woodlands as candidates.

Mulches may be used for moisture regulation and weed control.

- Avoid disease, don't place mulch too close to tree trunks.
- Mulch can provide shelter to generalist predatory insects.
- Mulch may attract hares, rabbits, rats and mice depending on the type of mulch.

Grow the tree then crop it – avoid the temptation to overcrop early.

- The quickest way to slow 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 two or three years.
- M26 apple stock will stop growth if cropped too heavily too early.

Hand remove flowers and fruit 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 chemical thinners 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.

Pros and cons of netting

- Netting an orchard block is an expensive venture.
- Netting can improve returns by reducing or preventing crop damage from birds, fruit bats, hail, wind and sunburn.
- Costs of establishing netting depend on the type of netting system (mesh size, colour, strength, support infrastructure, full exclusion vs open sided, etc.)
- Full exclusion netting may reduce activity of beneficial species such as insectivorous birds, microbats, and larger predatory insects such as hoverflies and wasps.
- Netting may reduce fruit colour development.
- Netting reduces transpiration and can lower irrigation requirements
- Netting affects bee survival and may interfere with bee orientation during flowering, resulting in lower pollination. Roof-only netting is better for bees than full netting. The impact of full netting can be reduced if the sides can be rolled up during flowering. This also allows access by other pollinators and biocontrol agents. Reducing the number of days hives are under netting will improve bee activity and survival. Practices that contract the flowering period are important
- Care must be taken when spraying pesticides under nets prior to flowering. Dormant sprays of copper sometimes drift onto 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 flowers. Close to harvest sprays can dry on overhead netting, fall later and cause residue problems.

Step 4: Pest and disease management plan

- **Develop a pest and disease Action Plan, activity chart, and conduct appropriate monitoring activities.**
- **Purchase and install appropriate traps, sensors and weather stations.**
- **Identify pest and disease threshold levels (based on your experience, competence and confidence) that are appropriate for the crop and that account for your ability to respond with suitable interventions if necessary.**
- **Record all monitoring results, your decisions and actions.**
- **Assess damage levels regularly throughout season and at harvest.**
- **Reassess plan for next season.**

A Pest Management Plan

- A pest management plan should be developed at the beginning of each season.
- The plan should allow for contingencies and incorporate appropriate responses to all possible scenarios so that you are not caught unprepared.
- If you plan for the worst-case scenario you can develop a monitoring program that provides early warning of trouble brewing and take appropriate action to reduce the risk of losses.
- "Unexpected" problems are the result of poor planning.
- Taking the "easy way out" by calendar spraying or targeting pests and diseases at inappropriate times "just in case" will often generate "unexpected" problems that would have been anticipated if allowance for side effects had been factored into the planning phase.
- Good planning means that you do not have to modify your plan because you have already identified alternative tactics to employ.
- A good plan is underpinned by a comprehensive and well-kept set of records from the current and previous seasons.

Which blocks?

The first stage of adopting IPDM usually involves changing the type of pesticide sprays applied, so if you are risk-averse start small!

A well-run IPDM system, like any pest management system, does not eliminate risk but because IPDM uses many complementary tactics in a systems approach rather than relying on a single tactic of spraying pesticides the overall risk of failure is reduced. Implementing IPDM is like growing a new variety or using a new tree-training system or planting a new block with a new variety on a new training system. Rarely would an orchardist plant an entire orchard to a new variety on a new training system without having had some prior experience with the variety or training system, in which case they are not entirely new. They would normally start with a relatively small block in which they could develop their knowledge, skill base, and expertise. Once they had gained confidence in the growing system and the potential of the variety they would then decide if further investment is warranted. The same holds true for IPDM. There will be a transition phase during which you develop new knowledge, skills, competencies, and confidence in the system. You may reduce the number of spray applications for some pesticides but initially increase others, such as specific biological products like codling moth granulosis virus, while the biodiversity in your orchard increases and the pest populations stabilise below economic threshold levels. It makes sense to compare results from your IPDM "experiment" and other similar blocks in which you are using your "traditional" approach. However, to do a valid comparison you at least need to monitor and record the pest and disease incidence in your comparison block (you will already be monitoring and recording what is happening in the IPDM block).

Most IPDM 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 IPDM but it gives you a chance to expand your comfort zone without the risk and associated stress of doing the whole orchard at once. As you gain confidence and start to implement IPDM across the whole orchard, pest and disease control becomes easier.

Which pests are likely to cause problems?

The most effective way to manage pests and diseases is to anticipate which ones are likely to cause a problem and develop a range of tactics to deal with them. Make a list of the pests and diseases that have been in your orchard over the last four seasons. Pests and diseases that have caused financial losses should be given priority, ranked according to the degree of loss, and considered as key pests to be targeted. Investigate options for managing these key pests and prioritise tactics that are the least disruptive to biological control agents that may be present in your orchard or surrounding areas. If pests have been present but haven't caused losses, then include them on the list, but consider if they are secondary pests that are being controlled either by your current spray program or by biological control agents that have adapted to your spray program. Again, investigate options for managing these pests, if their pest status increases, and prioritise those options that are less disruptive to biological control agents.

Pest lists and status will vary from block to block, orchard to orchard, and different regions. Block differences are probably due to variety and microclimate differences. Orchard differences may be due to historic pest management and climatic differences. Regional differences are often due to climatic differences and isolation.

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 Australian apple and pear orchards, and information on biological and cultural control options.

Format of the plan.

The plan should be in writing, otherwise it is a dream that could turn into a nightmare. The written plan should also be simple. The more sophisticated the plan becomes, the less flexibility you have to adapt to changed circumstances and meet the objectives of the plan. The first stage of planning is to understand the current situation and determine where you want to be and why. It is important to clearly define the problem before you seek the solution. It is also critical at this stage to not limit your thoughts to what can be achieved with your current resources. Once you clearly define the problem focus on defining the solution. This becomes your objective and your mission is to achieve that objective. To perform your mission you need strategies and the tactics to be deployed for those strategies to work. You are correct if this sounds to you like a battle plan. A simple format for your plan is a variation on the SMEACS briefing format used by emergency management agencies.

- ***Situation:*** identification of past, present and predicted situation
- ***Mission:*** statement of the mission as specific, measurable, achievable, relevant, time framed objectives
- ***Execution:*** the strategies or means of achieving the objectives
- ***Administration & Logistics:*** identification of administrative and logistical support arrangements
- ***Command & Communications;*** Who is responsible for what, and the communication channels.
- ***Safety:*** identification of potential risks and hazards

An example is given on the next page.

Example Action Plan in SMEACS format

Situation:

Codling moth, black spot and lightbrown apple moth (LBAM) are under control. Mating disruption is used for codling moth control but no trapping is used to monitor codling moth populations. Carbaryl used as a thinner has apparently controlled LBAM, looper, and Heliothis (Helicoverpa). Trials on predators for two-spotted mite are underway. Aim is to try to minimise use of pesticides. The case study block is fully netted using 16mm mesh. Transform has been used against apple dimpling bug (ADB) and wooly apple aphid (WAA). Transform may be causing mite issues and may also have impacted on *Aphelinus mali* populations.

Mission:

To capitalise on the low pest and disease populations and attempt to further reduce pesticide use while maintaining effective control and confidence in the approach being taken.

Execution:

- Establish codling moth and LBAM traps to determine population levels and monitor trends
- Monitor weather trends, especially movement of fronts from the channel country in Qld, as indicators of potential ADB incursions during pink bud to full bloom
- Develop some plots, within the orchard, in which Transform is not used. Compare populations of pest and beneficial species, and damage levels, in these plots against what is experienced in the treated plots.
- Monitor budworm and looper activity from pink bud through to 2 weeks after petal fall. Initially look for budworm adults around lights as an indicator, and check flowers for presence of eggs.
- Install a weather station in the block so that temperature and leaf wetness data and trapping results can be used in a predictive model to guide the need for sprays

Administration:

- Fred and agronomist to organise experimental plots, traps, record sheets
- Agriculture Victoria to supply pest prediction program
- Ask an expert facility in IPDM website for additional support and expertise

Communications:

Fred	mobile	Overall supervision
John	mobile	Spraying operations
Agronomist	mobile	Trial design, monitoring, chemical advice
IPDM Website		www.extensionaus.com.au/australianappleandpearIPDM

Safety:

- Experiments can be stressful but no useful results will occur unless the participants maintain their nerve. Stress can be reduced by setting realistic targets that stretch comfort zones without creating major financial risks
- Use of prediction models based on local data will provide early indications of potential danger periods

Apple and Pear IPDM

Chapter 3: Key pests and diseases, their activity periods, and monitoring methods

IPDM Quick Facts

The key pests and diseases in the eastern states and South Australia are:

- Codling moth *Cydia pomonella*,
- Queensland fruit fly *Bactrocera tryoni*,
- Lightbrown apple moth *Epiphyas postvittana*,
- Apple dimpling bug (*Campylomma liebknechti* on the mainland, *Niastama punctaticollis* in Tasmania),
- Apple scab *Venturia inequalis* on apples,
- Pear scab *Venturia pirina* and blossom blast *Pseudomonas syringae* pv. *syringae* on pears.

In Western Australia the key pests and diseases are:

- Mediterranean fruit fly *Ceratitis capitata*,
- Western fruit moth *Epiphyas pulla*,
- Lightbrown apple moth,
- Pear scab,
- Powdery mildew *Podosphaera leucotricha.*

Emerging problems are:

- Apple scab in Western Australia
- Alternaria (several species) in Queensland, New South Wales, and Western Australia.

Key pests that evolved with their host plant have activity periods closely aligned to susceptible life stages of the host plant.

Some native insects that did not evolve with apples or pears have become key pests by broadening their host range.

Secondary pest outbreaks arise as non-target impacts from treating key pests with pesticides that also kill predators and parasitoids that were keeping the secondary pests under control.

Fungicides are generally not directly toxic to invertebrate biocontrol agents but may have sublethal fecundity effects and may also impact on beneficial fungi in the soil beneath the trees.

Some minor problems may increase temporarily in importance while populations of biocontrol agents recover and “ecological balance” is restored.

There are many non-pesticidal options to manage these minor problems.

Monitoring the populations of pests, diseases, weeds, and beneficial organisms such as predators and parasitoid wasps is an important component of implementing integrated pest, disease and weed management in orchards. It does not need to be onerous or time consuming.

Standardised monitoring and record keeping allows advisors to more easily interpret and compare what is happening in your orchard

Key pests

Key pests and diseases are those that are the primary targets of management programs. They are usually pests and diseases that directly attack the crop (fruit) and require management each season. Their economic importance may relate to their potential to cause damage if not appropriately managed, and/ or their status as quarantine pests for interstate or export markets. The control measures applied against these pests and diseases drive choices for management of most other pests and diseases due to non-target impacts of the treatments applied against the key pests and diseases. Non-target impacts, such as killing biological agents that otherwise are controlling other pests, commonly cause secondary pest outbreaks that then require pesticide applications to prevent damage to the trees and the quality of the crop.

The key pests and diseases in the eastern states are codling moth *Cydia pomonella*, Queensland fruit fly *Bactrocera tryoni*, lightbrown apple moth *Epiphyas postvittana*, apple dimpling bug (*Campylomma liebknechti* on the mainland, *Niastama punctaticollis* in Tasmania), apple scab *Venturia inequalis* on apples, pear scab *Venturia pirina* and blossom blast *Pseudomonas syringae* pv. *syringae* on pears. In Western Australia the key pests and diseases are Mediterranean fruit fly *Ceratitis capitata*, Western fruit moth *Epiphyas pulla*, lightbrown apple moth, pear scab, and powdery mildew *Podosphaera leucotricha.* Apple scab is an emerging problem in Western Australia and Alternaria (several species) is an emerging problem in Queensland, New South Wales, and Western Australia.

Pesticides currently used against the fruit flies and moth species listed above are more specific in their action than the organophosphates and carbamates used in the past but most still have either direct toxicity or sublethal effects, such as causing reduced fecundity, to a range of biological control agents that would otherwise be active in the orchards. Fungicides are generally not directly toxic to invertebrate biocontrol agents but may have sublethal fecundity effects and may also impact on beneficial fungi in the soil beneath the trees. See Chapter 6 for further details.

As options for managing key pests and diseases evolve and IPDM is adopted some currently minor problems may increase temporarily in importance while populations of biocontrol agents recover and “ecological balance” is restored. There are many non-pesticidal options to manage these minor problems.

Activity periods for key pests

Key pests that evolved with their host plant have activity periods closely aligned to susceptible life stages of the host plant. For example, codling moth overwinters as diapausing (hibernating) larvae in cocoons under the bark on the lower trunk of the tree. In spring when the host tree starts to flower the diapausing codling moth larvae start to form pupae and then emerge as adult moths ready to mate and lay eggs on the newly developing fruit. European Red Mites that feed on the tree leaves overwinter as eggs around the buds. When the tree starts to break dormancy and the leaf buds start to open the mite eggs respond to the changed weather conditions and start to hatch and the nymphs move to the newly unfolding leaves where they feed. In both examples the pest responds to climatic cues in similar ways to the host tree. The timing of those cues varies between fruit growing regions, so the following activity charts only show the host tree growth stage rather than the dates or months at which they occur. Different apple varieties have their own climatic triggers governing their growth stages and some flower later than others and the fruit on some mature earlier than others. The same holds for pears. Key pests that evolved with the hosts have in-built safety measures that ensure that their populations emerge over a broad time period to ensure that at least some will always find the host in a suitable stage for the pest to complete its life cycle. Some key pests such as lightbrown apple moth (LBAM) and western fruit moth (WFM) are native insects that did not evolve with apples or pears but took advantage of the new plants as hosts. LBAM/WFM utilise alternative hosts when the apple and pear trees are dormant, so LBAM/WFM activity periods are not so well tuned to the apple and pear trees.

Activity periods for key apple pests and diseases:

Key Pest/ Disease	**Dormant**	**Green tip**	**Pink bud**	**Blossom**	**Fruiting**	**After Harvest**
Apple dimpling bug						
Apple scab						
Codling moth						
LBAM/WFM						
Budworm						
QFly						
Medfly						
Alternaria						
P.mildew						
Colour code						
Monitor alternative hosts			Active		Hibernating	
Often symptomless			Orchard hygiene to reduce inoculum			

Activity periods for key pear pests and diseases:

Key Pest/ Disease	Dormant	Green tip	White bud	Blossom	Fruiting	After Harvest
Pear scab						
Codling moth						
LBAM/WFM						
Budworm						
QFly						
Medfly						
Blossom blast						
Colour code						
Monitor alternative hosts			Active		Hibernating	
Often symptomless			Orchard hygiene to reduce inoculum			

More detail is provided in the sections for each pest or disease.

Pest and Disease Monitoring methods for apple and pear orchards

Monitoring the populations of pests, diseases, weeds, and beneficial organisms such as predators and parasitoid wasps is an important component of implementing integrated pest, disease and weed management in orchards. It does not need to be onerous or time consuming.

The methods outlined below provide guidelines (other than trapping) that should be read in conjunction with the monitoring calendar and the monitoring record sheet. Use of these guidelines will help to standardise record keeping and allow advisors to more easily interpret and compare what is happening in your orchard. Not all the listed pests or diseases will be present in your orchard, region, or state. They have been included to allow national applicability of the information.

Deciding on where to sample in your orchard.

Modern plantings commonly use trellised trees that are closely planted within the rows. However, there are many productive orchards that were established with free-standing trees at wider spacings. In the following text the term "tree" is interchangeable with "panel of trellis trees" because in trellised blocks it is not easy to move around each individual tree and a single side of a typical 10m panel of trellis is roughly equivalent to the circumference of a free-standing tree planted at 5.4-6m spacing within the row.

Most orchards have discrete blocks that are capable of being treated as management units. It is recommended that each block is sampled independently to allow for differences in micro-climate, varieties, age, and history from previous seasons. How many blocks you sample is up to you but the results from each block should be recorded on separate worksheets.

Within a block it is preferable to select trees at random each time you conduct monitoring, except for trees in which you place an insect trap. The trees holding your traps should be considered as separate to your monitoring trees. Random sampling gives each tree an equal chance of being selected and ensures that over time a representative sample of the entire block is taken. **Five sample trees selected randomly each time is sufficient if you monitor each week**. It is important to remember that these trees are samples and that, as you walk from one sample tree to another, you should develop situational awareness to notice if your sampling results reflect your overall impression of the tree health in the block.

Suggested monitoring methods

There are 4 general categories of sampling based on the use of 5 trees selected at random each date that you conduct monitoring. These have been designed to allow monitoring of multiple pests or diseases with the one sample and are:

- 20 flower clusters (4 clusters x 5 locations on the tree) per tree.

- 1-minute inspections per tree.
- 10 randomly selected leaves per tree
- 100 randomly inspected fruit per tree.

You do not need to use all 4 categories each time you monitor. For example, flower clusters are only inspected from pink bud to petal fall and the 100-fruit inspections are only conducted mid-January, late February or early March, and in the week before harvest.

20 Flower clusters/ tree to monitor Apple Dimpling Bug (ADB) and Thrips

- Place a white 1-4 litre plastic container, similar to an ice-cream container, underneath a shoot with at least 4 flower clusters immediately above the container.
- Tap the clusters from above with your hand 3-4 times in quick succession.
- Count and record the number of bugs caught in the container.
- Do this in five different locations on each of the sample trees.
- The bugs will be more active in warmer weather and could fly out of the container, so it is preferable to do this sampling in the morning.
- Thrips will also be dislodged into the container using this technique, so also look for and count thrips. If thrips are present and Western Flower Thrips (WFT) are known to be present in your district you can collect some of the thrips into a specimen jar so that you can have them identified later.
- Flower tapping is only conducted between pink in apples, or finger bud in pears, and petal fall. However, if Western Flower Thrips are identified in your samples you should continue to monitor throughout the growing season by using blue sticky traps to indicate if the thrips build up as the fruit matures. Feeding and egg-laying by WFT at this stage will cause russet on pears and pansy spot on apples.
- The same technique can be used to assess the resident population of ADB in surrounding areas prior to flowering of your fruit trees. Wattles on headlands and roadsides, and flowering ornamentals in gardens can be checked but you need to be able to distinguish ADB from psyllids on wattles.

- 

1-minute inspection/tree

As you spend one-minute walking around a tree, or along a panel of trellised trees, count and record the number of Budworm (Heliothis), Looper, Pear Slug, Lightbrown Apple Moth (LBAM) larvae, weevils, and mealybugs you see. During the same inspection look for:

- presence of diseases such as Scab, Powdery Mildew, and Alternaria on leaves and Fruit and Bitter Rot on fruit.
- Presence of Lacewings, Hoverflies, and Ladybirds

You can use the same sample to score the severity of Woolly Apple Aphid (WAA) infestations using the following scoring system:

0= nil WAA colonies observed

1= trace infestation (<5 small colonies)

2= light infestation (>5<10% of tree)

3= moderate infestation (>10<25% of tree with large colonies)

The same scoring system can be used to indicate the level of parasitised Woolly Apple Aphid colonies.

10 leaves/tree

This technique is used to determine the % leaves infested by mites and their predators, as well as Leafhoppers/ Canary Fly and Mealybug crawlers.

- If Two-Spotted Mites (TSM) are the main pest mite in the orchard 10 leaves can be randomly selected from about 1.5-1.8m above ground from the inner canopy.

- If European Red Mite (ERM) or Bryobia mite are the dominant species then sampling should start at first bloom on pears or pink on apples, and leaves should initially be sampled from the outer parts of the canopy.
- If TSM and ERM/Bryobia are present the 10-leaf sample should include leaves from both the inner and outer canopy.
- There is no need to count the number of mites or eggs per leaf. A simple presence/absence for each leaf is sufficient.
- The number of leaves with mites present can be converted to % leaves infested which in turn can be used to calculate the cumulative leaf-infested days throughout the season.
- The most important consideration is not the number of mites per leaf, because the level of damage depends more on the % of infested leaves and how long they have been infested.
- Presence/absence of predators can be scored using the same system and the same leaves used to score mites.

100 randomly inspected fruit/tree

- Randomly select 100 fruit, starting near the top of the canopy and working downwards.
- For free-standing trees inspect 25 fruit from each of 4 sides of the tree.
- For trellised trees inspect 25 fruit from each of 4 trees within a panel.
- The fruit do not need to be picked but should be carefully inspected without excessive lifting or twisting that would dislodge the fruit.
- Simply record presence or absence of the target damage for each fruit and then calculate the % damage attributed to each pest or disease.
- Fruit damage assessments should be conducted in mid-January (after natural fruit drop), one week before harvest of early varieties harvested in February or in late February-Early March for later varieties, and for late varieties again about a week before harvest.
- Codling moth damaged fruit detected in these samples can be removed from the tree and carefully cut open to collect the larvae if they are still present.
- The age of the larva can be determined by measuring the width, and noting the colour (black or brown), of the head capsule to identify the larval instar.
- Once the instar is determined, reference to a development chart (see table below) will indicate how many degree-days ago the larva hatched from the egg.

- Degree-days (DD) are insect growth units which can be approximated by subtracting the lower developmental threshold (the temperature below which the insect stops growing = 10^{o}C for codling moth) from the average temperature (maximum + minimum temperature divided by 2) for the day and adding the results for each day.

Codling moth larval Instar	Approx. head width (mm)	Head capsule colour	DD from egg hatch
I	0.3	Black	0-88
II	0.5	Brown	84-151
III	0.8	Brown	125-216
IV	1.25	Black	205-363
V	1.6	Brown	248-452

- Knowing the approximate age of the caterpillar allows you to identify when the egg hatched, which in turn allows you to check trapping results and spray dates for discrepancies that suggest either the traps are not working or there was a failure in the spray program (e.g. missed spray, poor choice of chemical, or possible resistance).

Trapping

Inspection of leaves and fruit detects presence of the damaging stages of pests and diseases. Traps can be used to detect and attempt to quantify adult insect populations. A wide variety of traps, lures and deployment protocols exist.

- Pheromone traps use a synthetic version of the scent (pheromone) that insects use to attract mates. Moth sex pheromones are produced by female moths and attract males.
- Many beetles produce aggregation pheromones that attract both sexes.
- Sometimes the capture of insects in pheromone traps is enhanced by using a combination of pheromone and host plant volatile chemicals.
- It is important to know what lure or combination of lures is being used because some only attract males, others attract only females and some combinations attract both sexes.
- Comparison of results from different traps is very difficult if the type of lure is not taken into consideration.

There are several designs for traps.

- Pheromone traps for codling moth, oriental fruit moth, and lightbrown apple moth are usually either delta traps or wing traps, whereas traps for mass-trapping of Carpophilus beetles are funnel traps and there are several trap designs for fruit flies.
- The design of the traps influences the shape of the pheromone plume emanating from the trap, affects the behaviour of the insect approaching the trap and its ability to enter and be retained by the trap.
- The number of insects captured per trap per week is often used as an action threshold.to initiate spraying. An alternative may be the cumulative number of insects trapped.
- Care must be taken when using thresholds developed from one trap-lure combination as a threshold for a different combination or even the same lure in a different trap design.
- Trap placement within the canopy, trapping density (number of traps per hectare), and layout of trapping grids also affect the number of insects captured in individual traps, so thresholds developed for traps at different heights or densities or grid layouts should be avoided unless some form of calibration is provided, or you have undertaken your own calibration studies.

Trap results can also be used as inputs to prediction programs (phenology models) that forecast when to expect critical life stages will begin. Moth capture in traps can be used to set biofix dates that initiate calculation of degree days. These are explained in chapters related to individual insects for which phenology models are available. Take care when selecting models developed in other countries because the outputs from some are based on Fahrenheit temperatures and need to be converted to degree days calculated from Celsius temperatures for use in Australia.

Chapter 4: Biosecurity and potential incursions of new pests

IPDM quick facts

- Apple and pear growers benefit from the biological web working behind the scenes to manage their existing pests and diseases as part of the IPM program.
- This biological web can be disrupted by incursions of new pests and diseases and poor choice of pesticides in response to the incursions.
- Attempts to eradicate or contain an incursion often involve use of pesticides that may be new to the orchard, or even Australia, and could have long term detrimental effects on biological control agents.
- The risks to IPM programs can be addressed by implementing biosecurity measures that reduce the risk of incursions occurring and improving the chances of detecting an incursion in its early stages.
- The “Look. Be Alert. Call an Expert” program conducted by Plant Health Australia provides simple biosecurity measures for adoption by growers.
- Unusual observations should be reported to the Plant Pest Hotline 1800 084 881.
- Orchard pest monitoring scouts should be made aware of the priority pests and diseases listed in this chapter and the Apple and Pear industry Biosecurity Plan, and strongly encouraged to collect and report any suspect new pests or diseases to experts for prompt identification. See www.planthealthaustralia.com.au/biosecurity/incursion-management/plantplan/ for further information.

Background

The sustained program of pest and disease management research and development supported by the Australian apple and pear industry generated a better understanding of the interactions occurring in the orchard and how they impact on crop quality and productivity. This is integral to better adoption of IPDM because past research often focussed on integrating biological control of an individual pest species into the pesticide-dominated program for controlling the broader pest and disease complexes attacking crops. There is now a suite of biological, agronomic, and decision-support tools available to help growers deal with the interactive biological web of pests, diseases, weeds, and biological control agents existing in their orchards. This biological web could be damaged by responses required to deal with an incursion of a new pest or disease. The most likely responses involve efforts to contain and eliminate the new pest, disease or weed. These initial efforts often include quarantining infested properties, destruction of host trees, and spraying pesticides to kill the invader. If the invader is new to Australia there will be no chemicals registered to control it, but some of the registered products used against other pests may be known to kill it in other countries and could be used under emergency off-label permits in Australia. The change in pesticide usage pattern or choice of pesticide may cause major disruption to current IPDM programs. The same may happen if the invader comes from another region of Australia. Either way, the introduction of new pests, diseases, or weeds has potential to affect fruit production, domestic and export market access, and impact on orchard finances and the environment.

The ability to detect new pests, weeds and diseases in Australia is important for early response to incursions that threaten food security, economic viability, and trade. Some important exotic pests, such as brown marmorated stink bug *Halyomorpha halys*, do not rely on transport of host material but instead may be transported in shipping containers full of machinery parts. Active surveillance programs are conducted using protocols agreed between governments and usually with industry support.

Apple and Pear Australia Ltd (APAL) represents the apple and pear industry as a member of Plant Health Australia (PHA), an organisation established to work with industry and government in coordination, development and implementation of plant health policies and management programs that improve Australia's response to outbreaks of new plant pests and diseases. Biosecurity planning through PHA helps industry and government identify potential pest and disease threats to the fruit industry, develop risk assessments to prioritise action, and protocols to reduce the probability of the pests and diseases reaching and establishing in Australia.

Increased volumes of imported goods, traveller numbers, and climate change are putting pressure on traditional surveillance programs for detecting incursions. Advances in technology, and constraints on government spending, have generated opportunities to expand the range of sources accessible in a more flexible approach to collection of surveillance data. This general surveillance activity is attractive to governments but also has pitfalls that need to be managed. The quality of collected data is important and the use, or misuse, of social media in distributing false information either deliberately or innocently through misidentification must be addressed in any citizen science approach to ensure quality of data. PHA runs a biosecurity awareness program 'Look. Be Alert. Call an Expert' that aims to increase awareness of simple biosecurity measures and the importance of early notification of unusual observations to the Plant Pest Hotline (1800 084 881) so that incursions can be identified and quickly addressed.

The Emergency Plant Pest Response Deed (EPPRD) is a legal document binding PHA, the Australian Government, all state and territory governments and national plant industry bodies with respect to management of responses to emergency plant pest incidents. PLANTPLAN is the technical response plan that supports EPPRD and is regularly updated to ensure best practice in emergency plant pest responses. Individual industry biosecurity planning covers industry and pest specific information, risk mitigation activities and contingency plans. See www.planthealthaustralia.com.au/biosecurity/incursion-management/plantplan/ for further information.

On-farm monitoring of existing pests, diseases and weeds can be used for general biosecurity surveillance data purposes if the people doing the monitoring are curious enough to seek identification of organisms outside the list required for normal monitoring duties. This chapter provides information on exotic pests and diseases listed as priorities in industry biosecurity plans. Orchard pest monitoring scouts should be made aware of these priority pests and diseases and strongly encouraged to collect any unusual specimens for identification by experts.

The current Apple and Pear priority pests and diseases are:

Apple brown rot	Brown headed leaf roller	Green headed leaf roller	Pear fruit moth
Apple maggot	Brown marmorated stink bug	Oblique banded leaf roller	Pear psyllid
Apple proliferation	Cedar apple rust	Omnivorous leaf roller	Plum curculio
Asian gypsy moth	European canker	Orange tortrix	Rosy apple aphid
Black stem blight	Fire blight	Oriental fruit fly	Spotted wing drosophila

Apple brown rot *Monilinia fructigena*

Apple brown rot is related to the brown rot fungus *Monilinia fructicola* that attacks stone fruit in Australia. In Europe it causes losses up to 35% in apples during warm humid periods. It is found in Europe, Asia, North Africa and parts of South America.

Appearance

- Infected fruit (apples and pears) develop spreading firm brown spots that create rotting areas that are normally surrounded by small, raised white-cream spots (conidial pustules) often in concentric circles.
- Entire fruit can be rotten and covered in pustules and then becomes mummified.
- The mummies tend to stay on the tree but sometimes rotten fruit falls to the ground before it has mummified.
- The infection can spread to stems and cause twigs to blight and develop cankers. Leaves on the twig may go dark brown and stay attached instead of dropping.
- Healthy fruit can be infected with spores near harvest and decay during storage and marketing.

Spread

The pathogen can be spread with infected plant material, fruit to fruit contact within the tree, and spores can be spread by wind and rain.

Could be confused with:

- Other brown rots present in Australia
- Blighted twigs look superficially like those caused by *Pseudomonas syringae* on pears

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

Apple maggot *Rhagolletis pomonella*

One of North America's most serious fruit flies the apple maggot attacks apples, hawthorn, and a range of stone fruits. It is native to north-eastern USA and southern Canada but has spread throughout the eastern, central, southern and western United States and has a restricted distribution in Mexico.

Appearance

- Adult flies have distinctive zig zag black bands on clear wings, a black abdomen with light crossbands (3 for males and 4 for females), a pronounced white spot on the back of the thorax, a wingspan about 10mm, and are similar in size to Qfly and Medfly.
- Apple maggot in northern parts of its range normally has only one generation a year, emerging as sexually immature adult flies in summer. These sexually immature flies feed on honeydew produced by aphids, psyllids and scale insects for about a week before becoming ready to mate.
- Larvae are typical fruit fly larvae, cream coloured with a blunt posterior and tapered front end containing two black mouth hooks.
- Larvae infesting fruit grow up to 10mm long before the fruit drops to the ground where the larvae leave the fruit and burrow 25-150mm into the ground, moult and then quickly moult again to form a pupa that usually enters diapause that allows it to overwinter.
- In warmer parts of its range there may be a partial second generation.

The apple maggot can be distinguished by the zigzag pattern on the wings and the pronounced white spot on its back

Joseph Berger, Bugwood.org

Spread

- Newly emerged sexually immature flies disperse throughout the orchard and surrounding vegetation seeking the honeydew they need to become mature enough to mate.
- Like other fruit flies it is spread long distances by transport of infested fruit containing eggs and larvae.
- Pupae can be transferred in contaminated soil.

Could be confused with

- Damage to fruit looks like that caused by Qfly and Medfly.
- Larvae are look like other fruit fly maggots and require specialist examination to confirm their identity or have to be reared out to adults (which is difficult because they may enter diapause as pupae and then require prolonged chilling followed by warmth before they emerge as adults).
- Adult flies can be distinguished from other small flies by the combination of zig zag bands on the wings and the pronounced white spot on their back. If wing pattern alone is used for diagnosis care needs to be exercised so that apple maggot is not confused with Medfly and signal flies (Platystomatidae) existing in Australia.

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

Apple proliferation

This disease caused by a phytoplasma is a serious disease of apples, with Golden Delicious and Starking being amongst the most susceptible cultivars.

Appearance

- Early emergence of leaves that are small, chlorotic, and have irregular serrations.
- Infected leaves produce large stipules at their bases.
- Delayed flowering with deformed flower parts that may resemble leaves.
- Premature development of axillary buds produces the appearance of 'witches' brooms' caused by proliferation of secondary shoots on top of main shoots in summer.
- Poor fruit set and small, incompletely coloured, poorly flavoured fruit.
- Trees lack vigour, have thin shoots and reddish-brown bark, and leaves are more susceptible to powdery mildew.
- Root systems compact.
- Autumn leaves develop early and may have lilac or purplish red colour.
- Severe infections kill trees.

Spread

- Leafhoppers are suspected as vectors
- Phytoplasma can be spread between trees by grafting
- Control
- Use resistant rootstocks.
- Use clean plant material for grafting.
- Check trees regularly and report unusual symptoms.
- Early detection improves probability of eradication.

Could be confused with

Witches' brooms occur in other plant species and are symptoms of stress, mutation, eriophyid mite attack, and infection by viruses or phytoplasmas. It is therefore important to have unusual symptoms checked by a specialist plant disease diagnostician to identify the cause.

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

Asian gypsy moth *Lymantria dispar*

Asian gypsy moth larvae feed on foliage of more than 650 plant species, causing heavy defoliation often leading to death of the host plant. As the name suggests it originated in Asia and is present in Russia, China, Korea and Japan. There have been several incursions into North America over the last 30 years and an incursion into New Zealand in 2003 was eradicated.

Appearance

- Male moths have a 30-40mm wingspan with greyish-brown wings that have darker wavy lines. Female moths are larger than males, with a wingspan of 40-70mm and white wings that have grey markings.

Male (bottom) and female (top) Gypsy moth adults

- Eggs are laid in large 20-30mm x 10-20mm yellow or tan fuzz covered egg masses on tree trunks, rocks, outdoor furniture, machinery, buildings and other solid objects.

Large numbers of eggs masses can be found on trees or other solid objects

- Larvae are covered in long hairs and have variable colour but when mature have a distinctive double row of 4-5 pairs of blue spots on the back followed by six pairs of red spots.

Hairy larvae showing distinctive blue and red spots

- Feeding damage and defoliation becomes evident and webbing may be present as infestations increase.

Spread

- Adults are strong fliers that may travel up to 40km before mating.
- Young larvae can disperse several kilometres by “ballooning” on silk threads blown by the wind.
- Eggs attached to nursery stock, vehicles and machinery, transport containers and equipment can be transported long distances.

Could be confused with

- Painted apple moth *Orgyia anartoides* and painted pine moth *Orgyia australis* are Australian native species in the same family (Erebidae) as Asian gypsy moth and have hairy egg masses that are not as large or abundant as those of Asian gypsy moth. Their larvae are hairy but do not have the distinctive red and blue spots of the gypsy moth larvae.
- Any moth, caterpillar or egg mass that appears to match the description of Asian gypsy moth should be referred to an expert for identification.

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

Black stem blight

Black stem blight, or Asian pear blight, is a disease of Nashi pear *Pyrus pyrifolia* and European pear *Pyrus communis* caused by the bacterium *Erwinia pyrifoliae.* Severe losses in production in Korean pear orchards have been reported.

Appearance

- Symptoms include black to brown stripes in leaf midribs, dark brown leaf spot and necrotic petioles.
- Necrosis can occur on entire branches, blossoms and fruitlets across large parts of the tree.

Spread

- Unknown but may be carried by honeybees.
- Likely distributed with infected plant material

Could be confused with

- Fireblight caused by *Erwinia amylovora*.
- Morphological, biochemical and molecular characteristics can be used by experts to distinguish between *E. pyrifoliae* and *E. Amylovora*.
- *E. pyrifoliae* has a narrower host range (Nashi and European pear) than *E. amylovora* (pome fruit and ornamentals).
- Blossom blast on pears caused by *Pseudomonas syringae* pv *syringae*.

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

Brown headed leaf roller (BHLR) complex

There are two species *Ctenopseustis obliquana* and *C. herana* within the brown-headed leafroller complex that are indistinguishable in appearance of all stages but are identifiable using genetic markers. They are native to New Zealand where they feed on more than 20 families of plants, including important horticultural species such as pome and stone fruit, grapes, and ornamentals. In New Zealand there are 4-6 overlapping generations per year and moths are common in November through March, corresponding with the pome fruit growing season.

Appearance

- Adults are moths 8-12mm long. Females have a wingspan 20-28mm and male wingspan is 17-24mm. Both sexes have walnut brown- brownish grey forewings with darker markings forming variable patterns, and pale brown mottled hindwings.
- The forewings are sometimes two-tone with females having a dark oblique mark halfway down the edge of each forewing. Males have an additional dark transverse stripe extending to half the length of the forewing.

www.padil.gov.au/pests-and-diseases/pest/main/136268

- Female moths lay up to 150 eggs in a smooth egg mass.
- Early instar larvae have a black head and prothoracic shield (the collar behind the head), and often settle close to the main veins on the lower leaf surface of shoot tips and new growth leaves where they construct silk feeding shelters that cause the leaf surfaces to roll together, or two leaves are webbed together.
- Some larvae settle in the fruit calyx of apples where to only sign of their presence is the fine silk webbing.
- Later instar larvae migrate from settlement sites and create new feeding shelters by rolling leaves, webbing two leaves together or webbing a leaf onto a fruit, where they feed on all surfaces except the main veins. This damage is very close in appearance to that caused by LBAM (*Epiphyas postvittana*) and green-headed leaf rollers (*Planotortrix* spp.).

Spread

- Their dispersal ability is similar to that of LBAM and they can be transported as egg masses, larvae, or pupae on infested fruit and other plant material.

Could be confused with

- The moths could be confused with LBAM.

- The larvae in their feeding shelters could be confused with other leafrollers unless careful attention is paid to the head and body colour, especially since in New Zealand they are often found in association with LBAM.

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

Brown marmorated stink bug *Halyomorpha halys*

This stink bug from eastern Asia (China, Japan, Taiwan) is a serious pest of agriculture in North America and Europe where it has also become a considerable nuisance pest by overwintering in large numbers in houses and other buildings.

Appearance

- Brown marmorated stink bug (BMSB) adults are 12-17mm long mottle-brown coloured, shield shaped stink bugs with distinctive black and white banding around the outer edge the abdomen. They attack at least 300 plant species including nuts, fruit crops, vegetables and ornamentals.
- They are sucking pests whose piercing mouth parts and saliva damages plant tissues.
- The 1.6mm long barrel shaped light green to cream coloured eggs are laid in clusters of 25-30 eggs on the undersides of leaves and turn a yellow-orange colour as they get closer to hatching.
- Nymphs undergo 5 nymphal instars as they grow from 3mm to 12mm long and change from orange and black first instar nymphs to mottled brown fifth instar nymphs that look like smaller versions of the adult but with wing buds instead of full wings.
- The nymphs cause the most damage with feeding damage on fruit causing sunken areas and corky spots, and premature fruit drop.

Spread

- BMSB spread locally by flight but longer distance spread is facilitated by hitch-hiking in cargo containers and the cargo itself, and even personal luggage.
- Recent detections in Australia have been in loads of bricks and electrical goods, and shipments of machinery parts.
- They are most likely to be in shipments arriving in Australia during the northern hemisphere late autumn- winter period which coincides with spring-summer in Australia.

Could be confused with

- All stages of BMSB can be confused with those of several native brown coloured stinkbugs in Australia. Adult BMSB have distinctive white bands on the last two antennal segments.

Adult

Steven Valley, Oregon Department of Agriculture, Bugwood.org

Nymph

Steven Valley, Oregon Department of Agriculture, Bugwood.org

Eggs and nymphs

David R. Lance, USDA APHIS PPQ, Bugwood.org

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information: See the PHA website www.planthealthaustralia.com.au

Cedar apple rust *Gymnosporangium juniperi-virginianae*

This fungus requires both Juniperus and apple trees to be in close proximity for the fungus to complete its life cycle. Although the disease it causes is called Cedar apple rust the main host, *Juniperus virginiana* (commonly called red cedar, eastern red cedar, pencil cedar, aromatic cedar, and Virginia juniper) is not a true cedar but is a member of the Cypress family Cupressaceae. Cedar apple rust is currently restricted to North America.

Appearance

- Symptoms vary depending on the host species and life stage of the fungus.
- The primary host is eastern red cedar *Juniperus virginiana* on which it causes galls called cedar apples on twigs and branches.
- The galls produce finger-like protrusions that contain teliospores that are released by rain. These teliospores germinate to produce a basidium that in turn produces basidiospores that cannot infect the primary host and are blown by wind to nearby secondary hosts such as apple trees where they germinate and cause small yellow-orange lesions on the upper surface of leaves and petioles.
- A few weeks later the infection causes small yellow-brown tufts or spore producing pustules to break out on the lower surface of the leaf. The aeciospores released from the pustules disperse via wind or insects back to the primary host species where they germinate and ultimately complete the life cycle by infecting the primary host.
- Infected stems may also show swellings and young fruit may abort.
- The more common symptoms on fruit are slightly raised bright yellow-orange lesions that turn brown and crack as the fruit enlarges.

Initial symptoms include bright yellow-orange lesions on leaves

Rust lesions develop on both leaves and fruit

Spread

- Transport of apple leaves and fruit can spread the fungus.
- The most common means of spread is movement of infected *Juniperus virginiana* material.

Could be confused with

- There are several species of Gymnosporangium infecting Juniperus that include Malus species (apples, crab apples) as one of the secondary hosts.
- Symptoms on apple trees could be confused for bacterial and other fungal diseases but presence of the yellow-brown tufts or spore producing pustules distinguish Cedar apple rust.

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

European canker *Neonectria ditissima* (syn *N.galligena*)

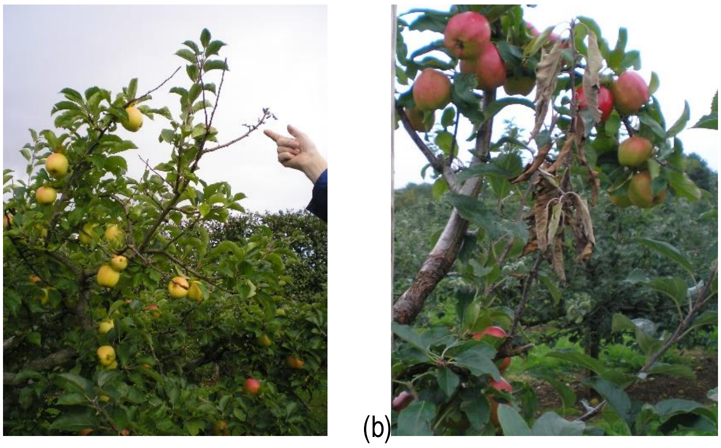
The causal agent of European canker was previously known as *Nectria galligena* but the taxonomy was revised to *Neonectria galligena* in 1999 and then *Neonectria ditissima* in 2006. This fungal disease was eradicated from Tasmania by 1991 and Australia is currently free of European canker. It is present in nearly all pome fruit producing regions of the world. Eye rot of apple fruit caused by the disease accounts for losses of up to 80% of susceptible fruit crops (e.g. Bramley's Seedling) overseas, but for modern varieties the more important issue is death of young trees and branches on older trees. Apples, European pears, Asian pears, crab apples, poplars, willows and elms are susceptible. Red Delicious, Golden Delicious, and Royal Gala are highly susceptible cultivars. Granny Smith is moderately resistant.

Appearance

- First symptoms are reddish brown lesions around leaf scars, spurs, or pruning wounds on small branches in late spring-early summer (Fig. 1).
- The lesions elongate to form cankers with concentric ring-shaped cracks.
- Shoot dieback, wilting and leaf drop can occur in spring.
- Eye rot (Nectria rot) symptoms on fruit rarely develop pre-harvest, usually developing in post-harvest storage in all parts of the fruit. Skin becomes dark brown over the rotted flesh that turns light brown and moist. A depression may develop as the flesh shrinks.
- Infection of fruit on the tree occurs through open calyxes, lenticels, scab lesions, or insect wounds and fruit may be symptomless until storage rots develop post-harvest.
- The disease is most noticeable as dead twigs and spurs that stand out when the tree is in full foliage (Fig. 2).
- Under favourable conditions perithecia (small, round, red granulations visible with the aid of a hand lens) may be present in the canker tissue (Fig. 3).

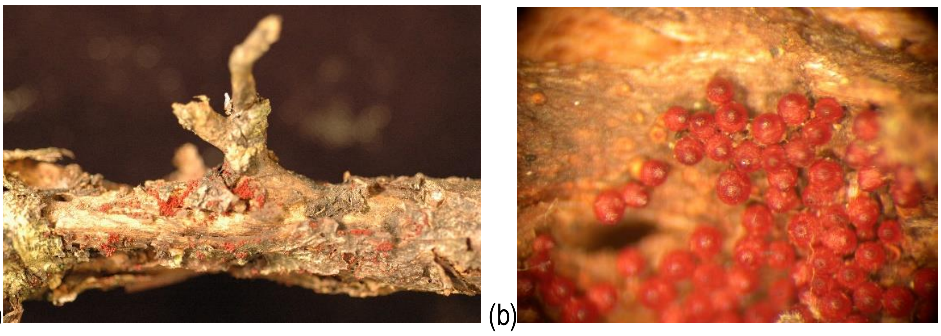
(a) (b)

Figure 1. Young canker on apple tree (a) cv,Royal Gala (b) cv Braeburn (photographer: J.Edwards)



(a) (b)

Figure 2: Twig death on tree during full foliage (a) cv. Golden Delicious (b) cv. Red Delicious (photographer: J.Edwards)



(a) (b)

Figure 3: Bright red perithecia on apple twig (a) easy to see on dry wood (b) view of perithecia through hand lens. (photographer: J. Edwards)

Spread

- Spores are spread from new cankers by rain or overhead irrigation.
- Although symptoms appear in spring the infections are thought to occur in autumn in leaf scars.
- Old cankers produce spores that can be dispersed large distances and initiate new infections, but water-borne spores spread the disease in already infected trees.
- Long distance spread is via vegetative propagation material, rooted plants, and fruit.

Could be confused with

- Galls caused by woolly apple aphid *Eriosoma lanigerum* but these usually show signs of aphid presence.
- Twig death caused by fireblight, although fireblight does not cause cankers.
- Cankers caused by various *Neofabraea* species of fungus.
- Perithecia could be confused with overwintering eggs of Bryobia or European red mites.
- Fruit rot caused by *N.ditissima* cannot be diagnosed from visual symptoms alone and culturing or DNA analysis by an expert is required.

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

Fire blight

This serious disease of apples, pears, quince and a wide range of ornamentals in the Rosaceae family is caused by the bacterium *Erwinia amylovora*, which is widespread in North America, New Zealand, most of Europe and parts of the Middle East.

Outbreaks are generally more severe when heavy rainstorms occur with warm humid conditions during flowering of the host tree. The bacteria can be spread by birds, insects including pollinating species, and can be transferred from infected tools. All parts of the tree can be affected.

Appearance

- Symptoms include blighting of blossom, shoots, leaves, fruit, limbs and trunk, and collar and rootstock.
- Blossom blight in spring is usually the first symptom when blossoms appear water soaked, wilt, shrivel, and turn brown to black before the infection progresses into the flower stem.
- As the infection spreads into succulent shoots they may take on a bent "shepherds crook' appearance
- Infected shots, bark, and leaves usually turn dark brown to black in pears and light to dark brown in apples.
- Translucent amber liquid may ooze from infected tissues, including fruit.
- Clusters of blighted shoots, twigs and branches look like they have been scorched by fire.
- Shoots and limbs can be girdled by the infections.

Spread

- Bacteria can be spread on the tree by rain and between trees and properties by pollinating insects such as honey bees and flies.
- Birds, fruit feeding bats, insects such as aphids and psyllids feeding on shoots, and humans using contaminated pruning tools can also spread the bacteria.
- Infected, symptomless plant propagation material can be a source of long-distance transfer.

Could be confused with

- Blossom blast and blight caused by *Pseudomonas syringae* pv *syringae* on pears
- Black stem blight caused by *Erwinia pyrifoliae*

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information: See the PHA website www.planthealthaustralia.com.au

Green headed leaf rollers (GHLR*) Planotortrix excessana and P. octo*

This leafroller complex comprises two species of tortricid moths in the genus *Planotortrix* found only in New Zealand. The larvae generally feed between leaves spun together, or rolled, by silken threads. They also feed on the fruit surface, usually in sheltered spaces between touching fruit or under leaves attached to the fruit by silk, or in the calyx. There are two to three generations per year in New Zealand. The two species can be separated using genetic tests or pheromones. Failure of current pesticide regimes to control leafrollers may suggest presence of exotic leafrollers.

Appearance

- The forewings of female GHLR moths often have dark brown variable zig-zag markings and a dark brown spot.
- The back end of male GHLR moths have a fan of large scales.
- Both sexes have forewings darker than the hindwings and the moths are 7-14mm long.
- The resting moths overlap their forewings to produce a bell-shaped appearance.
- Young larvae have light green bodies with brown heads, whereas older larvae have green heads

Spread

- Adult moths disperse by flying and marked individuals have been recorded up to 600m from release sites but most dispersed less than 100m.
- Young larvae can balloon on the wind for short distances.
- Long distance dispersal is mostly due to transport of infested fruit with larvae in the calyx, or egg masses on plant material.

Could be confused with

- Leaf rolling symptoms and feeding behaviour are difficult to separate from those of LBAM.
- Larvae have similar appearance to LBAM but mature LBAM larvae have a light-brown head and prothoracic shield behind the head.

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

Oblique banded leaf roller (OBLR) *Choristoneura rosaceana*

The larvae of this North American leafroller have a wide host range but plants in the rose family (including apples and pears) are preferred hosts. The pest overwinters as third instar larvae in cocoons called hibernacula usually located under bark scales or in bark cracks. Larvae emerge from the hibernacula in spring at bud burst and tie terminal leaves together as feeding shelters. As the larvae grow larger they move to single leaves and roll the leaf into a tubular feeding shelter in which they eventually pupate. Female moths lay eggs in flat overlapping masses on leaves. The young larvae that hatch from the eggs feed on foliage and fruit over summer before pupating and then emerge as moths that produce the second generation.

Appearance

- Larvae that emerge in spring have a yellowish green body with a dark brown head.
- The moths are tan to reddish brown coloured with alternating oblique light and dark bands across the forewings and are 16-30mm long. Females are larger and have more distinctive markings than the males.
- Eggs are flat, dull greenish yellow, laid in egg masses that look like overlapping fish scales.

Moths of the obliquebanded leafroller have alternating light and dark brown bands across their forewings.

Spread

- Dispersal within an orchard is by flight of adults or ballooning of young larvae on the wind. Long distance transport is most likely as hibernating larvae on dormant nursery stock.

Could be confused with

- Damage caused by leafrollers is difficult to distinguish between species.
- OBLR adults are fairly distinctive but could be confused with LBAM.
- Larvae may be confused with LBAM or BHLR larvae unless care is taken.

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

Omnivorous leaf roller *Platynota sultana*

This North American leafroller overwinters as larvae in nests of webbed leaves or in mummified fruit. The larvae remain active over winter although their development is slowed. Pupation occurs in spring. Four to five generations are produced per year. They have a wide host range and orchards can be infested by moths that developed on hosts outside of the orchard. Infestations in orchards are often patchy with hotspots near areas with alternative host plants such as vineyards.

Appearance

Omnivorous leaf roller adult moth

- The adult moths are about 11mm long and have the typical bell shape of other leafrollers when resting. The forewings are mostly brown.
- Eggs are green, elliptical and laid in clusters on fruit and upper surface of leaves.
- Larvae resemble other leafroller larvae but have small white tubercles at the base of protruding bristles along the back and sides. Early instars have a dark brown head and prothoracic shield but later instars have a light brown head and thoracic shield.
- Larvae feeding on fruit leave irregular, shallow feeding scars.

Spread

- Adults disperse by flight.
- Larvae may be transported in the calyx of infested fruit.
- Eggs and larvae may be transported on alternative host material

Could be confused with

- Other exotic leafrollers and LBAM.

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

Orange tortrix *Argyrotaenia citrana*

This North American leafroller is a pest of grapes in coastal areas and valleys in the Pacific North West but it also attacks apples, pears, stone fruit, berry crops and citrus. It has also been recorded on Eucalyptus, mallow, willow, and dock in California. All developmental stages are present throughout the year with overlap of the three generations.

Appearance

Orange tortrix adult moths and egg mass on a leaf

- Adult moths are about 10mm long and at rest have the typical bell shape of other leafrollers.
- The forewings are brownish or buff coloured and often have a darker brown coloured saddle or V-shaped area across the lower half of the folded wings. Males also have a pair of darker crescent shaped markings on the wing margins.
- Eggs are pale cream or green when first laid but darken with age as the larvae develop inside. The eggs are laid in clusters.
- Larvae have straw coloured to greenish bodies with a yellow-gold coloured head and prothoracic shield in each larval instar. Larvae wriggle backwards and drop to ground when disturbed.
- Unlike other leafrollers it does not tie leaves together to make a feeding shelter but on fruit it feeds under webbing spun at the stem end of fruit, where it causes irregular shallow feeding scars.

Spread

- Young larvae disperse short distances by ballooning on silk strands blown by the wind.
- Moths are good fliers.
- Long distance movement is by transport of infested fruit or alternative host material carrying egg masses.

Could be confused with

- Other exotic leafrollers.

- Moths look superficially like LBAM.
- LBAM larvae also wriggle backwards and then drop to the ground when disturbed.

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

Oriental fruit fly Complex

Papaya fruit fly *Bactrocera papayae*, Oriental fruit fly *Bactrocera dorsalis*, and Carambola fruit fly *Bactocera carambolae* are all part of the Oriental fruit fly complex. They can only be distinguished by an entomologist who is a fruit fly expert. Papaya fruit fly is native to SE Asia and is also present in New Guinea. It was detected in Cairns in 1995 and eradicated. Oriental fruit fly is widespread throughout Asia, Hawaii and northern parts of South America. It has a wide host range including apple, pear, peach and apricot. Carambola fruit fly is native to South America.

Appearance

- The adult fly is 6-8mm long with a narrow band along the edge of the wings.
- The thorax is dark with two prominent yellow strips on top and yellow marks on each side.
- The abdomen is yellowish with a black T-shaped mark.
- Eggs and larvae look like other tephritid fruit fly larvae.
- Like other tephritid fruit flies, egg-laying and larval feeding provides entry points for microbes that cause fruit rot.

Division of Plant Industry Archive, Florida Department of Agriculture and Consumer Services, Bugwood.org

A T-shaped mark is often visible on the abdomen

Spread

- Adult flies are strong fliers and can also hitchhike in vehicles.
- Eggs and larvae are transported in infested fruit

Could be confused with

Symptoms are like those caused by endemic fruit flies such as Queensland fruit fly *Bactrocera tryoni*.

The larvae look like typical tephritid fruit fly maggots and need either microscopic or genetic analysis to distinguish them from those of endemic fruit flies.

The adults have different colouration to *B. tryoni* but to the untrained eye they might appear to be similar.

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

Pear fruit moth *Acrobasis pyrivorella*

Pear fruit moth is native to temperate eastern Asia (northern China, far eastern regions of the former USSR, both Koreas, Japan, and Taiwan) where it affects pears only.

Appearance

- Infested fruit usually fails to develop properly, turns black and shrivelled.
- Larvae use silk threads to attach the infested fruit to the tree, where they can hang until the following fruit season.
- Conspicuous webbing on exit holes and masses of insect excreta appear on the fruit in summer.
- Moths are greyish with a violet tinge and a wingspan of 14-21mm.
- Moth forewings have a dark crescent shaped apical spot between two transverse stripes (see circled area in image below) and the hindwings are yellowish grey.

Spread

- Adults disperse by flight

Could be confused with

- Unknown

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

Pear psylla *Cacopsylla pyricola*

Pear psylla is the most important pest of pear in Europe and North America because of its damage potential, propensity to develop resistance to pesticides, and its role as a vector of the mycoplasma that causes pear decline which can kill trees. It is more of a problem on European rather than Asian pear varieties. It can complete its life cycle only on pear trees. It overwinters as adults under bark scales and bark crevices, under leaf litter on the ground, or sometimes outside the orchard. Egg laying occurs from bud swell to about 3 weeks after petal fall and hatch commences 14-30 days later. The five nymphal instars all feed on green leaf material and for the first four instars secreted honeydew encases most of the body. Five generations a year occur in California. The toxin injected into leaf tissue during feeding causes blackening and burning of foliage similar to mite burn. Honeydew drips onto other plant parts, causing russet on fruit and growth of a sooty fungus.

Appearance

- The eggs are tiny, elongated and laid on or near fruit spurs or along midribs and petioles of developing leaves.
- First instar nymphs are wingless, 3mm long, yellow with red eyes and black antennae.
- By third instar the nymphs are greenish yellow and small wing buds have developed.
- Fourth instar nymphs are greenish brown.
- Fifth instar nymphs are more active, have moved to the base of petioles, and are dark brown with obvious dark wing buds.
- Adults are dark reddish brown, have four transparent wings held roof-like over their bodies when at rest, and look like a tiny cicada.
- Pear decline reduces tree vigour, causes poor fruit set, small fruit size, and tree death

Spread

- Dispersal of adults occurs if trees defoliate early but usually occurs in late summer after harvest.
- In areas with warmer autumn weather the psyllids remain active for longer and dispersal can occur as late as leaf fall.

Could be confused with

- Adults could be confused with native psyllids that have blown in from nearby wattles and gum trees.

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

Plum curculio *Conotrachelus nenuphar*

The damage caused by this weevil makes it second only to codling moth as the most damaging insect pest of pome and stone fruit in eastern North America. The adult weevils cause feeding scars and oviposition wounds on fruit. Unlike weevil pests in Australia *C.nenuphar* larvae feed inside the fruit, destroying the flesh and causing rot that leads to premature fruit drop.

Appearance

Adult is mottled grayish-black and brown. NY State Ag Experiment Station

Crescent-shaped scar left by egglaying activities. NY State Ag Experiment Station

- The adult is mottled greyish black and brown with a series of humps on its back in which the second and third pairs are separated by a clear transverse band. Its head has a large but short snout that bears antennae.
- The eggs are laid in a crescent shaped slit on young apple and pear fruit, commencing shortly after petal fall.
- The larvae have a C-shaped whitish-cream coloured body with no functional legs, an elliptical dark head and brown thoracic shield.
- Larvae-infested young fruit drop to the ground.
- The scars from egg laying are crescent shaped or semicircular and distinctive.
- Presence of scarred mature fruit indicates that larval development was not successful.

Spread

Larvae can spread in infested cherries and other fruit but the most likely spread pathway is via adult weevils contaminating packing material.

Could be confused with

Similar to the North American apple weevil *Anthonomus quadrigibbus* and the apple blossom weevil *A.pomorum*, neither of which are in Australia.

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

Rosy apple aphid *Dysaphis plantaginea*

This aphid is potentially the most damaging aphid to apples in North America due to the amount of honeydew it produces and toxic saliva it injects while feeding causes stunted and malformed fruit, severe leaf curling and distortion, twisted shoots and reduced fruit yield. It overwinters as black shiny eggs laid at the base of long twigs and basal leaf scars. Nymphs begin to hatch between bud swell and two weeks after bud break and work their way into the opening leaf clusters where they feed on the sap. The nymphs usually mature by full bloom and the mature wingless female aphids give birth to live nymphs without having to mate. Large colonies rapidly develop with overlapping generations and mixed ages until early summer when winged adults start to develop and migrate to alternative hosts like plantain where they spend the rest of summer. In autumn winged females develop on the plantain and move back to the apple trees where they give birth to nymphs that develop into wingless females. In late autumn winged males are produced on the plantain and they move to the apple trees where they mate with the wingless females, who then lay overwintering eggs.

Appearance

- Overwintering eggs are black, shiny and oval shaped.
- Young nymphs are dark green to purple and covered with light grey dusty wax and have long cornicles ("tail pipes") with flanged tips.
- Wingless adults are rosy purple with black tips to the cornicles, legs, and antennae.
- Winged adults have black bodies, clear long wings and long antennae.

Rosy apple aphid eggs overwinter in basal leaf scars.

Observe the range of colors and sizes from newly hatched nymphs to adults in this colony of rosy apple aphids.

Rosy apple aphids develop into black, winged adults in preparation for migration to summer hosts.

Could be confused with

There are several aphid species that look superficially like rosy apple aphid but can be distinguished by the size, shape and colour of the cornicles.

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information

See the PHA website www.planthealthaustralia.com.au

Spotted wing drosophila (SWD) *Drosophila suzukii*

This pest originated in South-East Asia and is spreading throughout many horticultural production areas across the globe. It spread rapidly through North America and Europe. The preferred hosts are grapes, berries, cherries, nectarines and plums, but over-ripe or damaged apples and pears could be alternative hosts especially in urban areas or orchards near preferred hosts.

Appearance

Adult SWD small 2-3mm long flies with a wingspan of 6-8mm and prominent red eyes. The males are smaller than females and, unlike other Drosophila species present in Australia, have a dark spot on the end of each wing. The females do not have spots on the wings and when observed with the naked eye look like other vinegar flies commonly seen around rotting fruit. The females can be distinguished from other vinegar flies, when observed under magnification with a hand lens or microscope, by the presence of a double serrated ovipositor used to puncture fruit and lay eggs. The eggs are white, 0.6mm long and oval shaped. The larvae are cream-white maggots typical of vinegar flies.

Adult males are yellow-brown with dark abdominal bands, red eyes and distinct spots on the ends of their wings

Adult females are yellow-brown with dark abdominal bands, red eyes and no spots on their wings

Spotted-winged drosophila ovipositor

Spread

SWD adults can fly for localised dispersal and can hitchhike in vehicles. Eggs, larvae and pupae can be spread in infested fruit.

Could be confused with

Immature stages have appearance typical of other vinegar flies. Adult females can be confused with other vinegar flies until the ovipositor is examined. The dark spots on the wings of adult males are distinctive but the small size and restless activity of the flies makes it difficult to see these diagnostic spots with catching the flies.

If in doubt call the **Exotic Plant Pest Hotline 1800 084 881** and seek expert diagnostic advice

Further information: See the PHA website www.planthealthaustralia.com.au

Apple and Pear IPDM

Chapter 5: Integrated weed management

Quick Facts for on-farm weed management

Prevention is cheap

- Update your farm biosecurity plan to include weed prevention measures
- Include visitors and your home gardens in the biosecurity plan
- Periodically inspect roadsides in the neighbourhood for presence of weeds

Finding weeds early improves your chances of success

- Develop a monitoring program to detect weeds before they get established
- Regularly inspect carparks and recently disturbed areas
- Train staff on weed identification and empower them to report any unusual plants that they notice while carrying out their normal duties.
- Use mobile phones for photographs and recording GPS locations of weed detections

You need a Plan for your controls

- Develop a weed action plan
    - What is the current situation (nature, scale and location of the problem)?
    - What are you aiming to achieve?
    - What methods (strategies, tactics) are you considering, and why?
    - What are the pros and cons of these methods?
    - Do not rely on herbicides alone. An Integrated Weed Management approach will provide effective long-term control.
    - What resources are required to perform the works and what do you have on hand?
- Document the weed action plan using the SMEACS format in the pest and disease section of this manual

Weeds are just another form of pest (or disease) that requires monitoring and action thresholds

- Follow resistance management guidelines for all herbicide applications
- Herbicides create further disturbance so where possible establish vegetation that competes with the weeds but not your crop.

Herbicides can affect non-target organisms, including those that are not plants

- Refer to Table 6 in Chapter 6: Pesticides and the Australian Apple and Pear Industry for more information about impacts on biocontrol and soil biology. Some herbicides affect beneficial microbes by targeting enzymes or binding sites common to plants and microbes. This can disrupt soil biodiversity and lead to increases in plant pathogenic species.

Introduction

Weeds are commonly defined as invasive alien plant species that can cause loss of productivity and impacts on biodiversity and ecosystem function. A more appropriate definition is a plant growing in the wrong place or an aggressive plant that thrives in natural environments that have been disturbed or poorly managed. They are often introduced plant species but can be native species growing outside their natural range. They become weeds when they arrive in areas where conditions allow them to out-compete the endemic species, crop, or contaminate pastures or taint crops. They can reduce biodiversity by dominating habitats and thereby affecting most, if not all, of the organisms in the complex biological web that revolved around the endemic plant species.

The above descriptions are obviously a human assessment based on our perception of our place in the biosphere. This is reinforced by the Australian Weeds Strategy that defines a weed as "a plant that requires some form of action to reduce its negative effects on the economy, the environment, human health and amenity" (https://www.agriculture.gov.au/pests-diseases-weeds/pest-animals-and-weeds/review-aus-pest-animal-weed-strategy/aus-weeds-strategy).

In so-called natural plant communities, all plants would co-exist in dynamic balance with each other, mediated by constraints imposed by competition with other plant species, herbivores, climate, soil, and pathogens. Our need to obtain food and fibre through agriculture, shelter by building cities, resources by mining, and accessible recreation areas has resulted in disturbance of natural plant communities and created the concept of a "weed". To be considered a weed by humans a plant must have some undesirable characteristics such as:

- Competing with more useful plants for moisture, nutrients and light
- Poisoning of humans and domestic animals
- Tainting agricultural produce
- Contaminating agricultural produce
- Harbouring plant diseases and insect pests
- Harbouring vermin
- Interfering with transport, essential services and recreation
- Interfering with agricultural operations

Weeds can be classified as noxious weeds, environmental weeds, or just plain nuisances. The Australian Weeds Strategy further divides weeds into Weeds of National Significance (WoNS) and weeds of significance to individual States and Territories, which then cascade into Regional and Local Government weeds. Each State or Territory has legislation governing weed management. It is beyond the scope of this manual to detail all legislation relating to weed management across all levels of government. It is your responsibility to ensure that you are abiding by all relevant legislation.

There are several stages involved in weed management:

- Prevention using scientific-based risk assessments guiding quarantine measures
- Eradication while the population is still small
- Containment to limit spread of species that cannot be eradicated
- Asset protection when eradication and containment is considered impractical.

Each of the above stages is applicable to weed, pest, and disease management programs but the responsibility for action changes according to context and scale. For example, the federal government is responsible for quarantine measures at national borders into Australia; State and Territory governments are responsible for quarantine measures to protect their borders; and individual farm businesses are responsible for quarantine measures for their enterprise. Each level cascades to the next as an incursion progresses through the stages. If national borders are breeched then federal and state governments collaborate in eradication efforts. If eradication fails state governments attempt to contain the outbreaks to limited areas. If containment fails individual industries and farm businesses need to be prepared to protect their assets. The first step in asset protection is identifying the assets requiring protection.

Weed Management

In some situations, allowing a partial return to a more "natural" state creates conditions unsuitable for the weed species but this is rarely possible in an agricultural context. Where possible it is best to use quarantine to prevent establishment of new high-risk weed species. Once a weed has established there are several approaches for attempting control. These include:

- Prevention of seeding by mowing, grazing, cultivating, burning or spraying
- Germination of dormant seeds followed by destruction of seedlings
- Depletion of food reserves in the roots, rhizomes, bulbs and corms by well-timed sprays
- Providing competition by planting agriculturally, ecologically, or economically desirable plants
- Once the weeds have been removed it is important to replace them with some other desirable plants to prevent the weeds re-establishing.

Turning weeds into useful plants

Weedy species managed properly as part of the orchard ground cover without becoming dominant can be beneficial if they support predators and parasitoids that attack pest species or if they support other ecological functions. This is not an appropriate approach to Declared Weeds where there is a legislated requirement to destroy those weeds. Ground cover improves water penetration into the soil, slows the rate of water runoff on sloping ground, reduces dust, and may help with fruit colour development. Practitioners of conservation agriculture and regenerative agriculture advocate the need for at least 30% permanent soil organic cover coupled with species diversity that generates improvements in soil health while providing habitat for generalist biocontrol agents, decomposers, and ecological engineers such as earthworms. Competition between ground cover species and trees can be overcome by best practice fertilizer and irrigation management. It is also important to understand the ecological function of the various "weed" species so you can concentrate on preventing establishment of undesirable species while selecting and establishing appropriate ground cover species.

Tune in to messages from the ecosystem

Although weeds get most attention when they cause loss of productivity and impacts on biodiversity and ecosystem function, they often play the role of initial colonisers after disturbance events. Presence of weeds usually indicates an underlying problem. Excessive use of pesticides can result in soil contamination that exposes ground and soil dwelling invertebrates to lethal or sub-lethal (lower fertility or metabolic problems) residues or create imbalances in soil microbe populations that affect soil health and eventually performance of orchard trees. Creation of bare ground by herbicide application or cultivation is a disturbance event that often results in decreased soil health and increased weed populations. Presence of nutsedge *Cyperus* spp. indicates drainage problems and capeweed *Arctotheca calendula* indicates high soil nitrate levels. Fixing those problems usually reduces the weed issue.

When to look for weeds

The type of farm, the climate where the farm is located, and the lifecycles of the target weeds will determine the best times to look for weeds. For deciduous fruit orchards the main times to inspect for weeds would be:

- Late summer-autumn before harvest so that weed seeds do not contaminate picking bins
- Winter during pruning so that infestations can be dealt with before spring
- Spring between green-tip and flowering because flowering weeds may be more obvious
- Early summer during any hand-thinning so that weed control assessments can be made before irrigation scheduling begins in earnest.

Where to look for weeds

As with any pest management monitoring program there are various ways to decide where to look. The best approach is to use them all in context.

- Improving weed knowledge in field staff and encouraging them to develop situational awareness while conducting their normal duties increases the probability that they will notice and report a new weed or the spread of existing weeds. This is a sort of passive surveillance.
- Checking previous weed hotspots is a good way to assess success of previous control attempts but will not help with detection of new incursions unless situational awareness is used while travelling to and between hotspots.

- Focusing on areas that may be vulnerable to incursions is a logical approach and can incorporate previous hotspots since they are obviously potential sources. For orchards the areas to focus on include:
    - Near and downwind of previous infestations
    - Downhill of previous infestations
    - Watercourses, dams, and poor drainage areas
    - Roadways, tracks and machinery washdown areas
    - Areas where earthmoving and other contractors have been working
    - Areas where tree heaps were burned
    - Near sheds, tanks, bin stores, picker's huts, carparks
    - Newly worked or planted blocks
    - Garden beds around office buildings and homes on the farm
    - Around apiary sites
    - Boundaries with neighbours

Identifying weeds

- Once an unusual plant or suspected weed is detected it should be identified as soon as possible so that appropriate control measures can be applied if it is a weed.
- Take close-up photographs of flowers, seed heads, leaves and fruit, and collect specimens then use a weed identification guide, website, or phone app to narrow down the options.
- Specimens and/or photographs can be submitted to a weeds officer from the local Agriculture Department or Catchment Management Authority or equivalent in your state, an agronomist at the local rural merchandise store, or the local government environment officer.
- Seek advice from local Landcare members

Weed control methods for inclusion in a Weed Action Plan

If you have a weed action plan that integrates several control methods, recognises that weed management takes persistence over several years, and includes regular monitoring of weed populations and assessment of success and failures you should be able to keep weeds from causing economic losses.

Farm hygiene

- Restrict vehicle access to sensitive areas providing suitable parking areas and clear signage.
- Ensure mulches, gravel and other track surfacing materials are purchased from weed-free suppliers.
- Provide vehicle/ machinery washdown areas and require contractors to clean their equipment before entering the orchard.

- If grazing stock in the orchard over winter ensure they have come from a weed-free area or have a holding area where they can be held to purge gut contents of weed material, especially seeds, before giving them access to the orchard.

Digging and pulling

- Small numbers of weeds can be dug or pulled when found but if they are setting seed they should be bagged before pulling so the seeds are not dropped.
- Some have spines or are poisonous so gloves should be worn

Slashing and mowing

- Use to reduce leaf surface area and allow competitive plants to access sunlight
- Some annual weeds such as thistles have limited ability to reshoot after cutting
- Cutting before flowering or seed set can reduce the seed bank and eventually allow other competitive plants to flourish
- For capeweed in orchards slashing regularly helps to manage populations of lightbrown apple moth and Western fruit moth that use capeweed as a host over winter and early spring.

Grazing

- Although a common practice in the past, grazing by livestock (pigs, goats, sheep or cattle) in orchards is generally discouraged because of the damage the stock can do to the trees and the risk of pesticide residues in the meat.
- Grazing by ducks, geese and other fowl is used by some orchardists, especially organic growers, to help manage weeds and some pests such as snails. The birds need to be locked up overnight to protect them from foxes and should not be used for meat production if pesticides are used in the orchard.

Mulching

- Synthetic or natural organic mulches can supress weed growth in orchards by preventing light penetrating to germinating weed seedlings or providing a physical barrier to emerging weeds.
- The mulch will also prevent indigenous ground storey plants from germinating and competing with the weeds.
- Ensure mulch material is free from weed seeds.
- Do not mulch close to the tree trunks
- Mulching preserves soil moisture and improves soil organic matter as it decomposes but in some soils the combination of mulch and drip irrigation may affect soil structure.
- Organic mulch may present a fire risk

Altering soil properties

- Improving fertiliser, soil acidity and drainage may disadvantage some weeds.
- Capeweed prefers high nitrate levels in soli
- Dock and nutgrass prefer wetter or waterlogged soils.

Over-planting with competitive desirable plants

- Over-planting weeds with native plants or other desirable species (e.g. those that support predators and parasitoids) may reduce weed populations by competition for light and nutrients but in orchards these species need to be tolerant of traffic, mowing, and not compete with the trees.
- Local woodland or grassy woodland ground covers may be suitable in orchards because they are adapted to growing under trees

Chemical control

- Selective herbicides kill certain weed species but not other weeds and certain desirable species such as fruit trees in orchards.
- Non-selective herbicides kill most plants that they contact.
- Small outbreaks of weeds can be spot sprayed with non-selective herbicides, but larger infestations may require spraying with a selective herbicide due to the larger areas to be sprayed.
- All herbicides have potential to cause off-target affects if not carefully applied.

Herbicide selection

Herbicides kill weeds (and other plants) by interfering with various processes within the plants. There are currently 19 recognised modes of action for herbicides and, as with insecticides and fungicides, products with the same mode of action are identified by a common code on the label. Herbicide resistant plants present at low frequencies in weed populations become evident after repeated applications of herbicides with the same mode of action kill susceptible plants and allow the resistant one to become dominant. Different modes of action have different risks related to development of resistance by weeds.

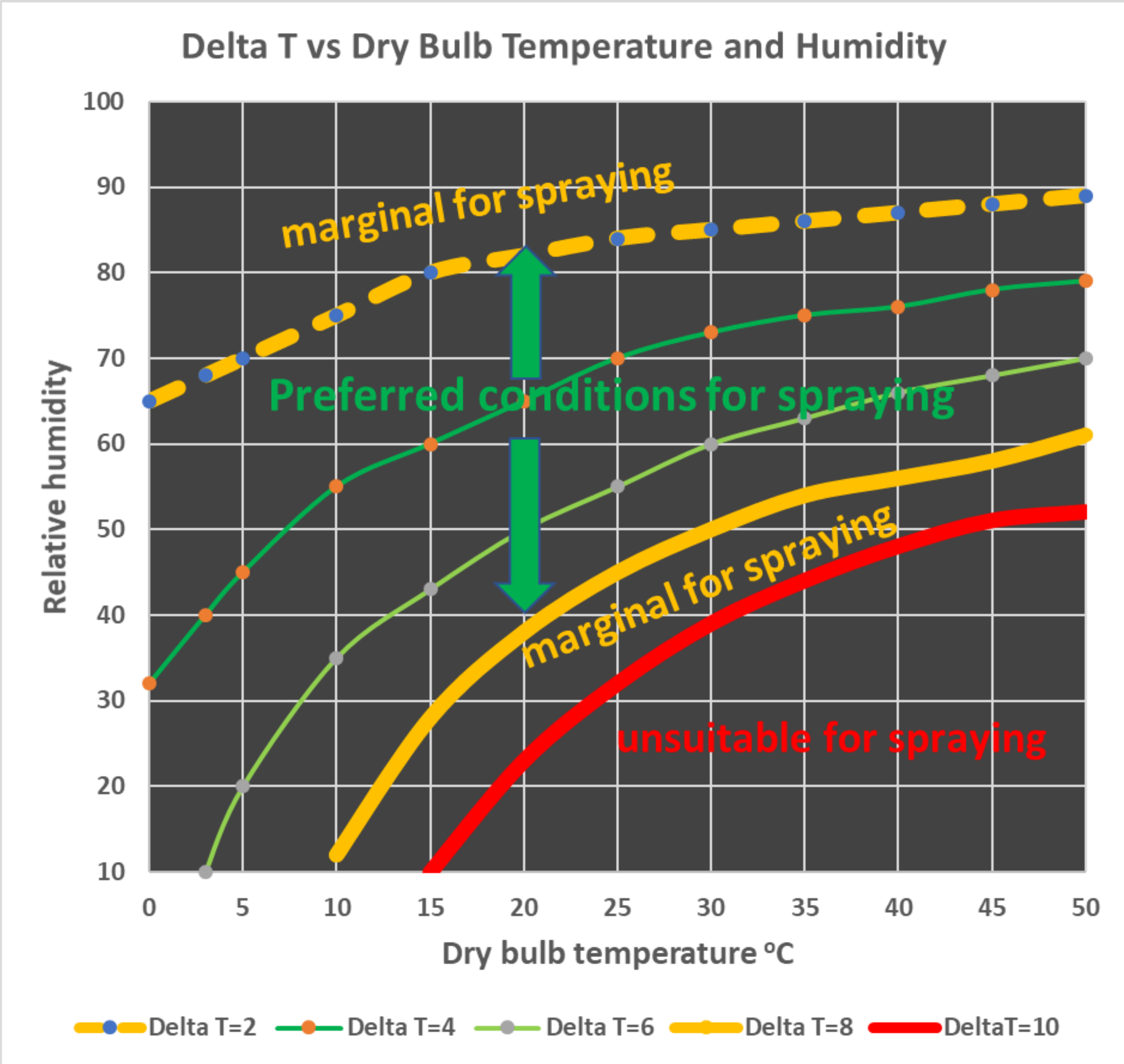
- ***Products in Groups A and B are high resistance risk herbicides.*** Specific resistance management guidelines must be followed for these groups.
    - **Group A** resistance is widely present in grass species in Australia, including annual ryegrass, wild oats, phalaris, and barley grass. Where a Group A herbicide was used for control of any grass no Group A herbicide at all should be used in the following season. Where resistance to a Group A herbicide is either suspected or known to

occur there is a good chance the resistant weeds could be cross-resistant to Group Z herbicides as well.
  - **Group B** is the herbicide mode of action that is most likely to have generated resistance. In Australia at least nine species of grass weeds and 17 broadleaf weeds are resistant to Group B herbicides. Group B herbicides include pre-emergents and post-emergents. If a post-emergent spray of a Group B herbicide is being considered it must not follow a pre-emergent Group B spray and no more than two Group B herbicides should be used in any four-year period on the same paddock.
- ***Products in Groups C, D, F, G, H, I, J, K, L, M, N, Q, and Z are considered moderate risk herbicides.*** Specific resistance management guidelines are available for these groups.
- ***Products in Groups E, O, P, and R are considered low risk*** because no cases of resistance have been detected in Australia and specific resistance management guidelines have not been produced.
- ***Herbicide compatibility*** should be checked before tank mixing as not all products are compatible. Before using more than one herbicide in a mix, ensure they are compatible by checking compatibility lists on the product label.
- ***Adjuvants are additives intended to improve efficacy or ease of application.*** The most common adjuvants are surfactants (wetters), penetrants, and dyes. Many products come already formulated with adjuvants and it is important that any additional adjuvants added to the tank are compatible with the chosen herbicide product and any other products in the tank mix. Compatible adjuvants are listed on the label.
  - ***Adjuvants that enhance product efficacy*** include:
    - ***Surfactants/Wetters/ spreaders*** enhance adhesion to leaf surfaces and improving coverage by reducing surface tension to spread the spray droplets.
    - ***Stickers*** increase adhesion of pesticides to target surfaces
    - ***Penetrants*** improve transport of the pesticide into the plant tissue
    - ***Extenders*** increase resistance to environmental degradation and lengthen the time that the active ingredient is toxic to the target
    - ***Humectants*** increase the time taken for an aqueous spray deposit to dry
  - ***Adjuvants that improve ease of application*** include:
    - ***Acidifying or buffering agents*** that adjust the pH of water to minimise alkaline hydrolysis of the pesticide
    - ***Anti-foaming or de-foaming agents*** that prevent foam overflow by suppressing foam formation in the tank
    - ***Compatibility agents*** that prevent antagonism between different components in a tank mix

- ***Drift control agents*** alter some of the properties of the spray solution so that larger droplets are produced
- ***Dyes*** used to mark sprayed areas to avoid over-spraying and to indicate coverage
- ***Water conditioners*** that suppress salt formation and precipation in spray tanks.

Avoiding spray drift can prevent chemical trespass into neighbouring properties, contamination of livestock and crops, poisoning of waterways, and in orchards inadvertent damage to the tree canopy and fruit. Drift can be avoided by:

- ***Selecting appropriate weather conditions*** in which to spray
  - Do not spray when inversion layers are present or when Delta T readings are outside the range 2-8°C.
  - Delta T was developed in Australia and is used to indicate when conditions are unsuitable for spraying due to evaporation and droplet survival. High Delta T (>10) means the droplets will shrink in size, increase potential for drift, or dry up before the plant absorbs the chemical. Very low Delta T (<2) droplet survival will be so long that drift could increase, speed of herbicide uptake will slow and the risk of rainfall washing off the chemical will increase.
  - Delta T is the difference between dry and wet bulb temperatures.
  - The chart below is a Delta T ready reckoner based on dry bulb temperature and relative humidity.
  - Suitable wind speeds for spraying are 3-10 km/h
  - Avoid midday turbulence by not spraying after 11.00 am in summer
- Maintain a down-wind barrier from neighbours and sensitive areas
- Avoid using boom sprayer in the orchard but if no better option exists keep boom height as low as possible while maintaining effective spray pattern
- In orchards when spraying the tree line use a spray shroud or a wick wiper
- Use the least volatile formulation of herbicide
- Use lower pressures and nozzles that produce larger drop sizes.
- Small, actively growing weeds that are not stressed take up herbicide more effectively and are the preferred targets


Delta T vs Dry Bulb Temperature and Humidity
100
90
80
70
60
50
40
30
20
10
0
5
10
15
20
25
30
35
40
45
50
Relative humidity
Dry bulb temperature °C
marginal for spraying
Preferred conditions for spraying
marginal for spraying
unsuitable for spraying
Delta T=2
Delta T=4
Delta T=6
Delta T=8
DeltaT=10

Apple and Pear IPDM

Chapter 6: Pesticides and the Australian Apple and Pear Industry

IPDM quick facts

- Pesticides are important components of any pest, disease and weed management program but poor choice of product can cause major disruption to IPDM and set off a chain of events that could cause greater economic loss than the target of the initial spray application.
- Products containing the same active ingredients may not be registered against the same pests or even on the same crops.
- Strict regulations and testing regimes are applied to importation of live organisms as biological control agents.
- Australian fruit growers should only purchase biocontrol agents from reputable commercial Australian suppliers.
- Overseas data on toxicity to beneficials should only be used as an indication of potential issues in Australia since strains of biological control agents available in Australia may be different to strains used overseas.
- The pesticide registration process in Australia requires data on environmental fate, toxicity to bees and a range of environmental indicator species but reports on impact to biocontrol agents, including generalist predators and parasitoids, is voluntary. Absence of a statement on bee toxicity indicates the product is considered safe to bees, whereas absence of statements regarding biocontrol agents or compatibility with IPDM indicate that no data has been provided.
- Tables in this chapter provide ratings based on Australian data where available and/or supplemented by compilations from overseas sources. The ratings indicate potential impacts for inclusion in contingency plans so that monitoring and abatement tactics can be implemented if no suitable IPDM compatible products are available to deal with a specific pest problem.

Introduction

Australian apple and pear growers have been working to reduce reliance on pesticides since the early 1970s and in 1991 the industry signed a Pesticides Charter with the Australian Consumers Association. The Pesticides Charter was recognition by both parties that pesticides vary in toxicity to humans, effect on the environment, and compatibility with beneficial species such as predators and parasitoids that provide biological control services, bees and other insects that provide pollination services, microbes that suppress pathogens, earthworms and other species that assist with soil aeration and water infiltration, root-colonising fungi that enhance water and nutrient use efficiency.

The range of pests, diseases and weeds that infest orchards requires growers to make complex decisions on appropriate choice of management options, including pesticides, that allow them to produce quality crops at volumes that support economic viability and environmental sustainability.

The Australian Pesticides and Veterinary Medicines Authority (www.apvma.gov.au) is responsible for registration of pesticides and maintains on-line databases containing current information on pesticides registered for use in Australia (PubCRIS database) or with minor-use permits for off-label use (Permits database). The PubCRIS database contains product names, registering company, active constituents, product category, and usually provides access to the product label.

Apple and pear growers benefit from the activities of species operating as a complex biological web that is largely unseen, is rarely factored into economic assessments, and is often not appreciated until the ability to manage existing pests and diseases as part of an IPDM program is disrupted by changes in production practices resulting from poor choice of pesticides and/or incursions of new pests, diseases and weeds.

The risks to the IPDM program can be addressed by implementing biosecurity measures such as those presented in Chapter 4 and by improving knowledge of the non-target impacts of the various pesticides available.

Implementation of IPDM has created greater awareness of the need for understanding the non-target effects of pesticides. The registration process requires data on environmental fate, toxicity to bees and a range of environmental indicator species but currently there is little information provided on toxicity and sub-lethal effects on biocontrol agents and generalist predators and parasitoids.

Various organisations have compiled data in an ad-hoc way and there are efforts underway to standardise testing methods but there are still large gaps in knowledge about sublethal effects.

This chapter presents lists of active ingredients registered for use on apples and pears (Tables 1-3), and where known, the non-target impacts of those ingredients (Tables 4-6). Although most specialist biocontrol agents available in Australia were introduced from overseas to control non-native pest species, they may be different strains to those used in other countries and therefore some of the published results of pesticide toxicity testing may not be applicable to strains used in Australia. The information provided in this chapter is a combination of published Australian data but if no Australian data was available overseas data was used. If discrepancies between different sources existed a conservative score in favour of the biocontrol agent was allocated as a safety margin. It should be used only as a guide to assist with planning strategies to encourage establishment of biological control agents and generalist predators. There are strict regulations governing importation of biological control agents, and Australian fruitgrowers should only purchase biological control agents from reputable commercial Australian suppliers such as members of the Australian Biological Control Association Inc. (www.goodbugs.org.au). Those suppliers will generally have conducted limited pesticide testing and should be able to provide advice on which pesticides to avoid or how long to wait after applying particular pesticides before you introduce the biocontrol agents into your orchard.

Trade names of the products are not given because the actual products have not all been tested, and there are too many products to list. There were, at the time of writing, 300 insecticide or miticide products, 167 fungicide or bactericide products, 445 herbicide products and 81 plant growth regulator products registered on the APVMA PubCRIS database for use on apples and pears in Australia. This reduced to 78, 48, and 47 active ingredients for insecticides, fungicides, and herbicides respectively. Further reductions could occur if standardised names (instead of synonyms) for active ingredients appeared in the database. Products containing the same active ingredients are not necessarily registered for the same target uses or even the same crop types ("hosts" in the terminology used in PubCRIS). There are 20 "host" categories relevant to fungicides or bactericides (Table 1); 16 for insecticides or miticides (Table 2); and 34 for herbicides (Table 3). As a result, PubCRIS is not easy to use and the results need to be checked against the product labels. Growers are advised to consult registered suppliers, agronomists, and pest management experts to find suitable products.

Table 1: Active ingredients of **Fungicide and Bactericide** products registered for use on apples and pears in Australia as at 26/August/2020. Source APVMA PubCRIS. Active ingredients and "host" crops are presented as they appear in PubCRIS. Although more than one active ingredient may be present in a registered product this table presents each active ingredient as a separate entity.

Fungicide or Bactericide	**Apple**												**Pear**					**Pome fruit**		
Active ingredients	APPLE	CROFTON APPLE	DEMOCRAT APPLE	APPLE CROP = APPLE ORCHARD	APPLE - SUNDOWNER	APPLE - GOLDEN DELICIOUS - POST HARVEST	APPLE - GRANNY SMITH - POST-HARVEST DIP	APPLE - JONATHAN - POST-HARVEST DIP	APPLE - LADY WILLIAMS - POST-HARVEST DIP	APPLE - POST-HARVEST DIP	APPLE - RED DELICIOUS - POST-HARVEST DIP	BONZA APPLE - POST-HARVEST	NASHI PEAR	NASHI PEAR (NIJISSEIKI) - POST-HARVEST	PEAR	PEAR - PACKHAMS TRIUMPH - POST HARVEST	PEAR - POST-HARVEST DIP	POME FRUIT	POME FRUIT - POST-HARVEST DIP	FRUIT CROP OR TREE
BOSCALID	■														■					
BUPIRIMATE	■																			
CAPTAN	■			■											■					
COPPER (CU) PRESENT AS CUPRIC HYDROXIDE	■														■					
COPPER (CU) PRESENT AS TRIBASIC COPPER SULPHATE	■														■					
COPPER AS COPPER AMMONIUM ACETATE	■														■					
COPPER AS CUPRIC (II) HYDROXIDE	■																			
COPPER PRESENT AS A CUPRIC AMMONIUM COMPLEX	■														■					

Fungicide or Bactericide	Apple												Pear					Pome fruit		
Active ingredients	APPLE	CROFTON APPLE	DEMOCRAT APPLE	APPLE CROP = APPLE ORCHARD	APPLE - SUNDOWNER	APPLE - GOLDEN DELICIOUS - POST HARVEST	APPLE - GRANNY SMITH - POST-HARVEST DIP	APPLE - JONATHAN - POST-HARVEST DIP	APPLE - LADY WILLIAMS - POST-HARVEST DIP	APPLE - POST-HARVEST DIP	APPLE - RED DELICIOUS - POST-HARVEST DIP	BONZA APPLE - POST-HARVEST	NASHI PEAR	NASHI PEAR (NIJISSEIKI) - POST-HARVEST	PEAR	PEAR - PACKHAMS TRIUMPH - POST HARVEST	PEAR - POST-HARVEST DIP	POME FRUIT	POME FRUIT - POST-HARVEST DIP	FRUIT CROP OR TREE
COPPER PRESENT AS COPPER AMMONIUM COMPLEX	■														■					
COPPER PRESENT AS COPPER OXYCHLORIDE	■														■			■		
COPPER PRESENT AS COPPER OXYCHLORIDE & COPPER HYDROXIDE	■														■					
COPPER PRESENT AS CUPROUS OXIDE	■														■					
CYPRODINIL	■														■					
DIPHENYLAMINE		■	■			■	■	■	■		■	■		■		■				
DITHIANON	■														■					
DODINE	■														■					
FLUAZINAM	■																			
FLUOPYRAM	■														■					
FLUXAPYROXAD	■																			
FOSETYL-ALUMINIUM	■																			
HEXACONAZOLE	■														■					
IMAZALIL	■														■					

Fungicide or Bactericide	Apple												Pear					Pome fruit		
Active ingredients	APPLE	CROFTON APPLE	DEMOCRAT APPLE	APPLE CROP = APPLE ORCHARD	APPLE - SUNDOWNER	APPLE - GOLDEN DELICIOUS - POST HARVEST	APPLE - GRANNY SMITH - POST-HARVEST DIP	APPLE - JONATHAN - POST-HARVEST DIP	APPLE - LADY WILLIAMS - POST-HARVEST DIP	APPLE - POST-HARVEST DIP	APPLE - RED DELICIOUS - POST-HARVEST DIP	BONZA APPLE - POST-HARVEST	NASHI PEAR	NASHI PEAR (NIJISSEIKI) - POST-HARVEST	PEAR	PEAR - PACKHAMS TRIUMPH - POST HARVEST	PEAR - POST-HARVEST DIP	POME FRUIT	POME FRUIT - POST-HARVEST DIP	FRUIT CROP OR TREE
IMAZALIL PRESENT AS BISULPHATE	■														■					
IMAZALIL PRESENT AS THE SULFATE	■									■					■		■			
IPRODIONE	■									■					■		■		■	
ISOPYRAZAM	■														■					
KRESOXIM-METHYL	■														■					
MANCOZEB	■														■			■		
MEFENTRIFLUCONAZOLE	■																			
MYCLOBUTANIL	■														■					
PENCONAZOLE	■			■											■					
PENTHIOPYRAD	■												■		■			■		
POTASSIUM BICARBONATE	■																			
POTASSIUM SILICATE	■																			
PYRACLOSTROBIN	■														■					
PYRIMETHANIL	■														■					
SULFUR (S) AS WETTABLE SULFUR	■														■					
SULFUR (S) PRESENT AS	■														■					■

Fungicide or Bactericide	Apple												Pear					Pome fruit		
Active ingredients	APPLE	CROFTON APPLE	DEMOCRAT APPLE	APPLE CROP = APPLE ORCHARD	APPLE - SUNDOWNER	APPLE - GOLDEN DELICIOUS - POST HARVEST	APPLE - GRANNY SMITH - POST-HARVEST DIP	APPLE - JONATHAN - POST-HARVEST DIP	APPLE - LADY WILLIAMS - POST-HARVEST DIP	APPLE - POST-HARVEST DIP	APPLE - RED DELICIOUS - POST-HARVEST DIP	BONZA APPLE - POST-HARVEST	NASHI PEAR	NASHI PEAR (NIJISSEIKI) - POST-HARVEST	PEAR	PEAR - PACKHAMS TRIUMPH - POST HARVEST	PEAR - POST-HARVEST DIP	POME FRUIT	POME FRUIT - POST-HARVEST DIP	FRUIT CROP OR TREE
POLYSULFIDE SULFUR	■														■					■
SULFUR AS THIOSULFATE	■														■					
TEBUCONAZOLE	■																			
THIABENDAZOLE	■														■					
THIRAM				■											■					
TRIFLOXYSTROBIN	■														■			■		
ZINC EDTA	■														■					
ZIRAM	■														■			■		

Table 2: Active ingredients of **Insecticide and acaricide** products registered for use on apples and pears in Australia as at 26/August/ 2020. Source APVMA PubCRIS. Active ingredients and "host" crops are presented as they appear in PubCRIS. Although more than one active ingredient may be present in a registered product this table presents each active ingredient as a separate entity.

Insecticides and acaricides	**Apple**							**Pear & Quince**						**Pome Fruit**		
Active ingredients	APPLE	APPLE TREE	APPLE - STARK CRIMSON	APPLE CROP = APPLE ORCHARD	APPLE ORCHARD	APPLE - DORMANT TREATMENT	DORMANT APPLE	NASHI PEAR	NASHI (ASIAN PEAR) - NIJISSEIKI	PEAR	PEAR ORCHARD	DORMANT PEAR	QUINCE	POME FRUIT	POME FRUIT TREE	FRUIT CROP
(E,E) 8,10 DODECADIEN-1-OL	■			■				■	■	■	■		■			
1-DODECANOL	■							■		■			■			
2-METHYL-1-BUTANOL	■							■		■						
3-METHYL-1-BUTANOL	■							■		■						
ABAMECTIN	■									■						
ACETALDEHYDE	■							■		■						
ACETAMIPRID	■									■						
ALPHA-CYPERMETHRIN	■									■				■		
BIFENAZATE	■									■						
BIFENTHRIN	■			■	■					■	■					
BUPROFEZIN										■						
CARBARYL	■									■				■		■
CARPOPHILUS AGGREGATION PHEROMONES	■							■		■						
CHLORANTRANILIPROLE	■							■		■				■		
CHLORPYRIFOS	■			■	■					■	■			■		
CLOFENTEZINE				■						■						
CLOTHIANIDIN	■									■				■		

Insecticides and acaricides	Apple							Pear & Quince						Pome Fruit		
Active ingredients	APPLE	APPLE TREE	APPLE - STARK CRIMSON	APPLE CROP = APPLE ORCHARD	APPLE ORCHARD	APPLE - DORMANT TREATMENT	DORMANT APPLE	NASHI PEAR	NASHI (ASIAN PEAR) - NIJISSEIKI	PEAR	PEAR ORCHARD	DORMANT PEAR	QUINCE	POME FRUIT	POME FRUIT TREE	FRUIT CROP
CYCLANILIPROLE	■															
CYDIA POMONELLA GRANULOSIS VIRUS	■									■						
DIATOMACEOUS EARTH		■														
DIAZINON	■			■		■	■			■		■				
DIMETHOATE																
DODECENOL ACETATE - 8 Z	■							■	■	■			■			
DODECENYL ACETATE - 8 E	■							■	■	■			■			
DODECENYL ACETATE - 8 Z	■							■	■	■			■			
E,E-9,11-TETRADECADIEN-1-YL ACETATE	■															
E-11-TETRADECEN-1-YL ACETATE	■															
ETHANOL	■							■		■						
ETHYL ACETATE	■							■		■						
FENBUTATIN OXIDE	■									■						
FENITROTHION	■															
FENOXYCARB	■									■						
FLONICAMID	■									■						
HEXYTHIAZOX				■						■						
IMIDACLOPRID	■															
INDOXACARB	■							■		■						
INDOXACARB (25:75)	■							■		■						

Insecticides and acaricides	Apple							Pear & Quince						Pome Fruit		
Active ingredients	APPLE	APPLE TREE	APPLE - STARK CRIMSON	APPLE CROP = APPLE ORCHARD	APPLE ORCHARD	APPLE - DORMANT TREATMENT	DORMANT APPLE	NASHI PEAR	NASHI (ASIAN PEAR) - NIJISSEIKI	PEAR	PEAR ORCHARD	DORMANT PEAR	QUINCE	POME FRUIT	POME FRUIT TREE	FRUIT CROP
INDOXACARB (96:4)	■							■		■						
MALATHION	■			■						■				■		
METHANOL	■									■						
METHOMYL	■									■						
METHOXYFENOZIDE	■									■				■		
NOVALURON	■									■						
NUCLEAR POLYHEDROSIS VIRUS OF HELICOVERPA ARMIGERA	■							■		■				■		
NUCLEAR POLYHEDROSIS VIRUS OF HELICOVERPA ZEA	■							■								
OMETHOATE	■															
PARAFFIN OIL	■									■				■		
PARAFFINIC OIL	■									■				■		
PETROLEUM OIL	■									■				■	■	
PIPERONYL BUTOXIDE		■														
PIRIMICARB	■															
PROPARGITE	■									■						
PYRETHRINS		■														
SEC BUTANOL	■							■		■						
S-INDOXACARB	■							■		■						
SPINETORAM								■						■		
SPINOSAD	■		■					■		■			■	■		

Insecticides and acaricides	Apple							Pear & Quince						Pome Fruit		
Active ingredients	APPLE	APPLE TREE	APPLE - STARK CRIMSON	APPLE CROP = APPLE ORCHARD	APPLE ORCHARD	APPLE - DORMANT TREATMENT	DORMANT APPLE	NASHI PEAR	NASHI (ASIAN PEAR) - NIJISSEIKI	PEAR	PEAR ORCHARD	DORMANT PEAR	QUINCE	POME FRUIT	POME FRUIT TREE	FRUIT CROP
SULFUR (S) PRESENT AS POLYSULFIDE SULFUR	■									■						
SULFUR AS THIOSULFATE	■									■						
TAU-FLUVALINATE	■															
TEBUFENOZIDE	■									■						
TETRADECAN-1-OL	■							■		■			■			
TETRADECANOL	■							■		■			■			
THIACLOPRID	■													■		
Z,8 DODECENOL	■							■					■			

Table 3: Active ingredients of **Herbicide** products registered for use in apple and pear production in Australia as at 26/August/ 2020. Source APVMA PubCRIS. Active ingredients and "host" crops are presented as they appear in PubCRIS. Although more than one active ingredient may be present in a registered product this table presents each active ingredient as a separate entity.

Herbicide	Apple										Nashi, Pear, or Quince												Pome Fruit					Fruit Tree				Orchard		
Active ingredient	APPLE	APPLE ORCHARD OVER 2 YRS OLD	APPLE OVER 3 YRS OLD	APPLE OVER 4 YRS OLD	APPLE - PINK LADY	APPLE CROP = APPLE ORCHARD	APPLE ORCHARD	APPLE - DORMANT TREATMENT	DORMANT APPLE	DORMANT APPLE OVER 3 YRS OLD	NASHI PEAR	NASHI (ASIAN PEAR) - NIJISSEIKI	NASHI PEAR ORCHARD	NASHI PEAR -DORMANT-OVER 3 YRS OLD	PEAR	PEAR ORCHARD	PEAR - OVER 2 YRS OLD	PEAR OVER 4 YRS OLD	DORMANT PEAR	DORMANT PEAR OVER 3 YRS OLD	QUINCE	QUINCE - DORMANT - OVER 3 YRS OLD	POME FRUIT	POME FRUIT ORCHARD	POME FRUIT ORCHARD OVER 2 YRS OLD	POME FRUIT, OVER 3 YRS OLD	POME FRUIT - DORMANT	TREEFRUIT	TREEFRUIT OVER 3 YRS OLD	FRUIT TREE-DORMANT-OVER 3 YRS OLD	NON- BEARING FRUIT TREE	ORCHARD - ESTABLISHED	ORCHARD - GENERAL	ORCHARD - SEE LABEL
2,2-DPA PRESENT AS THE SODIUM SALT				■														■																
ASULAM PRESENT AS THE SODIUM SALT							■																											
CARFENTRAZONE-ETHYL	■														■								■					■						
DICHLOBENIL							■																											
DIQUAT																																		■
DIQUAT DIBROMIDE																																	■	■
DIQUAT PRESENT AS DIQUAT BROMIDE																																		■

Herbicide	Apple										Nashi, Pear, or Quince												Pome Fruit					Fruit Tree				Orchard		
Active ingredient	APPLE	APPLE ORCHARD OVER 2 YRS OLD	APPLE OVER 3 YRS OLD	APPLE OVER 4 YRS OLD	APPLE - PINK LADY	APPLE CROP = APPLE ORCHARD	APPLE ORCHARD	APPLE - DORMANT TREATMENT	DORMANT APPLE	DORMANT APPLE OVER 3 YRS OLD	NASHI PEAR	NASHI (ASIAN PEAR) - NIJISSEIKI	NASHI PEAR ORCHARD	NASHI PEAR -DORMANT-OVER 3 YRS OLD	PEAR	PEAR ORCHARD	PEAR - OVER 2 YRS OLD	PEAR OVER 4 YRS OLD	DORMANT PEAR	DORMANT PEAR OVER 3 YRS OLD	QUINCE	QUINCE - DORMANT - OVER 3 YRS OLD	POME FRUIT	POME FRUIT ORCHARD	POME FRUIT ORCHARD OVER 2 YRS OLD	POME FRUIT, OVER 3 YRS OLD	POME FRUIT - DORMANT	TREEFRUIT	TREEFRUIT OVER 3 YRS OLD	FRUIT TREE-DORMANT-OVER 3 YRS OLD	NON- BEARING FRUIT TREE	ORCHARD - ESTABLISHED	ORCHARD - GENERAL	ORCHARD - SEE LABEL
FLUAZIFOP-P PRESENT AS THE BUTYL ESTER	■														■																			
FLUMETSULAM																																		
GLUFOSINATE-AMMONIUM																								■										
GLYPHOSATE																							■			■								
GLYPHOSATE AS AMMONIUM SALT																							■			■								
GLYPHOSATE AS ISOPROPYLAMINE AND POTASSIUM SALTS																							■											
GLYPHOSATE ISOPROPYLAMINE SALT																										■								
GLYPHOSATE MONOETHANOLAMINE SALT																							■											

Herbicide	Apple										Nashi, Pear, or Quince												Pome Fruit					Fruit Tree				Orchard		
Active ingredient	APPLE	APPLE ORCHARD OVER 2 YRS OLD	APPLE OVER 3 YRS OLD	APPLE OVER 4 YRS OLD	APPLE - PINK LADY	APPLE CROP = APPLE ORCHARD	APPLE ORCHARD	APPLE - DORMANT TREATMENT	DORMANT APPLE	DORMANT APPLE OVER 3 YRS OLD	NASHI PEAR	NASHI (ASIAN PEAR) - NIJISSEIKI	NASHI PEAR ORCHARD	NASHI PEAR -DORMANT-OVER 3 YRS OLD	PEAR	PEAR ORCHARD	PEAR - OVER 2 YRS OLD	PEAR OVER 4 YRS OLD	DORMANT PEAR	DORMANT PEAR OVER 3 YRS OLD	QUINCE	QUINCE - DORMANT - OVER 3 YRS OLD	POME FRUIT	POME FRUIT ORCHARD	POME FRUIT ORCHARD OVER 2 YRS OLD	POME FRUIT, OVER 3 YRS OLD	POME FRUIT - DORMANT	TREEFRUIT	TREEFRUIT OVER 3 YRS OLD	FRUIT TREE-DORMANT-OVER 3 YRS OLD	NON- BEARING FRUIT TREE	ORCHARD - ESTABLISHED	ORCHARD - GENERAL	ORCHARD - SEE LABEL
GLYPHOSATE PRESENT AS THE ISOPROPYLAMINE SALT																							■	■		■								
GLYPHOSATE PRESENT AS THE MONO-AMMONIUM SALT																							■			■								
GLYPHOSATE AS THE MONO-AMMONIUM SALT AND GLYPHOS																							■											
GLYPHOSATE PRESENT AS THE MONOETHANOLAMINE SALT																							■											
GLYPHOSATE PRESENT AS THE POTASSIUM SALT																							■	■										
HALOXYFOP PRESENT AS	■						■				■		■		■	■																	■	■

Herbicide	Apple										Nashi, Pear, or Quince												Pome Fruit					Fruit Tree				Orchard		
Active ingredient	APPLE	APPLE ORCHARD OVER 2 YRS OLD	APPLE OVER 3 YRS OLD	APPLE OVER 4 YRS OLD	APPLE - PINK LADY	APPLE CROP = APPLE ORCHARD	APPLE ORCHARD	APPLE - DORMANT TREATMENT	DORMANT APPLE	DORMANT APPLE OVER 3 YRS OLD	NASHI PEAR	NASHI (ASIAN PEAR) - NIJISSEIKI	NASHI PEAR ORCHARD	NASHI PEAR -DORMANT-OVER 3 YRS OLD	PEAR	PEAR ORCHARD	PEAR - OVER 2 YRS OLD	PEAR OVER 4 YRS OLD	DORMANT PEAR	DORMANT PEAR OVER 3 YRS OLD	QUINCE	QUINCE - DORMANT - OVER 3 YRS OLD	POME FRUIT	POME FRUIT ORCHARD	POME FRUIT ORCHARD OVER 2 YRS OLD	POME FRUIT, OVER 3 YRS OLD	POME FRUIT - DORMANT	TREEFRUIT	TREEFRUIT OVER 3 YRS OLD	FRUIT TREE-DORMANT-OVER 3 YRS OLD	NON- BEARING FRUIT TREE	ORCHARD - ESTABLISHED	ORCHARD - GENERAL	ORCHARD - SEE LABEL
HALOXYFOP-P METHYL ESTER	■						■				■		■		■	■																	■	■
HALOXYFOP PRESENT AS THE HALOXYFOP-R METHYL ESTER	■						■				■	■	■		■	■																	■	
HALOXYFOP-P METHYL ESTER	■										■				■																			
HALOXYFOP-P PRESENT AS THE HALOXYFOP-P-METHYL	■						■				■		■		■	■																	■	
HALOXYFOP-P PRESENT AS THE METHYL ESTER	■					■					■				■	■																	■	
HALOXYFOP-R METHYL ESTER	■										■				■																			
METAMITRON	■																																	
NONANOIC ACID					■																											■		

Herbicide	Apple										Nashi, Pear, or Quince												Pome Fruit					Fruit Tree				Orchard		
Active ingredient	APPLE	APPLE ORCHARD OVER 2 YRS OLD	APPLE OVER 3 YRS OLD	APPLE OVER 4 YRS OLD	APPLE - PINK LADY	APPLE CROP = APPLE ORCHARD	APPLE ORCHARD	APPLE - DORMANT TREATMENT	DORMANT APPLE	DORMANT APPLE OVER 3 YRS OLD	NASHI PEAR	NASHI (ASIAN PEAR) - NIJISSEIKI	NASHI PEAR ORCHARD	NASHI PEAR -DORMANT-OVER 3 YRS OLD	PEAR	PEAR ORCHARD	PEAR - OVER 2 YRS OLD	PEAR OVER 4 YRS OLD	DORMANT PEAR	DORMANT PEAR OVER 3 YRS OLD	QUINCE	QUINCE - DORMANT - OVER 3 YRS OLD	POME FRUIT	POME FRUIT ORCHARD	POME FRUIT ORCHARD OVER 2 YRS OLD	POME FRUIT, OVER 3 YRS OLD	POME FRUIT - DORMANT	TREEFRUIT	TREEFRUIT OVER 3 YRS OLD	FRUIT TREE-DORMANT-OVER 3 YRS OLD	NON- BEARING FRUIT TREE	ORCHARD - ESTABLISHED	ORCHARD - GENERAL	ORCHARD - SEE LABEL
NORFLURAZON	■														■								■											
ORYZALIN	■										■				■								■								■			
OXYFLUORFEN	■		■					■	■	■	■			■	■				■	■	■	■	■			■	■		■	■				
PARAQUAT DICHLORIDE																																	■	
PARAQUAT PRESENT AS PARAQUAT DICHLORIDE																																	■	■
SIMAZINE	■	■				■									■		■						■		■									
SIMAZINE AND RELATED TRIAZINES	■														■																			

Resistance management

CropLife Australia maintains pesticide resistance management review groups that link with international resistance action committees to standardise labelling and terminology used in the promotion of resistance management strategies. The development of resistance to pesticides by insect pests, plant pathogens, and weeds generally occurs through misuse or overuse of a pesticide that leads to heritable changes in pest populations and results in repeated failure of a pesticide when used according to the label directions. Pesticides are grouped into classes (Insecticides and acaricides, fungicides, herbicides, etc) and within those classes are given codes indicating their mode of action (MoA). Resistance management strategies are based around alternations or sequences of different modes of action. Resistance Management Strategies for insecticides, fungicides and herbicides used in apple and pear production are available on the CropLife Australia website www.croplife.org.au and the MoA of active ingredients are listed in tables 4-6 along with the impact of those active ingredients on important beneficial organisms that provide ecosystem services such as pollination and biological control of pests in orchards. It is important to protect those beneficial species, not just because of the ecosystem services they provide, but also because they can contribute to management of pesticide resistant pests. It is usually easier to prevent or delay the development of resistance than it is to revert a resistant population to susceptibility.

Insects can develop different types of resistance.

- ***Metabolic resistance*** allows insects to detoxify, destroy, or quickly rid themselves of the toxin. The enzymes involved in these processes may also be broad-spectrum and degrade many different insecticides, leading to cross-resistance.
- ***Target site resistance*** occurs when the insect develops a modification to the enzyme, or other binding site targeted by the insecticide, that reduces the ability of the insecticide to affect the insect.
- ***Penetration resistance*** results from changes in the insect cuticle that slows absorption of the chemical and often occurs in tandem with other forms of resistance.
- ***Behavioural resistance*** occurs when the insect can detect the presence of the toxin and avoid it by either leaving the sprayed area or dodging around droplet residues.
- ***Compounds within the same chemical sub-group usually share the same MoA***

Fungal pathogens can also develop different types of resistance depending on their MoA and the genetic structure of the pathogens being targeted.

- Fungal populations can contain individuals with natural resistance which become more prevalent as selection pressure from repeated applications of the same fungicide or fungicides with the same MoA.
- Risk of resistance developing depends on the chemical group and the pathogen.
- Specific strategies have been developed to help reduce the risk.
- The most basic strategy involves rotation of fungicides from different activity groups but this could lead to cross resistance or resistance to multiple chemical groups if not done properly.
- Targeted applications against specific development stages, using the appropriate delivery method, timing, rates and coverage as provided on the label are important components of any resistance strategy.
- Fungal pathogens are generally very sensitive to environmental conditions, especially humidity and length of wetting periods. Manipulation of the growing environment can improve management of pathogens and pests.
- ***Resistance management strategies*** have been developed for fungicides targeting apple and pear scab:
    - Group 3- DMIs (demethylation inhibitors)
    - Group 7 – SDHIs (succinate dehydrogenase inhibitors
    - Group 9 – Anilinopyrimidine
    - Group 11 – QoI (quinone outside inhibitor)
    - Group U12 – Cell membrane disruption fungicides

Herbicide resistance involves two main mechanisms

- Target site mechanisms in which the plant protein that normally binds to the herbicide changes in ways that prevent the herbicide from disrupting the plant biochemical pathway.
- Non target site resistance mechanisms that prevent sufficient herbicide reaching the target site
- Group A and Group B herbicides are high resistance risk herbicides
- Groups C, D, F, G, H, I, J, K, L, M, N, Q, and Z herbicides are moderate risk herbicides.
- Refer to Chapter 5 Integrated Weed Management for more detail, including cultural methods for control of weeds

Effects of Pesticides on Beneficial Species

Table 4: Toxicity of insecticide and miticide active ingredients towards beneficial species in pome fruit orchards. Ratings are given by letters within the coloured cells (L=low; M=moderate; H=high) and where numbers are present in the cells these represent number of weeks after application that effects last. Empty cells indicate lack of data.

Chemical			Predatory mites				Parasitoid wasps			Other predatory insects					Others		
Active ingredients	**Mode of action Group**	**Chemical sub-group**	**Galendromus (Typhlodromus) occidentalis**	**Galendromus (Typhlodromus) pyri**	**Phytoseiulus persimilis**	**Neoseiulus californicus**	**Aphelinus mali**	**Mastrus ridens**	**Trichogramma spp.**	**Lacewings**	**Ladybirds**	**Syrphid (Hover) flies**	**Cryptolaemus montrouzieri**	**Predatory bugs**	**Spiders**	**Earwigs**	**Bees**
ABAMECTIN	6	6	M	M	M	H		L-M	H (2)	H	M-H			H	H	L	H
ACETAMIPRID	4	4A				M-H	L	L-M									M-H
ALPHA-CYPERMETHRIN	3	3A	H (4)		H (>4)	H			H (4)	H (4)		H			H	H	H
BIFENAZATE	20	20	H		H					L	L			L			M
BIFENTHRIN	3	3A	H	M-H	H	H			H (4)	H (4)		H			H		H
BUPROFEZIN	16	16	L		L	L	L		L	L	M-H	L	M	H			L
CARBARYL	1	1A	L-M	L	L	M-H	H		H (3)	H	H	H	H (4)	H	H	H	H
CHLORANTRANILIPROLE	28	28	L		L	L	L	L-M	L	L	H		H	L	L		L
CHLORPYRIFOS	1	1B	L-M	L	M	M-H	H		H (3)	H	L-M	H	H 2-3	L-M	H	H	H
CLOFENTEZINE	10	10A	L		L	L			L	L	L-M			L			L
CLOTHIANIDIN	4	4A	H		H	H		H									H
CYCLANILIPROLE	28	28															H
DIAZINON	1	1B	L		M	M	H		H (3)	H	H		M	H	H		H
DIMETHOATE	1	1B	H (1)	H (1)	H (3)	M-H	L		H (3)	H (1)	H (1)	H					H
FENBUTATIN OXIDE	12	12B	L		L	L	L		L		L		L				L
FENITROTHION	1	1B				M											H
FENOXYCARB	7	7B	L		L	L	L	L	L	L			M			L	M
FLONICAMID	9	9C		H	L	L				L			L				L-M
HEXYTHIAZOX	10	10A	L	L	L	L	L		L		L		L	L			L
IMIDACLOPRID	4	4A	L		M	M-H	H		L-H (2)	H (4)			H (3)			M	H
INDOXACARB	22	22A	L		L	L	L	H	L			L			H	H	H
MALATHION	1	1B	M	M	M	M			H (3)	H		H	H (4)		H		H
METHOMYL	1	1A	M	H	H	M			H	H	M-H	H	H		H		H
METHOXYFENOZIDE	18	18	L		L	L	L		L	L	L		L	H	L		L
NOVALURON	15	15				L											L
OMETHOATE	1	1B				H	M					H					H
PARAFFIN or PETROLEUM OILS	OIL		L-M	L-M	L-M	L-M			M	M	L	L-H	L				L-M
PIRIMICARB	1	1A	L		L-M	L	L		M	L	L		L	L		L	M
PROPARGITE	12	12C	L-M		L-M	M			L	L	L		L	L		L	L
PYRETHRINS	3	3A	H	L-H	H (3)	H	H (2)		H (2)	H	H	H	H	H	H	H	H
SPINETORAM	5	5				H	H	H			M			M			H
SPINOSAD	5	5	L		M	M-H	M-H		M			H		M	L		H
SULFOXAFLOR	4	4C		L	L	L	M			L			M				H
SULFUR (S) AS POLYSULFIDE SULFUR	M	M3	M		M		M-H		H			L		L-M	H		L-M
SULFUR AS THIOSULFATE	M	M3	M		M		M-H					L			H		L-M
TAU-FLUVALINATE	3	3A	H (>4)	M-H	H (>4)	H	L		H (4)	H	H	H	H	H	H	M	L-M
TEBUFENOZIDE	18	18	L		L		L		L	L	L		L			L	L
THIACLOPRID	4	4A	L		L		M-H		L								L

Table 5: Toxicity of fungicide active ingredients towards beneficial species in pome fruit orchards. Ratings are given by letters within the coloured cells (L=low; M=moderate; H=high) and where numbers are present in the cells these represent number of weeks after application that effects last. Empty cells indicate lack of data.

Chemical			Predatory mites				Parasitoid wasps			Other predatory insects					Others		
Active ingredients	**Mode of action Group**	**Chemical sub-group**	**Galendromus (Typhlodromus) occidentalis**	**Galendromus (Typhlodromus) pyri**	**Phytoseiulus persimilis**	**Neoseiulus californicus**	**Aphelinus mali**	**Mastrus ridens**	**Trichogramma spp.**	**Lacewings**	**Ladybirds**	**Syrphid (Hover) flies**	**Cryptolaemus montrouzieri**	**Predatory bugs**	**Spiders**	**Earwigs**	**Bees**
BOSCALID	7					L											L
BUPIRIMATE	8					L										L	L
CAPTAN	M4					L	L										M
COPPER AS CUPRIC HYDROXIDE	M1																L
COPPER AS TRIBASIC COPPER SULPHATE	M1																L
COPPER AS COPPER AMMONIUM ACETATE	M1																L
COPPER AS CUPRIC AMMONIUM COMPLEX	M1																L
COPPER AS COPPER OXYCHLORIDE	M1					L-M											L
COPPER AS COPPER OXYCHLORIDE & COPPER HYDROXIDE	M1																L
COPPER AS CUPROUS OXIDE	M1																L
CYPRODINIL	9					L		L-M									L
DITHIANON	M9						L									L	L
DODINE	U12					L	L									L	L
FLUAZINAM	29																M
FLUOPYRAM	7																L
FLUXAPYROXAD	7																L
FOSETYL-ALUMINIUM	33	P07				L											L
HEXACONAZOLE	3					L											L
IPRODIONE	2					L											L-M
ISOPYRAZAM	7																L
KRESOXIM-METHYL	11					L	L										L
MANCOZEB	M3		L	H	M-H	L-M	L	L-M	H	M-H	M-H		L			L	L
MEFENTRIFLUCONAZOLE	3																L
MYCLOBUTANIL	3						L										L
PENCONAZOLE	3					L										L	L
PENTHIOPYRAD	7																L
POTASSIUM BICARBONATE	M2				H												L
POTASSIUM SILICATE	M2				H												L
PYRACLOSTROBIN	11																L
PYRIMETHANIL	9					L	L										L
SULFUR AS WETTABLE SULFUR	M2		M-H							L	L-H	L	M-H	L	L		L
SULFUR AS POLYSULFIDE SULFUR	M2		M-H							L	L-H	L	M-H	L	L		L
SULFUR AS THIOSULFATE	M2		M-H							L	L-H	L	M-H	L	L		L
TEBUCONAZOLE	3																L
THIRAM	M3															L	L
TRIFLOXYSTROBIN	11		L	L	L												L
ZIRAM	M3		L	M-H	L			L-M									L-M

Table 6: Toxicity of herbicide active ingredients towards beneficial species in pome fruit orchards. Ratings are given by letters within the coloured cells (L=low; M=moderate; H=high) and where numbers are present in the cells these represent number of weeks after application that effects last. Empty cells indicate lack of data.

Chemical		**Beneficials**			
Active ingredients	**Mode of action Group**	**Predatory mites**	**Carabid beetles**	**General beneficials**	**Bees**
2,2-DPA PRESENT AS THE SODIUM SALT	J	H			
ASULAM PRESENT AS THE SODIUM SALT	R				L
CARFENTRAZONE-ETHYL	G				L
DICHLOBENIL	O				L
DIQUAT	L		H		
DIQUAT DIBROMIDE	L				L
FLUAZIFOP-P PRESENT AS THE BUTYL ESTER	A			H	L
GLUFOSINATE-AMMONIUM	N				L
GLYPHOSATE	M		L		L
HALOXYFOP-P METHYL ESTER	A				
HALOXYFOP-R METHYL ESTER	A				
NONANOIC ACID		H		H	L
NORFLURAZON	F				L
ORYZALIN	D				L
OXYFLUORFEN	G			H	L
PARAQUAT DICHLORIDE	L	H	L		M
SIMAZINE	C	L	L		L

Apart from non-target impact via direct contact with spray droplets and residues, beneficial species are also impacted by the effects of herbicides on ground cover vegetation that acts as a source of nectar, pollen, prey, or shelter. The impact on prey and shelter is particularly important for the generalist predatory Carabid beetles.

Chapter 7: Mating disruption

IPDM quick facts

- Insects use chemical cues to detect hosts, broadcast danger warnings, attract mates, and to aggregate in sheltered sites.
- Traps baited with sex pheromones, kairomones, or combinations of both, can be used to monitor insect populations
- Mating disruption dispensers are pest specific tools that, when used at appropriate spatial density, emit pheromones at concentrations that disrupt insect communication systems and cause delayed mating that in turn reduces the fecundity of female pest insects.
- Mating disruption works best on low populations of pests but can be used against higher populations as part of an IPDM program where complementary tactics such as releasing egg parasitoids or applying ovicidal pesticides to reduce egg hatch; use of entomopathogenic viruses, fungi, bacteria, or IPDM compatible pesticides to kill pest larvae; trapping of adult female pest insects; and parasitoid wasps to prey on overwintering larvae and pupae are used to lower pest populations to levels suitable for mating disruption.
- Mating disruption does not prevent mated females entering treated blocks from neighbouring untreated areas.
- Trapping adult moths in areas under mating disruption requires traps baited with higher pheromone loads than standard lures, and best results are achieved with combinations of pheromone and kairomones that work synergistically and attract both sexes of the pest.
- Different mating disruption products have different requirements for spatial density and distribution of dispensers; storage, preparation, application, and placement techniques; and it is critically important to read and understand the label before using the products.
- Mating disruption products need to be deployed before adult moths are present.
- Mating disruption products are species-specific and therefore have no side effects on species other than those on the label. This means that secondary or minor pests that were being controlled by broader spectrum pesticides may become more important until predator and parasitoid populations (that were impacted by the pesticides) recover and exert control.

Insect Communication

Most insects use emission and detection of chemicals as part of their communication system. Volatile chemicals produced by host plants (host plant volatiles or HPVs) are used by pest insects to find suitable plants on which to lay eggs. Some plants produce other volatile chemicals in response to attack by pests and many predatory insects use detection of those chemicals to indicate presence of prey. Some beetles produce chemicals (aggregation pheromones) to send a message to other members of their species that a good food source or a good shelter is available. Aphids and some other insects like bees and wasps produce alarm chemicals to warn other members of their population that danger is present. The discovery that many insects have a species-specific chemical signalling system based on sex pheromones that allow males and females to find one another, mate and produce a new generation has led to development of highly specific techniques that humans use to detect, monitor and control insect pests.

Commercially available products using artificially produced pheromones and host plant volatiles can be used to manage orchard pests in several ways:

- Sex pheromone traps are used in Australian apple and pear orchards to monitor population trends indicated by capture of male moths and use the data to forecast spray dates for
    - Codling moth
    - Lightbrown apple moth (LBAM) and
    - Oriental Fruit moth (OFM)
- Para-pheromones (male attractants of plant origin) are used to detect and monitor male fruit fly population trends.
- Aggregation pheromone traps are used to monitor, and control by mass-trapping, Carpophilus beetles.
- The introduced parasitoid wasp *Mastrus ridens* uses the larval aggregation pheromone produced by cocooning codling moth larvae, to locate and identify suitable hosts to parasitize.
- HPVs can be used to attract predatory species such as ladybirds and lacewings into orchards before pest populations become reach damaging levels.
- Sex pheromone dispensers that “flood” the orchard with pheromone are used as mating disruption products for control of codling moth, LBAM, and OFM
- Combining HPVs and pheromones in a single trap enhances capture of both male and female codling moths in orchards treated with mating disruption and reduces risk of under-estimating pest population size.

What is mating disruption?

When sex pheromones were first developed for monitoring of pest insects studies in which marked moths were released and then recaptured in pheromone baited traps at relatively large distances from the release sites led to the conclusion that male moths could detect very low concentrations of the pheromone compounds and follow a single scent trail to locate a specific female moth. This thinking supported establishment of widely separated traps in grids for monitoring population trends in orchards and development of action thresholds based on magnitude of male capture in the traps. A refinement of that approach was development of pheromone-mediated mating disruption in which a grid of powerful dispensers released relatively massive quantities of pheromone into an orchard to provide so many strong scent trails that the male moths becomes confused and unable to find females. The concept of false trail following leading to confusion and exhaustion of hapless males became accepted as the mechanism behind mating disruption as a pest management strategy. As researchers gained more experience with mating disruption new knowledge on insect behaviour and mechanisms of disruption developed. Different species appeared to be disrupted by different mechanisms and some exhibited different mechanisms at different times in the season. In some cases, competitive attraction between the pheromone dispensers (artificial point sources) and female moths (natural point sources) leading to false trail following explained the results. In other cases, sensory overload of the male moth's antennae and resultant over-excitation of the antennal lobe in the brain due to the high concentration of pheromone close to the dispensers was shown to shutdown the moth and take him out of action for the rest of the night. However, mated female moths could still be found in disrupted orchards. Further studies demonstrated that mating was delayed relative to that in non-disrupted orchards. The impact of delay was a reduction in fecundity which meant female moths laid fewer eggs and the rate of population increase declined. Insects are 'cold-blooded' and since their growth rate is dependent on temperature their lifespan is measured in physiological time (degree-days) rather than chronological time (days). The delay in mating is therefore measured as degree-days. Temperatures at which degree-days accumulate more quickly should result in greater delay in mating and therefore greater efficacy of mating disruption. For codling moth the most important mechanism for mating disruption appears to be competitive attraction, which suggests that higher densities of pheromone point sources should give better results than lower densities.

Most of the mating disruption products available in Australia are "passive" dispensers in that the pheromone release rate varies with temperature and they cannot be switched on and off to conserve their contents during periods when moths would not be active. Aerosol emitters actively release small particles of pheromone and can be programmed to release at only when moths would be active, such as evenings in the time a few hours before dusk until a few hours after dusk. Aerosol emitters against codling moth also work by competitive attraction but because the amount of pheromone released each "puff" creates a large plume dispersed by the wind in the surface layer of the orchard tree canopies the pheromone is deposited on and adheres to the leaves, which then act as addition point sources releasing pheromone. Research in the USA demonstrated that five Aerosol dispensers per hectare gave equivalent control of codling moth as 500-1000 passive dispensers per hectare.

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 which use these pheromones are effective only against the pest at which they're targeted. For example, products containing only codling moth pheromone affect codling moth, but not light brown apple moth, oriental fruit moth nor any other insect in the orchard. However, there are products available that contain, either mixed or in separate compartments, pheromones for control of both codling moth and OFM to be used where both species exist together in the same orchard block. Mating disruption agents have no effect on biological control agents (predacious mites, hover flies, Trichogramma etc.) 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 used in an IPDM program supporting biological control agents should allow for the number of insecticide applications to be reduced (but note the section on emergence of secondary pests below). New formulations of mating disruption products that can be applied mechanically, or that contain dispensers for two species, are reducing the cost of labour for application of dispensers. 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 which will lower the possibility of fruit being contaminated with insecticide residues provided that with-holding periods are followed.

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. Several factors need consideration.

Pest numbers. Mating disruption works best when pests are present in low numbers. Where pests are present in very high numbers it is important to work out why such a high population is present. It could be due to excessive pesticide use selecting an insecticide-resistant population. If this is the case then a combination of mating disruption and appropriately timed sprays of an insecticide with a different mode of action to those previously used should be considered, in conjunction with cultural controls such as orchard hygiene to clean up after harvest so that no, or very few, unsprayed fruit are left on the trees to be infested after harvest of the main crop. For example, leaving as few as 4-5 fruit per panel could result in an extra 500 codling moth or OFM larvae per hectare overwintering in the orchard. LBAM is not dependent on fruit, does not diapause over winter, and survives on ground cover plants like capeweed and a wide range of introduced shrubs and native plants, Mated females will probably be present before green tip so introducing egg parasitoids like Trichogramma in early spring when those LBAM females will be laying eggs on the fruit trees could be considered, before application of mating disruption. It is also possible to augment mating disruption by applying IPDM compatible insecticides.

Block shape and size. Mating disruption should not be used in blocks or contiguous areas of trees which are under 2 hectares unless they are isolated from other sources of the pest and preferably enclosed by windbreaks, or protected by hail netting, that reduces the effects of wind and helps contain the pheromone. Mating disruption does not work well in long thin blocks that have high perimeter: area ratios.

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. This effect can be reduced to some extent by higher loadings higher up the slope.

Wind and shelter. The pheromone concentration is diluted in windy or exposed blocks. Hill sites are often windy and present several potential problems. Pheromone is heavier than air and will tend to drift downhill. Most pest moths do not fly in turbulent windy conditions. Wind blowing up the windward side of a slope will often create a calm zone just over the top on the lee side but then creates a turbulent zone a little further down the slope where the wind direction may reverse. The calm zone on the lee side near the crest of the hill, combined with a potential reduction in pheromone concentration due to downhill drift, could provide good conditions for moth flight and mating. However, the reversal of wind direction due to turbulence may counter the pheromone drift. North and West facing slopes also experience surface winds travelling uphill (anabatic flow) as a result of warming during the day and, because such aspects tend to stay warmer longer the anabatic flow if strong enough may redistribute pheromone onto foliage higher up the slope. Slopes with a South or East aspect would be expected to be cooler and would experience katabatic (nocturnal downhill) flow earlier in the afternoon or evening so would probably be more at risk from poor performance of mating disruption. Wind also affects longevity of passive pheromone dispensers by increasing evaporation rate on the surface of the dispenser.

Trees. A uniform block with high levels of canopy cover (no gaps between tree canopies in the row) is better than one with many young, undeveloped, or missing trees.

Optimising the effectiveness of mating disruption

Numbers of dispensers and timing of application

There are now more than a dozen mating disruption products available for codling moth management and some of them are dual action in that they also target OFM. The various formulation types also have different requirements in terms of dispenser placement and the number of dispensers applied per hectare. As with any pesticide***, it is essential to read and understand the label before using the product***. The mating disruption dispensers must be set up well before the emergence of the first moths in spring. Records of monitoring from previous seasons can be used to calculate this date provided your traps had been in place early enough to detect first emergence. Since both codling moth and OFM are dependent on deciduous fruit trees as hosts they have synchronised their spring emergence to coincide with growth stages of their major hosts. The first-generation larvae of OFM target growing shoot tips and the moths that lay the eggs that produce those larvae start emerging when peaches are starting to flower. Mating disruption against OFM therefore needs to be in place from bud-swell if possible and preferably no later than start of flowering of peaches in late August-early September in most apple and pear growing areas in Australia. Codling moth mating disruption dispensers should be in place by spur burst and preferably no later than pink on pome fruit. Where combined codling moth and OFM mating disruption products are being used, the dispensers should be in place before OFM adults begin to emerge. Using the trees as indicators is usually more reliable than trying to forecast emergence based on historical pest monitoring data. Prediction of emergence date based on degree-day accumulation from mid-winter as used in the USA has not proven reliable in Australia probably because of our milder winters. The timing of application will vary between regions and application times from other districts should not be used. Where there is uncertainty contact your local horticultural consultants.

Length of effectiveness. 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 below) has indicated that moth populations are not under control, a late season insecticide application may be necessary. Release rates from passive dispensers varies as temperature fluctuates. Cooler conditions result in lower release rates, which is why passive dispensers need to be in place well before moths emerge, so that enough pheromone has deposited on leaves during the day to provide enough point sources around dusk to disrupt moths.

Effective application. When applying dispensers for mating disruption the objective is to create many relatively uniformly distributed point sources emitting pheromone across the block. Where there is greater risk of moth infestation the number of point sources (dispensers) per unit area should be higher. The product labels and associated technical bulletins provide detailed instructions for deployment that must be followed. Application methods for these products vary with the type of dispenser used. General hints that apply to all dispensers include:

- Draw up a good block plan before starting the job and conduct a briefing so that staff deploying the dispensers are clear on where the dispensers are to be located, how high in the tree canopy, and how to get them there without damaging the dispenser or the tree.
- For twist-tie type dispensers gently bend the dispenser around the branch and use one loose twist to attach them so that they move easily but cannot fall off. Tying too tightly can crack the casing, causing leakage of pheromone, or lead to girdling of the branch. Some products come with colour coding so that staff can distinguish between the old and new dispensers. This is particularly important if winter pruning was delayed and pruning is continuing in early spring.
- Dispensers should be placed high in the tree canopy because this is where calling females will generally be located. Provision of a ladder, or preferably either a cherry picker or picking platform will ensure staff have no excuses for not placing hand applied dispensers high in the tree and will reduce the time needed to distribute the dispensers.
- Mechanically applied formulations need to be mixed properly before use and if they have been stored under refrigeration may require time to reach air temperature before stirring.
- Aerosol dispensers should be mounted in ways that prevent ants entering the dispenser and, because the propellant sometimes is phytotoxic, should be positioned so that they do not directly spray on to nearby foliage.
- Do not place pheromone traps, used for monitoring pest populations, closer than 1m to pheromone dispensers or in the case of aerosol dispensers they should be placed several trees upwind of the dispenser.

Is mating disruption working? Monitoring in mating disruption blocks

As with any form of pest management it is important to monitor and determine if what you have done has been successful. In conventional orchards which rely on insecticide applications monitoring is carried out using pheromone traps. One measure of performance of mating disruption used in research and registration trials is the degree of trap shutdown in the treated plots compared to untreated plots. Commercial orchards will not have enough untreated plots to use as comparisons but a modified method, that carries some risk, is to use capture of moths in standard pheromone traps as an indicator that mating disruption is not working. The theory is that if male moths are captured in standard pheromone traps in a block treated with mating disruption then they must be able to find female moths in the block. While this is correct it does not mean that mating disruption is not working. As mentioned at the start of this chapter, mating disruption works by delaying mating and not by eliminating it completely. Therefore, capture of moths in pheromone traps in mating disruption treated orchards simply indicates that pest populations are so high that supplementary treatment with pesticides or biocontrol agents may be required. The risk associated with under-estimating codling moth populations in disrupted orchards can be reduced by using pheromone traps baited with high dose (10X) pheromone lures combined with kairomones, such as pear ester (often code named DA), that not only improve capture of male codling moths but also attract females. In the case of OFM both males and females are attracted to so-called "soup traps" containing fermenting brown sugar solution and a few drops of terpinyl acetate. These liquid traps are messy and need to be serviced and refreshed frequently. A dry trap equivalent baited with pheromone, acetic acid and terpinyl acetate has performed well in trials overseas and should soon be available in Australia.

Crop monitoring. Structured monitoring for early signs of damage, and development of situational awareness in all orchard staff are important tools for detecting potential problems before they get out of control. The monitoring techniques presented in chapter 3 are suitable for this purpose.

Emergence of secondary pests

Where orchard size, condition and topography make it possible to use mating disruption to control pest moths there is one other issue to consider and plan for contingencies. As with all pest management strategies which minimise the use of broad-spectrum insecticides, insect pests previously considered occasional or secondary may increase in importance in the short-term. If the orchardist has been using other IPDM compatible control measures before changing to mating disruption the orchard will usually have active populations of beneficial species that will be keeping pest mites, aphids and mealybugs under control. Pests such as budworms (Helicoverpa or Heliothis larvae) and loopers that may have been controlled by early season codling moth, LBAM or OFM sprays may require alternative treatments but there are egg parasitoids, insect virus products, and other "soft" products that can be purchased instead of resorting to chemicals that are known to be toxic to beneficials (see Chapter 6 for impact of pesticides on beneficials). The damage caused by these secondary pests is seldom serious enough to consider a return to conventional management of codling moth, light brown apple moth and/or oriental fruit moth.

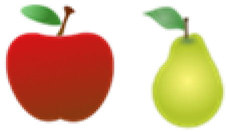
More information

*See **Chapter 3** and the specific chapters covering the individual pests for monitoring methods.*

*See **Chapter 6** for impact of pesticides on beneficial species*

Consult PubCRIS (https://portal.apvma.gov.au/pubcris *) for current status and copies of product labels for registered mating disruption products (use the phrase "mating disruption" in the search window) and check which crops they apply to, then click on the [view label] box. **ALWAYS READ THE LABEL**.*

Apple and Pear IPDM



Chapter 8: Pest and Disease Factsheets

Alternaria leaf blotch and fruit spot

Apple dimpling bug

Apple leafhopper (Canary fly)

Apple mosaic virus

Apple scab (Black spot) and pear scab

Armillaria root rot

Bitter pit

Bitter rot

Codling moth

Fruit flies

Grasshoppers

Helicoverpa and loopers

Leafrollers

Mealybugs

Mites

Oriental fruit moth

Pear blossom blast

Pear and cherry slug

Phyophthora root and crown rot

Powdery mildew

San Jose scale

Silver leaf

Snails

Spring beetles

Thrips

Weevils

White root rot

Woolly aphid

Apple and Pear IPDM

Alternaria leaf blotch and fruit spot

IPDM quick facts

- Do not rely on overseas information about Alternaria because symptoms associated with leaf blotch and fruit spot of apple in Australia are subtly different to those expressed overseas.
- Alternaria leaf blotch is a serious disease of high value apples (e.g. Royal Gala, Pink Lady and Fuji) in Qld and NSW apple production areas, especially during wet seasons. It is a minor disease in other regions. Alternaria fruit spot has been recorded at levels that limit production in the Granite Belt (Qld), Sydney Basin and Orange (NSW).
- All leaf stages and types are susceptible to Alternaria leaf blotch. Lesions first appear in late spring (about 40 days after bloom) or early summer as small circular, round spots, often with purple borders. Spots can enlarge to irregular brown-reddish shaped lesions (2-5 mm diameter).
- Alternaria fruit spot infections occur after leaf blotch from about 100 days after bloom to 2 -3 weeks before harvest. Lesions typically begin in fruit lenticels as small, lightly sunken, light to medium brown spots, observed after rainfall before harvest or after cold storage. Lesions on fruit do not grow during cold storage, but once fruit is removed existing spots continue to grow providing an entry point for other fruit rots.
- The pathogen survives as mycelium in infected leaf litter, canopy leaves, twigs and buds, with leaf residue the main source of overwintering inoculum for leaf infection.
- The period from mid spring to early summer is of the greatest risk for leaf blotch primary infections. Thereafter disease increases rapidly during humid (above 70%), wet and warmer summer weather (25-33°C). Disease severity can vary from year to year and among apple varieties. The severity of leaf infection increases when warm and rainy conditions occur in summer, often causing considerable defoliation (leaves turn yellow by midsummer).
- Leaf lesions, which appear before fruit lesions, can act as an indicator of when to begin control measures. Monitor leaves from mid-spring onwards to determine leaf blotch incidence and severity and risk of further infections.

- The decision to apply protective fungicides for early and late season disease control should be made based on block history (disease pressure), cultivar susceptibility/importance, levels of primary infection detected during scouting and weather factors that influence disease development.
- No action thresholds have been established to guide fungicide application. However, research in Australia showed that an initial incidence of leaf blotch of less than 5% in early summer resulted in 20-45% of leaves infected at 110 days after bloom, causing severe defoliation.

Management Notes

The Australian IPM program includes monitoring and cultural and chemical control practices integrated to manage Alternaria leaf blotch and fruit spot. Orchard sanitation is essential to reduce the levels of overwintering inoculum. This includes application of urea to trees or ground at leaf fall to promote breakdown of leaves and raking and mulching of pruned plant materials before leaf emergence in spring. In blocks with a history of disease, protective broad-spectrum fungicides can be applied once initial leaf symptoms appear in October-December to reduce sources of inoculum for further leaf infections and preharvest fruit infection, especially when warm and wet conditions prevail. These can be applied as part of regular late spring scab spray program. Application of late-season protectant fungicides should be considered, as permitted by withholding periods, if the preharvest risk of fruit infection is high. There are fungicides effective against Alternaria that are registered for scab or for Alternaria control either as full registration or under permit (please consult your chemical supplier). After harvest, consider applying broad-spectrum fungicides at sites where severe defoliation has occurred.

***Figure 1**: Symptoms of initial lesions of Alternaria leaf blotch.*

Figure 2: Older lesions of Alternaria leaf blotch.

Figure 3: Alternaria fruit spot symptoms.

The pest and its impact

The disease Alternaria leaf blotch of apples is relatively 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,* several other species of Alternaria appear to cause leaf blotch and fruit spot symptoms.

This has important implications:

- Australian species seem to cause subtly different symptoms to those from overseas.
- In some areas, notably the Granite Belt, fruit symptoms are more severe than is the case in either overseas infections or in infections occurring 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.
- Consequently, 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, 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 which 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) which 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 similar disease to that seen overseas but may be quite different and respond to different management techniques.

Damage

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

Progression of leaf symptoms. Early purplish lesions (left), later light brown lesions (centre) and yellowing leaves (right)

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.

Defoliated trees in January after an Alternaria infection

Fruit. Both the incidence and appearance of fruit symptoms varies. In Queensland, fruit damage is often 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 6-8 weeks prior to harvest. Interestingly, fruit spots do not appear during storage, and preharvest Alternaria fruit spots do not appear to enlarge significantly during cold storage. However, once 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 and Victoria. Where they are seen they are sometimes like those seen in Queensland, but more often they are less conspicuous depressed, dark lesions which 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*.

Alternaria fruit spot symptoms commonly seen in Queensland (left) and New South Wales (right)

Similar Damage

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

Alternaria fruit spot has similar symptoms to those caused by bitter pit (left) and Elsinoë piri (right)

Individual lesions caused by *Elsinoë piri* look like those caused by Alternaria but are usually far more numerous; there may be hundreds on a single piece of fruit.

Prevention and good orchard management

Remove or destroy 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 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 on Granny Smith. Note that 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. While 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 leaves from around October onwards. At this stage the disease is indicated by presence of small purple lesions. This can be used to guide decisions on the need for early and late season fungicide applications. However, where monitoring indicates that the disease is already well-established then fungicide applications are unlikely to have a great effect, and more careful management is required for next season.

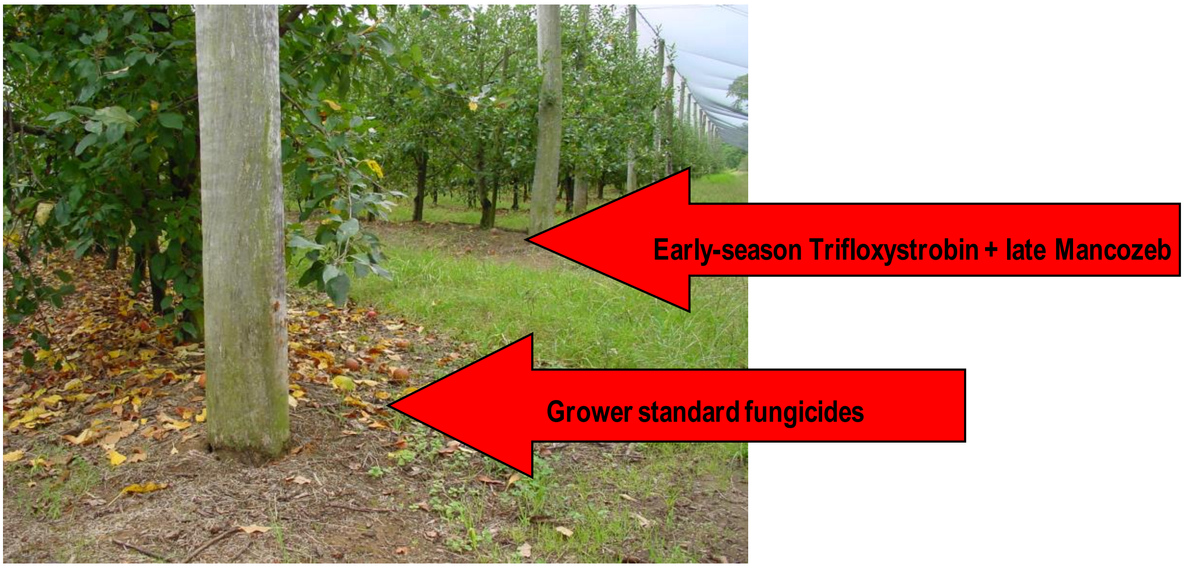
Management

Responsible use of pesticides

The decision to apply protective fungicides for control of Alternaria leaf blotch and fruit spot should be made based on region (climate), cultivar susceptibility and block history (disease pressure) and, during the growing season, based on a combination of the risk of further disease development from levels of primary leaf infections detected during scouting and the weather. In orchards where the risk is known to be high, fungicide applications during two distinct periods of fruit development (early and late season) are required to properly manage Alternaria leaf blotch and fruit spot.

Early season fungicide applications.

If the risk of Alternaria leaf blotch is always high, a block of three fungicide applications at weekly intervals must be applied from petal fall to suppress early disease development. The disease may not be evident at this stage but it may be present as very small lesions or overwintering spores in plant debris. Often growers only react when they see disease symptoms, but the benefits of spraying before symptoms are apparent will become evident later in the season. There are several protectant fungicides that will provide some degree of disease control have an effect but the greatest reduction in disease severity was observed with applications of trifloxystrobin as part of a scab program.



Rows of gala apple trees which have been treated with two different fungicide regimes. A grower's standard fungicide applications was made to the near row. Early season trifloxystrobin and late season mancozeb were applied to the far row. Note the difference in leaf fall.

Resistance warning: Trifloxystrobin is a group 11 fungicide and is often mixed with a group 7 fungicide. Both groups are restricted by resistance management guidelines to a maximum of three sprays per season. Furthermore, after two consecutive applications of group 7 and/or group 11 fungicides at least the next two sprays applied must be from groups other than 7 or 11 before any more group 7 or group 11 fungicides are applied. This means that any group 11, group 7, or mixture of group 7 and group 11 fungicide used against black spot (scab) between spur burst and petal fall must be counted as part of the total three applications permitted for the season. In areas at risk of Alternaria and black spot it will be especially important to conserve applications of group 11 group 7 fungicides for use after petal fall so that they can fulfil roles against black spot and Alternaria with the same application.

IPDM warning: Trifloxystrobin is compatible with IPDM but some Group 7 chemicals that may be combined in products that contain trifloxystrobin can be detrimental to beneficials used in IPDM. (Refer to Table 5 in Chapter 6 for toxicity of fungicide active ingredients and READ THE PRODUCT LABEL.)

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

IPDM warning: Since mancozeb has negative impacts on some species of predatory mites that control European Red Mites (ERM) and the Trichogramma wasps that help control lightbrown apple moth (LBAM), growers in areas where ERM and/or LBAM are problematic should use orchard hygiene and appropriate early season tactics to reduce risks from Alternaria so that they do not risk disrupting to biological control of ERM and LBAM by needing to apply mancozeb later in the season.

Problems may occur when significant rainfall occurs during the withholding period 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 only occur where leaf damage has been severe for a long period of time; maintaining tree health until two to three weeks prior to harvest should result in reduced fruit damage.

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 the 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 where control has been achieved.

Caution. While some aspects of information from overseas may be useful, Australian Alternaria blotch and fruit spot behaves quite differently with respect to control. Recommendations from overseas publications should only be used in Australia with extreme caution. For example, Australian research has shown that many fungicides which have provided control overseas (such as captan) are ineffective on Alternaria here.

More information

The following local publications provide information which will be useful in understanding and managing this disease.

Horlock, C. 2007. Final Report HAL project AP05002. Alternaria fruit spot: New Directions. 53pp.

Persley D 2008. Diseases of Field Crops. Apple and Pear. Queensland Department of Primary Industries and Fisheries.

Acknowledgements

Many of the images included in this chapter were obtained from Christine Horlock (Senior Plant Pathologist, QDPI&F) and have been reprinted here with her permission.

Apple and Pear IPDM

Apple dimpling bug

IPDM Quick Facts

- The pest commonly called apple dimpling bug in Tasmania (*Niastama punctaticollis),* is a different insect to the pest called apple dimpling bug on the mainland (*Campylomma liebknechti.).*
- Tasmanian apple dimpling bug *Niastama punctaticollis* has also been recorded from NSW and SA but does not appear to be an orchard pest in those states.
- *N. punctaticollis* is a pest in Tasmania where macrocarpa (*Cupressus macrocarpa*) windbreaks, or even solitary trees, are alongside orchard blocks. The damage reduces with distance from the macrocarpa.
- *C. liebknechti* is present in Qld, NSW, SA, and WA and damages apples in those states.
- Life cycles and management varies between the two pests. Always be sure that the management you are using applies to the pest in your orchard.
- Varietal susceptibility to dimpling bug damage varies with light coloured varieties like Granny Smith and Golden Delicious frequently damaged. Gala is also susceptible.
- Monitoring of macrocarpa in Tasmania and flowering wattle trees on the mainland in late winter-early spring before apples, pears and nashi reach spur burst will give an indication of local populations of dimple bugs.
- Pome fruit is most susceptible to damage by dimpling bugs between the pink bud and full bloom stages. If resident populations near orchards are easily detected, then a prophylactic spray at pink bud would usually be warranted. Refer to Chapter 6 for information about toxic effects of pesticides on beneficial species to avoid disrupting pollination and mite control.
- The variable action threshold for *C.liebknechti* is based on the number of bug-days accumulated during the flowering period from pink bud to petal fall.
- A threshold for *N.punctaticollis* has not been developed but in most cases spraying the nearby macrocarpa prior to pink bud on apples gives sufficient control.

- Although they damage developing fruitlets by feeding on the flower ovaries both bugs also prey on Helicoverpa eggs, aphids and mites.

The Pests and their Significance

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

Immature bugs are called nymphs because, although they are smaller, they resemble adults despite not having wings. Nymphs go through several developmental stages called instars in which they grow in size and develop progressively more evident wing buds.

Mainland Australia

The apple dimpling bug on mainland Australia is *Campylomma liebknechti*. It is present in all mainland apple growing states and often builds up large numbers in the inland Queensland channel country before weather patterns in spring cause dispersal East and South into the apple growing regions of the Queensland Granite Belt, NSW, Victoria and South Australia. Similar dispersal is thought to occur from inland Western Australia into the Southern apple growing areas of Western Australia. Adult *C.liebknechti* are greenish-brown bugs about 3mm 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.

Campylomma liebknechti

C.liebknechti nymphs are a pale green colour and only the older nymphal instars develop characteristic black spines on the legs. The early instars can be confused with apple leafhopper (canary fly) nymphs but on closer examination the leafhopper nymphs have smaller, slender antennae that project laterally from the head and they also have a distinctly segmented, wedge-shaped elongated abdomen. The *Campylomma* nymph has thicker four-segmented antennae with a dark coloured joint between the first and second segments. They can also be confused with early instar green aphids but aphid nymphs are more

Campylomma 4th instar nymph (E. Beers)

globular and have cornicles (‘exhaust pipe” projections) on the abdomen.

While *C.liebknechti* causes serious damage to apples and minor damage to pears and nashi, it is also considered an important predator of Helicoverpa eggs, aphids and mites. It commonly feeds on 62 species of plants including Australian native and introduced tree species such as tagasaste (*Chamaecystisus proliferus*), Chinese hawthorn (*Photinia robusta*), Geraldton wax and wattle (*Acacia sp.*). Wattle is an important host across mainland Australia and large numbers can breed up on a single tree.

Tasmania

The apple dimpling bug in Tasmania is *Niastama punctaticollis*. It has also been recorded from the Gammon Ranges in South Australia. This insect looks quite different to *C.liebknechti*. The adult *N.punctaticollis* is about 2mm wide and 7mm long compared to the smaller *C.liebknechti*. The green body contains red markings which are covered by the wings when the insect rests. The wings are dark chocolate brown with some green and red markings.

Adults lay their eggs in macrocarpa in the period 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 (1.5mm long) but get longer with each new instar until mature nymphs are 5mm long. The body of the nymphs is pale green with red markings on the upper surface of the legs and the eyes are bright red. Nymphs have no wings but wing buds become more evident with each successive instar.

From late September until about the end of October adult bugs leave 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 pink bud through until one week after petal fall. Most damage occurs between early pink and complete petal fall, with the most severe damage occurring between early pink and full bloom.

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

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

Similar symptoms

It may be difficult to distinguish low levels of apple dimpling bug damage from damage caused by plague thrips (*Thrips imaginis*), green crinkle virus or nutritional problems such as boron deficiency without cutting the fruit. Thrips damage is surface deep whereas dimple bug damage goes deeper and by cutting the fruit in half through the dimple you will usually see that the core is deformed in line with the dimple. There are no deformities of the core associated with green crinkle or boron deficiency. Boron deficiency often causes deformities with associated corky areas to develop in the flesh of the fruit. Similar looking feeding damage by Harlequin bugs (*Dindymus versicolor*) and stink bugs has fine puncture marks in the skin. Green crinkle is a graft transmissible disease, primarily in Granny Smith apples, that results in deformed fruit with depression and wart-like swellings.

Boron deficiency can be confused with apple dimpling bug damage

Prevention and good orchard management

Varieties

Damage seems more serious on lighter 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 unless dimpled. 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 tagastaste, although *C.liebknechti* can appear suddenly in large numbers as a result of weather events dispersing the bugs from inland breeding grounds.

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* relies on a much smaller range of tree species than its mainland cousin.

Crop thinning

If dimple bug numbers have been high early in the flowering period, you may want to reconsider an aggressive chemical thinning program because it may remove good fruit as well as the dimple bug damaged fruit. Dimple bug damage causes severely damaged fruitlets to preferentially shed. Damaged fruit that has not shed naturally can be removed during hand-thinning.

Monitoring

The decision to manage apple dimpling bug should be made on the basis of the severity of damage it has caused in previous seasons, and the numbers of insects detected through monitoring. Monitoring should commence in other host trees (Acacia, Tagasaste etc for mainland Australia and macrocarpa for Tasmania) before apple trees are at the early pink bud stage. 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, it is wise to apply a suitable pesticide to the macrocarpa immediately to reduce the population before they move to the orchard

Guidelines for monitoring in apple orchards

- Start sampling apple trees at pink bud stage and sample twice weekly until petal fall
- Sample in the cool of the morning (before 9.00am), as the bugs become too active for accurate identification and counting when it becomes warmer.
- Dimple bugs are in greater numbers on the sunny side of the tree.
- Tap 20 flower clusters, on the sunny side of each of 5 randomly selected trees, over a container. A white ice-cream tub is very good as the bugs are more easily seen and the container is deep enough to slow their escape. In Tasmania concentrate the initial monitoring efforts in blocks close to macrocarpa trees because these blocks will usually be first and hardest hit by incoming bugs. On the mainland initial monitoring can be concentrated in rows or blocks closest to bushland or flowering wattles and other hosts but do not neglect to check

other blocks that are at susceptible stages as weather fronts come through, especially with arrival of westerly or northerly winds in the eastern states and easterly or northerly winds in Western Australia.

- Record the number of dimpling bugs found and determine whether a spray is required according to thresholds (see below).
- Do not stop sampling after a spray; re-invasion from the bush is likely. Sampling after spraying will also assist you in determining the effectiveness of the spray.
- Poor sampling is likely to result in under estimation of dimple bug numbers which may lead to increased levels of damage.
- Ants deter dimple bugs. If ants are found in the sampling container move to another tree.

Thresholds

Early published thresholds for *Campylomma liebknechti* varied within the range of 2-4 apple dimpling bugs for every 100 apple flower clusters monitored proved problematic due to variation in the length of the flowering period and inclement weather sometimes interfering with sampling. To overcome this a threshold based on bug-days (cumulative bug activity) over the flowering period was developed in NSW.

- Bug-days are calculated by taking the average number of bugs captured on two sample dates and multiplying that by the number of days between samples. For example, if on the first sample date 2 bugs were captured and 7 days later 4 bugs were captured the average number of bugs = (2+4)/2=3, and the number of bug-days would be 3x7=21.
- The time available for ADB to damage fruit is the approximately 30 days between late pink bud and two weeks after petal fall even though bugs may be present after this time.
- The economic threshold (ET) developed in NSW was based on spraying with fluvalinate and took account of the cost of the pesticide and its application but not the non-target impacts of the pesticide.
- The ET for the total of 30 days was 44 bug-days based on sampling 100 flower clusters each sample date. The spray threshold ST (or action threshold) was then calculated as ST=ET/(FP-d) where FP=length of flowering period (late pink to 2 weeks after petal fall) and d= number of days after late pink bud.
- Using the ET of 44 bug-days and a flowering period of 30 days the equation becomes ST=44/(30-d). This means that:
    - at late pink the spray threshold is 44/30=1.47 bug-days
    - at 7 days after late pink ST=44/(30-7)=44/23=1.9 bug-days

- at 14 days after late pink ST=44/16= 2.75 bug-days
- at 21 days after late pink ST=44/9=4.9 bug-days
- and at 28 days after late pink ST=44/2=22 bug-days.

The very low threshold between pink and full bloom generally justifies a prophylactic spray being applied at late pink and then the use of the variable threshold to determine if a further spray is required later in the flowering period. It is important to minimise the number of sprays applied because those sprays can have a drastic impact on the survival of predatory mites, that control twospotted and European red mites, and parasitic wasps that control other pests. Chemicals other than fluvalinate are now registered against ADB and the spray thresholds for those products are likely to be higher, although they have not yet been determined.

What you do at this stage of the season sets in train a string of consequences, both planned and unplanned, that cascade through the rest of the season. See Chapter 6 for information on side effects of pesticides on beneficials.

Responsible use of pesticides

Mainland Australia

There is a critical period of approximately three weeks for protecting fruit. This period is from pink to one week after petal fall.

Consult your agronomist or pest management advisor about suitable pesticides to use against dimple bug. If your orchard has a history of dimple bug damage or there are large populations of dimple bug in surrounding vegetation a prophylactic spray at early pink bud is probably warranted. Check the active ingredient of recommended products against Table 4 in Chapter 6 for their compatibility with IPDM and not just their effect on bees. Plan for what chemical you will spray if dimple bug or thrip populations reach threshold levels after pink bud, by choosing a product safe to bees and that does not have a long residual effect on other beneficials.

If chlorpyrifos is to be used against dimple bug it should only be used as a prophylactic spray and should not be used after early pink bud, and spray drift on to flowering weeds, or nearby flowering trees where bees are likely to be working, should be avoided. The orchard cover crop could be mown before spraying to reduce bee fatalities but that means you have left it too late to be applying chlorpyrifos or other chemicals toxic to bees. Flowering weeds are important energy sources for bees working orchards and also for parasitoid wasps that prey on pest insects in the orchard. If Western flower thrips have been a problem in the orchard mowing the cover crop may push the thrips into the tree flowers and create more problems.

If spraying is required during the flowering period, regardless of how safe the chemical may be to bees, it is preferable to spray in the late evening after bees have stopped foraging.

READ THE LABEL AND STRICTLY FOLLOW ALL BEE SAFETY AND APPLICATION TIMING DIRECTIONS

Tasmania

In Tasmania pesticides are applied to macrocarpa in order to reduce the number of adult bugs prior to 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 three 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 is the only insecticide registered for this use. Hence care should be taken to avoid drift into the orchard, adjoining properties, pasture or waterways and the precautions listed above should be taken to protect bees.

More information

Bower, C., Page, F.D., Williams, D.G. and Woods W. 1993. Management of apple dimpling bug. Final Report HRDC project A/003/R1. 93pp.

Sivyer, M. and Learmonth, S 2005. Fact Sheet Note 178. Apple Dimpling Bug. Department of Agriculture and Food. Government of Western Australia. 2pp.

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. 2pp.

Apple and Pear IPDM

(Australia)

Apple leafhopper (Canary fly)

IPDM Quick facts

- The apple leafhopper (or canary fly in Tasmania) is increasingly becoming an issue in IPDM orchards, possibly due to drier conditions.
- Malathion is the only registered chemical control in Australia however, it is known to have numerous off-target effects on both pollinators and natural enemies and therefore should be used with caution.
- Apple leafhoppers are sap feeding insects 3-4 mm long and yellow in colour.
- Their feeding causes mottles on the leaves, impacting photosynthesis.
- High numbers can cause irritation to pickers when the cast skins are inhaled or get into eyes in much the same way as mites can cause irritation.
- Apple leafhopper have 1 -3 generations per year depending on the region and the climate.
- Apple leafhoppers overwinter as eggs laid in autumn beneath the bark of twigs and smaller branches of their host plants.
- There are 5 nymphal instars that look like smaller, wingless adults that develop progressively more obvious wing buds in each instar.
- Host plants include apple, hawthorn and blackberry.
- Adults of the first generation normally occur in early December and the second emergence occurs in March, during the harvest.
- There is one known natural enemy for apple leafhopper in Australia, a tiny parasitic wasp, *Anagrus armatus,* that is an egg parasitoid.
- Apple leafhopper has several common names and its scientific name has been revised numerous times since 1918, which means that it is difficult to find reliable information in the published literature.

- No economic thresholds have been developed since the 1930s because it has only recently started to become an issue again.
- Use of yellow sticky traps placed high in the tree can indicate trends in populations and generations.
- The 1-minute assessment of 5 randomly selected trees/ block described in the pest and disease monitoring section of Chapter 3 could provide data useful for developing thresholds if leaf damage is linked to yield and fruit size distribution data from harvest assessments.
- Counting leafhoppers/ leaf is not reliable because the adults are highly active and hop of the leaf when disturbed, resulting in only nymphs being counted.
- Degree-days for development were developed in the 1980s in New Zealand but biofix methods have not been verified in Australia. Generation time (egg to adult) was 453-474 $DD_{10.5\ C}$

The pest and its impact

The apple leafhopper *Edwardsiana. froggatti* is originally a European species probably introduced to Australia on apple or pear trees in the early years of European settlement. It has had several scientific names given to it since 1918, including *Typhlocyba froggatti,* and in Tasmania is generally known to apple growers as canary fly. It is present in all Australian apple growing states and the apple growing areas in New Zealand (where it may be called *Edwardsiana crataegi*). The adults and nymphs feed on the leaves where they pierce the epidermis and suck the green chloroplasts from cells, which results in leaves being speckled with white markings.


Photograph © J. Botting 2007

The insect overwinters as eggs laid in autumn under the bark of twigs and smaller branches on host trees and bushes, including blackberries and hawthorn. These eggs start to hatch in mid-October and the nymphs go through five instars (growth stages) before becoming the first-generation adults towards the end of November through into December-January. Nymphs are whitish green, wingless smaller versions of the adults that grow progressively more obvious wing buds as they transform from one instar to the next. The adults are 3-4mm long and pale greenish-yellow to bright yellow (hence the name canary fly).

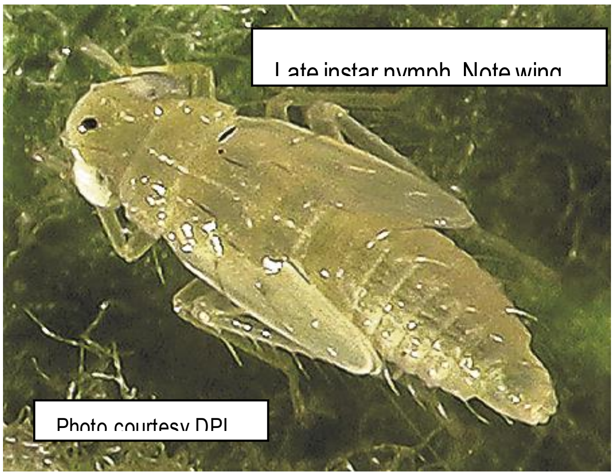

Late instar nymph. Note wing

Photo courtesy DPI

Nymphs and adults are generally found on the undersides of older leaves. When moulting the nymphs insert their claws into the leaf tissue while they cast their skin. For the first four instars the cast skins tend to detach from the leaf and blow away. The fifth instar cast skin remains attached to the leaf. The adults fly or hop quickly from their feeding or resting sites if disturbed. If populations are high the cast skins blowing in the wind can cause allergic reactions in fruit pickers and other workers through inhalation or if they rub their eyes. High densities of adults also


Leaf damage by leafhopper

tend to irritate orchard workers.

The first-generation adults mate in mid-summer and lay eggs into leaf tissue in or near the leaf veins to produce another generation. If infestations are severe the leaves can be so badly damaged that leaf drop occurs, and the insects foul the fruit with excrement that gives the fruit a black speckled appearance which requires extra washing to remove. The second-generation adults occurring in autumn lay overwintering eggs.

In New Zealand the leafhoppers developed resistance to azinphos methyl used against codling moth. This may have led to increased prevalence of the pest before organo-phosphate pesticides were removed from the production system.

Biological Control

E.froggatti eggs parasitised by the parasitoid wasp *Anagrus armatus nigriventris* Girault were imported from New Zealand into Tasmania in 1935 and high levels of parasitisation of the leafhopper population was recorded within 18 months. High levels of parasitisation were also recorded in 1947 and by 1960 there had been few serious outbreaks. The parasitoid overwinters as a larva in the host egg and adult wasp emergence is synchronised with summer egg laying by the leafhopper, in November and December. A second generation of parasitoids is present from January through April. Female wasps are short-lived and can parasitise up to 20 host eggs in rapid succession. The sex ratio of wasps emerging in spring is heavily biased towards females. Unmated females will parasitise hosts but will only produce male offspring whereas mated females produce both males and females.

The parasitoid was also distributed to WA and SA in the 1940s but does not appear to have established.

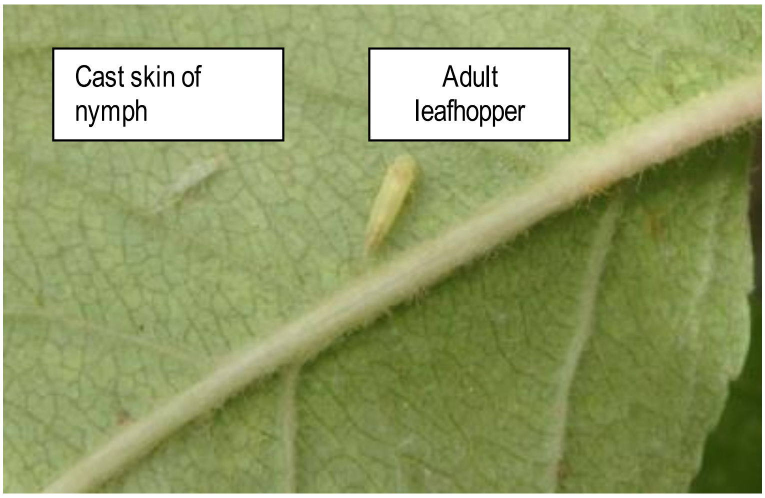
IPDM warning: The timing of adult emergence in spring coincides with spray applications targeting codling moth, LBAM, and diseases such as scab, Alternaria, and bitter rot. Although no data are available on impact of pesticides on *Anagrus* it is likely that pesticides that are directly toxic to, or have fertility impacts on, other species of parasitoid wasps (see Chapter 6) may have the same effects on *Anagrus*. This may have some bearing on the lower than expected performance of *Anagrus* in recent years in Tasmania.

There is some evidence that spiders are effective predators against the leafhopper.

Whirligig mites (*Anystis baccarum*) are widespread, large, red, hairy and very active predators against other tree-dwelling leafhoppers.

Monitoring

Yellow sticky board traps have been used in New Zealand for monitoring adult apple leaf hoppers and have the added advantage of trapping some *Anagrus armatus* so that you get an indication of parasitoid activity at the same time. Hanging the traps at least 2m high within the tree canopy reduces the catch of other leafhopper species that may be feeding on the ground cover and therefore reduces the effort and skill required to identify and count the apple leafhoppers. *Anagrus armatus* is very small and difficult to identify on the leaf but trapped on a yellow sticky board it is easier to deal with. Experience in NZ suggests that placing a clear acetate sheet over the yellow sticky board and giving it a thin coating of stickem makes it easier to handle the traps, especially if the scouts need to take the sheets back to the office or lab to view them under a microscope. The acetate sheet can be lifted off the board and placed onto a backing sheet and then rolled with the backing sheet to the outside to form a cylinder that can be stapled. This protects the sticky side of the sheet and can then be unstapled to view the catch. No thresholds have been developed but the results will provide data on population build-up.



Leaf sampling is difficult for monitoring adults but the nymphs are less likely to jump away and cannot fly. A simple presence -absence count of infected leaves will give an indication of nymph activity and potential leaf damage. The sampling protocol for mites given in chapter 3 could be used for this purpose and, because the effect of leafhopper feeding is cumulative, the % infested leaves could be converted to cumulative leaf-infested days using the same calculation method as for mites. Again, no thresholds have been developed but by keeping good records and assessing yields and packouts you should be able to develop some thresholds of your own. Even without thresholds, leaf inspections that indicate the presence of cast skins of fifth instar nymphs would provide evidence that adults are about to emerge. This in turn suggests that most nymphs have hatched from eggs and are present on the leaves. The parasitoids would not have emerged from parasitised eggs at this stage so it would probably be the most appropriate time to apply a spray if necessary.

Degree-day model

A degree-day model developed in New Zealand used 453-474 degree-days base 10.1°C for egg to adult development based on a combination of laboratory and field studies. The model has not been tested in

Australia although some of the data used to construct the model was derived from a study in 1929 from Bathurst. The information is therefore provided only as an example for possible testing. Developing a biofix date on which to start accumulation of degree-days for prediction of the first flight of adults proved problematic because the leafhopper overwinters as eggs that undergo some development before entering diapause, and the detection of the first hatching of nymphs was difficult due to the small size and cryptic location of the first instar nymphs. An arbitrary date of the first of May as biofix did not give accurate prediction of the emergence of first-generation adults but did a reasonable job of predicting emergence of second-generation adults. Accumulation of 511 degree-days base 10.1°C after detection of the first adult of the first generation was suggested as a suitable date to spray because all of the first generation eggs would have hatched but second generation eggs would not have been laid and the parasitoid *Anagrus* would not have emerged from parasitised first generation eggs. Growers or advisors wishing to test the validity of this degree-day accumulation could use the leaf sampling procedure above to detect the cast skins of fifth instar nymphs as an indicator of emergence of first-generation adults as a biofix date.

Management

At the time of writing this manual the only pesticide registered for control of apple leaf hopper in Australia on apples was malathion, which has detrimental effects on Trichogramma wasps (used to control LBAM and codling moth eggs) and other beneficial species (Chapter 6). Unless the pest has a resurgence in pest status it is unlikely that registration will be pursued for new products although the insect growth regulator buprofezin, registered against mealybugs on pears, is registered against leafhoppers on citrus. Buprofezin was effective against apple leafhopper in NZ laboratory trials but is not registered for any use on apples in Australia.

Apple Mosaic Virus

IPDM quick facts

- 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 produce leaves which have pale to cream spots on spring leaves as they expand.
- Disease is transmitted by budding and grafting from infected trees
- Apple mosaic virus is not transmitted by insects
- There is no cure once the tree is infected. Consider removing infected trees.
- The number and severity of affected leaves depends on seasonal temperatures, with the symptoms being more severe in years with moderate spring temperatures.
- Infection can cause a severe reduction in bud set on infected trees.
- 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 which is commercially viable. It is most likely that yields are similarly affected but damage is more obvious on varieties such as Cripps Pink, Jonathon, 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 it cannot be cured. The only meaningful way of controlling this disease is to only plant virus-free material. Where 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. Where 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 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.

More information

E.V. Podeckis and R. Welliver, 2008. Apple Mosaic Virus. Kearneysville Tree Fruit Research and Education Center. http://www.caf.wvu.edu/Kearneysville/disease_descriptions/omvirus.html

Apple and Pear IPDM

Apple and Pear Scab, *Venturia inaequalis* (apple scab), *Venturia pirina* (pear scab)

IPDM quick facts

Identification

The two diseases, which have similar symptoms, development and management, affect flowers, fruit and foliage causing serious yield and fruit quality losses, particularly in wet seasons.

Leaves:

- Lesion development occurs on both sides of leaves. Young lesions are velvety brown to olive green spots with indistinct margins, noticeable until after petal fall. As lesions become older, they enlarge and turn dark green to brown with distinct margins.

Fruit:

- Initial lesions on flower stalks or young fruit are small black velvety spots, noticeable after petal fall. As spots grow, they become brown, corky and scabby. Fruit infections occurring in summer may be visible before harvest as pin-point scab (summer spots) or may not become evident until storage.

Period of Activity

- Apple and pear scab occur from green tip until leaf drop in autumn. Inoculum for primary infections (ascospores) in spring is produced mostly in fallen leaves that were infected the previous season. Ascospores mature from shortly before bud break to late November, with most maturing during flowering. Mature ascospores are discharged during spring rains and daytime but some discharge occurs at night if scab inoculum is high.
- Susceptible plant parts are infected when temperature and leaf wetness conditions are conducive to spore germination. Primary lesions produce conidia for secondary infections. Leaves are most susceptible to infection by spores when expanding and fruit when young, although older fruit can be infected by conidia during long periods of moisture.

Scouting Notes

- At harvest and before leaf fall monitor leaf scab to determine the levels of scab carry over, and hence potential for spring primary inoculum (ascospores) using **the autumn assessment method.**
- Monitor temperature from before bud break (late August) to December to determine ascospore maturity, using a suitable **degree day model**, and rainfall for discharge.
- From green tip to harvest monitor trees for scab to determine disease pressure and new unprotected plant tissue. Either use automated weather stations coupled to computer aided decision systems, a scab warning service if one exists in your area or monitor temperature and hours of leaf wetness from green tip to leaf fall to determine primary (ascospores) and secondary (conidia) infection periods using the **Mills Charts**.
- At harvest monitor fruit in bins to determine effectiveness of the IPDM program.

Thresholds

- Because spores are microscopic, action thresholds for scab are based on monitoring scabbed leaves in autumn and ascospore maturity in spring (primary scab-risk), and scabbed leaves in spring-summer (secondary scab-risk).
- Analysis of apple and pear scab ascospore data sets indicated that about 5% of ascospores are mature by green tip, 50% by mid-late Sep and 95% by early-to-mid Oct across most apple and pear growing regions, except WA. Preliminary validation showed the New Zealand degree day model was adequate to predict apple and pear ascospore maturity when started in late Aug (biofix).
- If growers have access to the ascospore maturity model, start fungicide sprays when mature spores are reported by the degree day prediction, otherwise at bud break-green tip, and spraying for scab may be diminished after the ascospore model and monitoring indicates the primary season is over and enough spring rainfall has occurred.

Management Notes

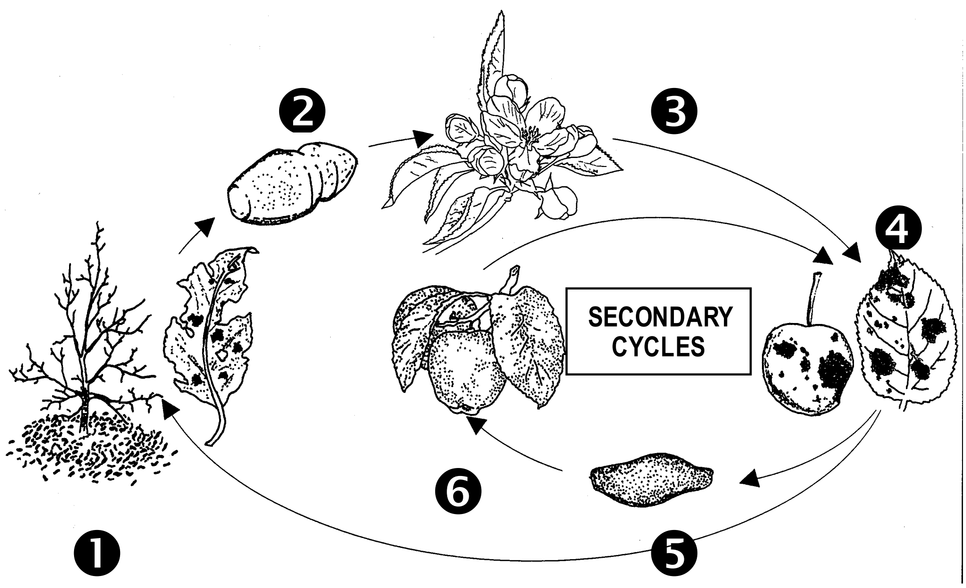
The key to controlling scab is to prevent primary infections using postharvest sanitation to reduce primary inoculum and protecting susceptible plant tissue from infection during infection periods. Effective disease management in the primary phase will mean much less potential secondary infection and therefore less use of fungicides and less risk of serious losses due to fruit scab. Knowledge of cultivar susceptibility, ascospore maturity and infection period is critical to maximizing the efficiency of fungicides.

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 which infects apples cannot infect pears and the pathogen which infects pears cannot infect apples. Apple scab is now present in all Australian apple production regions and pear scab in all pear producing 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. Fungicides used for control of scab can have detrimental effects on some biocontrol agents that help manage insect and mite pests, leading to outbreaks of secondary pests.

Understanding the pathogen's life cycle will allow for IPDM based management decisions that may reduce the number of fungicide applications, improve fungicide resistance management, and avoid non-target impacts that disruption IPDM.

Life Cycle



At the start of the season, as temperatures rise, pseudothecia (spore producing bodies) that developed within infected fallen leaves produce primary inoculum (mature ascospores) ❶. Primary spores from pseudothecia are expelled into the wind when leaf litter is wetted ❷, settle on young soft tree growth and infect susceptible tissues ❸. These primary infections only occur when the combination of time that leaves, fruitlets or flowers are moist from rain, dew or mist and the temperature is appropriate for spore germination. Primary infections result in lesions ❹ which produce a different type of spore (conidia) ❺. Conidia can also spread through the orchard by rain splashing and on wind currents and have slightly different temperature and moisture requirements to infect the leaves or fruits that they land on ❻. Where the 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.

After leaf fall the scab pathogen in infected leaves on the orchard floor undertakes sexual reproduction producing pseudothecia where primary inoculum is produced. The more scab on leaves the greater the chances of sexual reproduction. Disruption of this process by breakdown of leaves will greatly reduce primary inoculum production for spring.

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 forming very large lesions.

***Figures 1 and 2**. Initial and old lesions on apple leaves.*

***Figures 3 and 4**. Initial and older lesions on pear leaves.*

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 apple scab on apple leaves.

Fruit. Symptoms on the fruit are like those on the leaves although lesions tend to have more well-defined margins. As the lesions become older and shed their spores, they become brown, dry-looking, corky and cracks appear. At this stage lesions look brown or black. Fruit growth is retarded in the vicinity of 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.

***Figures 5 and 6**. Initial and older lesions on young and older apple fruit.*

***Figures 7 and 8**. Initial and older lesions on pear fruit.*

Twigs. Twig infections are relatively rare with apple scab in Australia but can be common for pear scab. Twig infections are more likely in areas where the climate is wetter, drying times are longer, and scab infections are severe. 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. Unlike in leaves, pseudothecia do not develop on the twigs and conidia, not ascospores, are released in spring from the infections on the twigs. Since conidia require shorter leaf wetness periods for infection than do ascospores, the release in spring of conidia from twig infections can result in earlier than expected infections. It is therefore important after a severe scab infection season to inspect trees for signs of twig infections and to prune out those infected twigs.

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

Prevention and good orchard management

Although once scab gets established it is difficult to control there are many steps that can be taken to reduce the severity of the disease. These steps are based on practices to reduce the numbers of infective spores (inoculum) in the orchard. An important but often overlooked step is to plan your orchard with scab management as a major focus. Unless you are planting a new orchard the opportunity to plan the orchard layout and structure to suit scab management presents itself whenever a new block is being prepared. The aim is to make conditions as least favourable to the disease as possible, then to use sanitation practices to reduce inoculum and thereby reduce the number of fungicide applications that may be required. The need for and timing of fungicide applications can be guided by predictive models that account for weather conditions, ascospore maturity, and leaf canopy development. Scab resistant varieties are becoming more available but traditional breeding methods have difficulty with maintaining commercial traits (colour, flavour, storability etc) during back-crossing to incorporate resistance genes.

Planning an orchard or new block

- Establishing a new block or orchard is an opportunity to plan integration of measures to reduce incidence and severity of apple or pear scab in the long term.

- Select less susceptible varieties if they are suitable commercially and agronomically suited to the site.
- Plant more tolerant varieties in areas where drying of tree foliage takes longer.
- Choose row orientations and spacings to not only achieve maximum light interception but also quick drying of foliage after rain events.
- Avoid overhead irrigation systems unless they are designed specifically for cooling and avoid long periods of wetness that simulate rainfall events that produce infection periods.
- Use a training system that allows good air flow and spray penetration through the canopy.
- Avoid vigorous rootstocks and excessive nitrogen applications.
- Use hail or bird netting that can be rolled up to provide better drying conditions if necessary.
- Design rows so flail mowers and sweepers can be used to clean up inoculum over winter.

Resistant Varieties

Currently the most widely grown commercial varieties of apple in Australia are susceptible to scab although the level of susceptibility varies. Apple varieties incorporating scab resistance and commercial desirability are being bred in many places in the world including Australia. Kalei is a scab resistant apple developed in the DAFF Qld apple breeding program at Stanthorpe and released in 2012. It showed a lot of promise and retained excellent eating and storage qualities while being resistant to scab and tolerant of both *Alternaria* and Western Flower Thrip (*Frankliniella occidentalis*). Unfortunately, it has not been taken up by either conventional or organic growers probably because, despite performing well in consumer evaluations, it lacked the distinctive difference in appearance to allow it to compete for supermarket shelf space. Newer varieties with scab resistance, such as Rocket, are club varieties with restricted availability.

There are seven known races of the apple scab fungus *Venturia inaequalis* worldwide. Research in Victoria and Queensland in the 1990s revealed that only Race 1 was present in Australia at the time. The most common resistance genes used in breeding programs occur in the V*f* locus that contains at least 17 genes that confer various levels of resistance to scab races 1-5 but not races 6 and 7. When resistant varieties based on V*f* become widely available in Australia they are likely to maintain their resistance for long periods unless scab races 6 or 7 enter the country and become established.

- 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, Fuji, Kanzi, Envy and Jazz are considered moderately susceptible;

- Jonathan is generally acknowledged as being less susceptible to apple scab but is no longer widely grown and:
- Kalei, Rocket and Red Love are resistant to apple scab but are not widely available.

Pruning and tree training

Pruning and tree training to create or maintain an open canopy 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 fallen on the ground harbour the scab fungus during the winter allowing it to re-infect trees during early spring. The number of spores that are produced during sexual reproduction over winter can be reduced by sanitation practices that break down the leaves more quickly.

A postharvest treatment of urea is good practice to enhance microbial degradation of fallen leaves. It is a valuable supplement to scab control, should be used annually, and 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 which might have been missed. No special attention to a ground spray will be necessary where dilute sprays by air-blast are used. Better results can be expected if the orchard floor is clean at the time of spraying. It is necessary to be aware that some damage to spurs and laterals can occur in very dry seasons. Care should also be taken 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 or mulching mower. This physical breakdown helps the leaves to decompose more quickly and reduces occurrence of fungal mating.

Sanitation

Although the most commonly recognised source of primary inoculum is leaf litter, an appreciable number of spores (conidia) can also come from diseased fruit which is left to hang on trees. This is especially the case where 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 where it will be exposed to the sun and can also be run over with a slasher or mulching mower to increase the rate of breakdown. **IPDM Comment:** An added advantage of removing all fruit from trees at harvest is that leaving even small numbers of fruit increases the risk of insects like codling moth, oriental fruit moth, and fruit flies infesting those fruit and creating a higher carryover into the next season. Leaving as few as 3 fruit per tree can mean that an extra 400 codling moth females/Ha could then overwinter on the trees.

Monitoring

Monitoring for scab risk in autumn, spring and summer

Monitoring the development of disease, scab fungus and tree growth during the growing season is essential to determine the risk of scab infection and thus optimize fungicide application and effectiveness. Because the scab spores are microscopic, action thresholds for scab are based on monitoring scabbed leaves visually at harvest and before leaf fall and during tree growth in spring and summer in conjunction with pest monitoring using the methods described in this manual. The harvest and pre leaf fall assessments are useful to determine potential scab carry-over from season to season. Monitoring in spring and summer is used to determine the risk of infection from asexual spores (conidia) and spray effectiveness. Action thresholds for the scab pathogen are based on information from ascospore degree day models which predict primary inoculum (ascospore maturity) availability in spring and from the Mills table which predict spore (ascospores and conidia) infection requirements on susceptible tissue. These models are included in scab warning systems available to growers. Predictions of ascospore discharge after rain events, tissue susceptibility (new unprotected tissue) and fungicide decay provided by other models in some scab warning systems can enhance the prediction of infection risk before or after each wet event. Information from scab warning systems used in conjunction with information from scab monitoring can provide a more accurate prediction of the likely severity of scab infection risk during each wet event in the primary and secondary scab season.

Harvest and autumn. Monitor foliar and fruit scab at harvest and shoot scab pre leaf fall to determine potential levels of scab carry over for next spring (see MacHardy method below). These assessments are also important for evaluating the effectiveness of the IPDM plan and developing the plan for the next season.

Spring (primary scab-risk). Monitor leaf and fruit scab during the primary infection season (September to November) to determine occurrence of primary infections and optimize spring fungicide application. Begin monitoring from petal fall, or earlier, in conjunction with pest monitoring. Information from scab monitoring should be used in conjunction with information from ascospore degree day and Mills models to optimize the interval of fungicide application. The leaf and fruit scab assessment at the end of the primary infection season (November), after the supply of primary inoculum (ascospores) is exhausted, is important to determine the need for further scab fungicides to control secondary scab in summer.

Summer (secondary scab-risk). Monitor leaf and fruit scab from December to harvest to determine occurrence of secondary infections by conidia and optimize summer fungicide application.

Monitoring techniques

Separate monitoring programs for each pest or disease may improve accuracy of determining when thresholds are about to be exceeded but they are not cost effective or practicable in an IPDM context.

The monitoring techniques described in chapter 3 provide cost-effective methods of avoiding major issues. The critical periods for decision making on scab management are just prior to harvest, close to petal fall, late Winter-Spring especially between green tip and petal fall, and damage assessments in December.

Visual monitoring of foliar scab at harvest and pre leaf fall

At harvest: The assessment of scab infections at harvest can be incorporated into the damage assessments conducted just prior to harvest. The 100 fruit/tree, 5 trees/block inspection method described in Chapter 3 will indicate if a problem exists and incorporation of a 1-minute inspection of the foliage (also described in Chapter 3) on each of 5 trees per block will be a cost effective way of providing extra confidence in the data. If no or very little scab is detected at harvest a follow-up inspection before leaf fall may be required if weather conditions after harvest have been conducive for new infections to occur.

Pre-leaf fall: For this inspection a sequential monitoring program based on the potential ascospore dose model (PAD) using replicates of 10 randomly selected shoots on each of 10 randomly selected trees requires less time (and is therefore lower cost) than the research program sampling of 600 shoots. Shoots should be randomly selected from all over the tree. Examine all the leaves in each shoot and count the number of leaves with scab lesions. Once more than 19 leaves with scab have been detected you can stop inspecting further leaves because at this level of infection the orchard is considered high risk. If less than 5 leaves with scab were detected in your ten tree inspection the orchard can be considered low risk. If you detected 5-19 scab infected leaves in your ten-tree sample you need to inspect another 10 trees, accumulating results of the previous samples as you go. Once you have accumulated more than 24 scab infected leaves the orchard is high risk and you can stop sampling. If less than 13 infected leaves were detected by the time you finished this second set of trees the orchard is low risk and you can stop sampling. However, if you have now detected 14-23 infected leaves you will need to inspect another set of ten trees. The process is repeated, using cut-off points listed in Table 1 until a maximum of 6 sets of ten trees have been inspected. If the orchard is categorised as high risk a winter and early spring sanitation program should be implemented to reduce the spring inoculum and a tight spray program in spring will be required, using IPDM compatible fungicide options for early and late season scab control.

Table 1: *Threshold levels of cumulative scab infected leaves detected in sets of 10 randomly selected trees in which 10 randomly selected shoots/tree were inspected.*

Risk assessment	**Number of sets of ten randomly selected trees**					
	1	**2**	**3**	**4**	**5**	**6**
Low	<5	<13	<21	<30	<40	<50
High	>20	>24	>31	>37	>44	>50
Keep sampling	5-19	14-23	22-30	31-36	41-43	

Caution: The pre leaf fall assessment is most reliable where protectant programs were used (e.g. latent scab lesions suppressed by curative systemic fungicides are much harder to see). Therefore, in orchards where demethylation inhibitor (DMI) (Group 3) fungicides have been used intensively PAD may be underestimated due to presence of latent (undetectable) scab lesions.

Late-Winter-early Spring

If the Autumn pre-leaf fall inspection categorises the orchard as having low levels of inoculum for the next season the MacHardy Model (see below) or a suitably programmed electronic forecasting unit is likely to give the most accurate prediction of infection risk during the next season. If the orchard was categorised high risk use Mills tables or an electronic forecasting unit in conjunction with the ascospore maturity model (see below) to improve identification of infection periods. Either way requires monitoring of weather conditions and the 1-minute tree inspection technique described in Chapter 3 can be used in Spring to detect early infections. **IPDM Note:** Leaves used for mite sampling (especially for ERM and Bryobia mites from green tip) can also be used as additional indicators of scab infection at this stage in the season.

Summer

The 1-minute tree inspections for LBAM, Looper and leaf infections (including scab) described in Chapter 3 will give an indication of scab infections without having to do specific sampling just for scab. Likewise, the damage assessments in December can be used to assess the effectiveness of the scab program.

Ascospore maturity degree-day model

In spring, temperature drives the maturation of primary inoculum (ascospores) in pseudothecia produced in infected leaf litter and rainfall drives the daily release of mature ascospores. Ascospores are discharged during spring rains, most during day-time but some at night if inoculum is very high. Most mature ascospores are released when abundant susceptible leaf and fruit tissue is available (bloom) except during extremely dry conditions that may delay the release.

Either use automated weather stations coupled to a computer based degree day model, a scab warning service if one exists in your area or monitor ambient temperature (daily minimum and maximum) to estimate degree days (base 0 °C) starting from a suitable biofix start date and then use accumulated degree days to estimate the likely levels of mature ascospores ready to be discharged during a wet event using the information described below ONLY as a general guide to track down ascospore maturity. Monitor rainfall data on site to estimate the likely levels of mature ascospores discharged after each wet event. Analysis of apple and pear scab ascospore data sets collected in Australia indicate that about 3-5% of ascospores are mature by green tip of common pear and apple cultivars, 50% by mid-late September (bloom) and 95% by earl-mid October in years with normal rainfall across most apple and pear growing regions, except WA (Figure 9 - 11). A degree day model developed for pear scab (*V. pirina*) in Victoria has been available to pear growers in Victoria for many years and other ascospore degree-day models (apple scab and pear scab) developed overseas are also available to Australian growers. However, only the New Zealand degree day model (apple scab) has been validated with some apple scab data sets collected from NSW, Vic, SA, Qld and Tas. Validation analysis showed the New Zealand model was adequate, with a minor modification, to predict apple and pear ascospore maturity in Australia when degree day accumulation started in late August (Figure 11). For apple scab, the New Zealand model gave a better fit in regions with more rainfall than with lowest rainfall, with the 5% maturation threshold occurring after the green tip stage for early apple cultivars in all regions, except Tas and SA, where the two phenomena occurred within one week of each other. A biofix based on the first detection of a spore in a spore trap in each region gave the best prediction of maturation, but a biofix of 22 August for all regions, as used in NZ model, gave equally good predictions. Validation with pear scab data sets gave similar results.

The New Zealand model fitted to Australian data in Figure 11, should be used ONLY as a general guide to predict the maturity of ascospores of *V. pirina* and *V. inaequalis*. Use daily records of rainfall at each locality to estimate the likely levels of mature ascospores discharged after each rainfall wet event. Begin degree-day accumulations at bud-break of early varieties or the 22 August (biofix) whatever is first. Use degree day accumulations to estimate the percentage of mature ascospores from the curve. This should fall within a 90% range. If warm weather brings bud-break forward the likely advance in ascospore maturity will be accounted for by the temperature-driven degree-day model.

A simple degree day (DD) calculation adds the maximum temperature (Tmax) and the minimum temperature (Tmin) of each day, divides the sum by 2 to calculate the average temperature, and then subtracts the base temperature (lower developmental threshold temperature of the organism). For scab the base temperature (Tbase) chosen is 0°C, which means that the DD calculation is simplified further to be simply the average temperature for the day.

In this model (Figure 11), 50% maturation modelled from the 22 Aug biofix is 528 $DD_{0°C}$, which is only 6 $DD_{0°C}$ different from the value of 534 $DD_{0°C}$ days used in the NZ model. At about 250-300 $DD_{0°C}$ there is rapid maturation of ascospores indicating high risk of infections, and at 900 $DD_{0°C}$ more than 95% of the ascospore supply should be depleted if sufficient rain has occurred. After 100% maturity is predicted, usually mid-to-late November, and after significant rain, check trees for scab to decide need of more sprays.

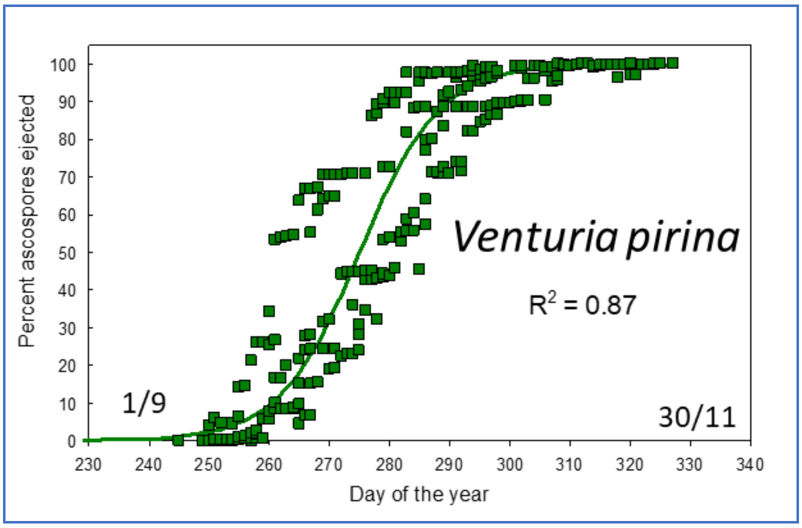


Figure 9. *Cumulative percentage of ascospores of pear scab (V. pirina) trapped using spore traps during 5 years in Victoria, Australia.*

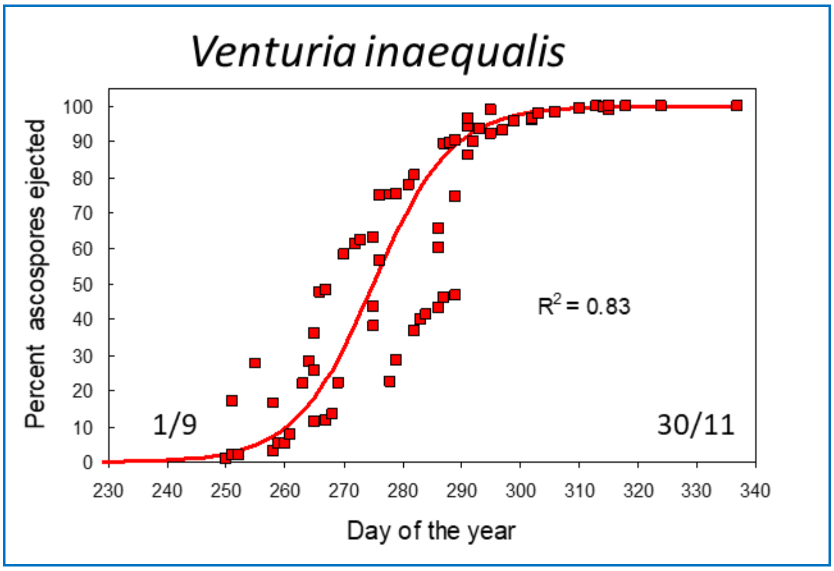


Figure 10. Cumulative percentage of ascospores of apple scab (V. inaequalis) trapped using spore traps during 5 years in Victoria, Australia.

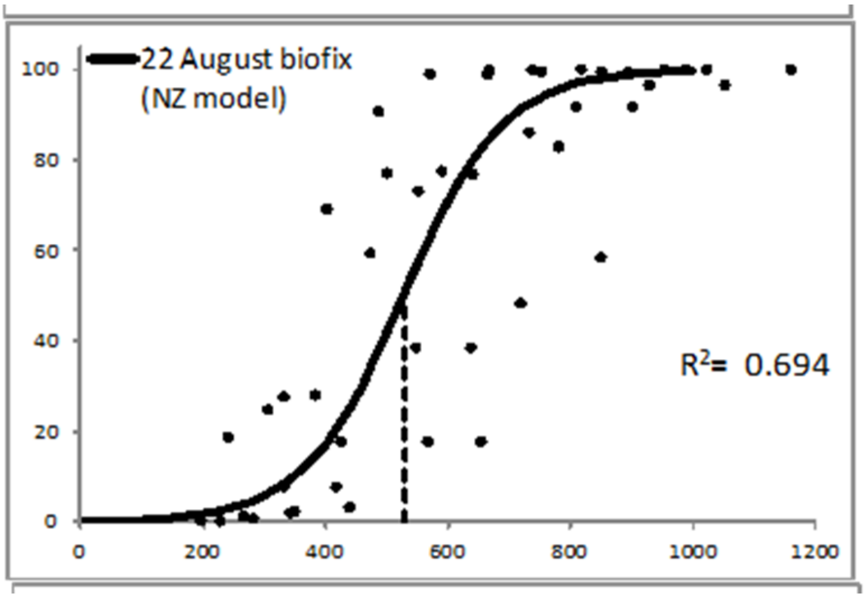


***Figure 11**. Cumulative percentage of ascospores of apple scab (V. inaequalis) trapped using the glass slide method during 1 season in Tasmania, Victoria, South Australia and Queensland, Australia. The curve is the prediction for cumulative ascospore maturity plotted against cumulative degree days started on the 22 of Aug.*

A simple technique to predict primary and secondary scab infections

Primary Infections result from ascospores released in Spring from leaf litter. Trees can be inspected for scab lesions on leaves from very early in the season using the 1-minute tree inspection technique, supplemented by the leaf sampling conducted for mites. The first lesions can appear 10-14 days after bud break. Early infections are most likely to be noticed on the flower bud leaves (sepals) and fruitlets. However, by the time these early lesions are seen a considerable amount of leaves and fruit may be infected. It is far better to predict the development of the disease and manage it before it is seen.

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:*** ascospores are rarely released at night except when overwintering inoculum is high.
- ***Wetness:*** Leaves or fruit must remain wet continuously for at least 9 hours at optimum temperatures for infection to occur.
- ***Leaf, twig or fruit age:*** Older tissue is less susceptible to infection, requiring long wetness periods at warm temperatures for infection (e.g. summer spot on fruit).

- ***The number of disease-causing spores:*** Even where all other conditions favour disease development, if disease-causing spores are not present no infection will occur.

Several tools or models can be used to predict the likelihood of scab infections. The choice of which is most suitable for your orchard involves a trade-off between accuracy and simplicity

As predictive tools account for more of the factors above they become more complex, but also more accurate. These more complex tools are usually incorporated into electronic forecasting units.

STEP 1. Choose which model.

The simplest predictive model only requires orchardists to monitor and record leaf wetness and temperature. This technique tends to over-estimate the number of times infection will occur and may result in more fungicide sprays than necessary unless spore availability (ascospores and conidia), tissue susceptibility, and scouting results are considered. Information on the relationship between leaf wetness, temperature and the severity of the scab infection is contained in what is commonly called a "Mills chart" (after the researcher who discovered the relationship). The information in the Mills chart relates to the primary disease-causing ascospores which are present at the start of the season. This is summarised in the Mills table graph below (Figure 12). After the primary infection is established, secondary infection cycles caused by conidia spores require fewer hours of leaf wetness to infect.

The Mills chart can be used in conjunction with weather monitoring to determine the occurrence of periods favourable for spore infection (infection periods) and when infection is likely to appear in unprotected tissue. Either use automated weather stations coupled to computer aided decision systems, a scab warning service if one exists in your area to determine Mills infection periods or monitor temperature and hours of leaf wetness from green tip to leaf fall.

Advantages of using Mills Charts

- Works well with orchards that have had more serious scab problems in the previous year, because primary inoculum (ascospores) will always be available in sufficient amounts from green tip onwards to infect susceptible tissue. If sporulating wood infections have been detected these also can provide conidia for infections.

Disadvantages of using Mills Charts

- May miss some important infection periods that have occurred in shorter wet periods than the chart indicates, especially when overwintering inoculum is high.
- May over-predict infection periods that start at night and wetness finishes before ascospores released at daybreak have a chance to infect susceptible tissue

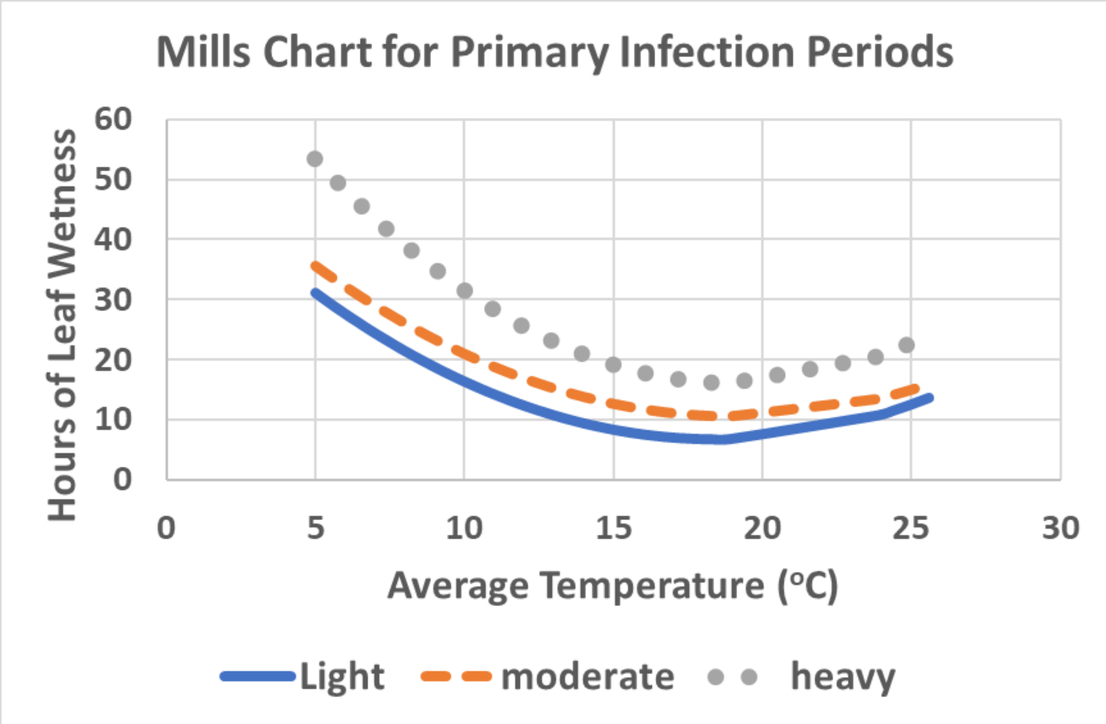


Figure 12: *Effect of temperature on the number of hours wetness required for light, moderate and heavy rates of infection, based on Mills Table data. Use this chart if your pre-leaf fall autumn assessment indicates high risk or disease pressure is always high due to block characteristics.*

The Mills Chart also predicts the number of days after infection before lesions will be evident. This is summarised in the graph below.

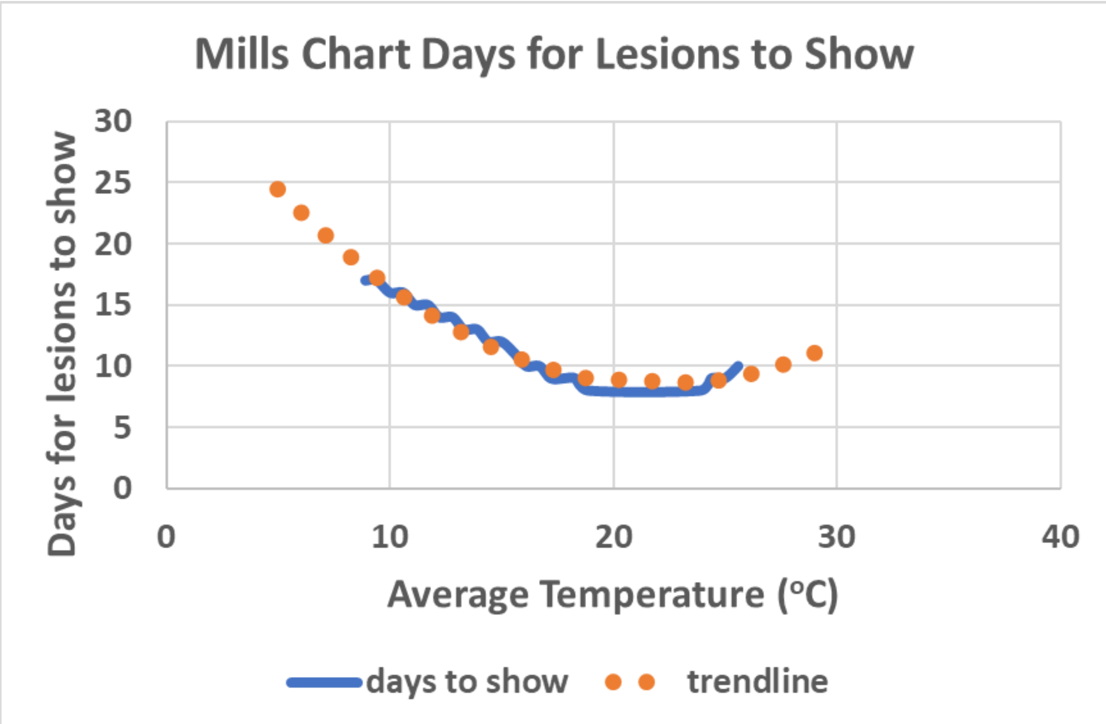


Figure 13: *Influence of temperature on the number of days after infection before lesions show, based on Mills Table data.*

A second simple model, the MacHardy model, accounts for the fact that ascospores 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. The model also predicts secondary infection

Advantages of using the MacHardy Model

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

Disadvantages of using the MacHardy Model

- May not account for rare, massive ascospore releases that occur at night (most likely following a long dry period which delayed ascospore release)
- 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.

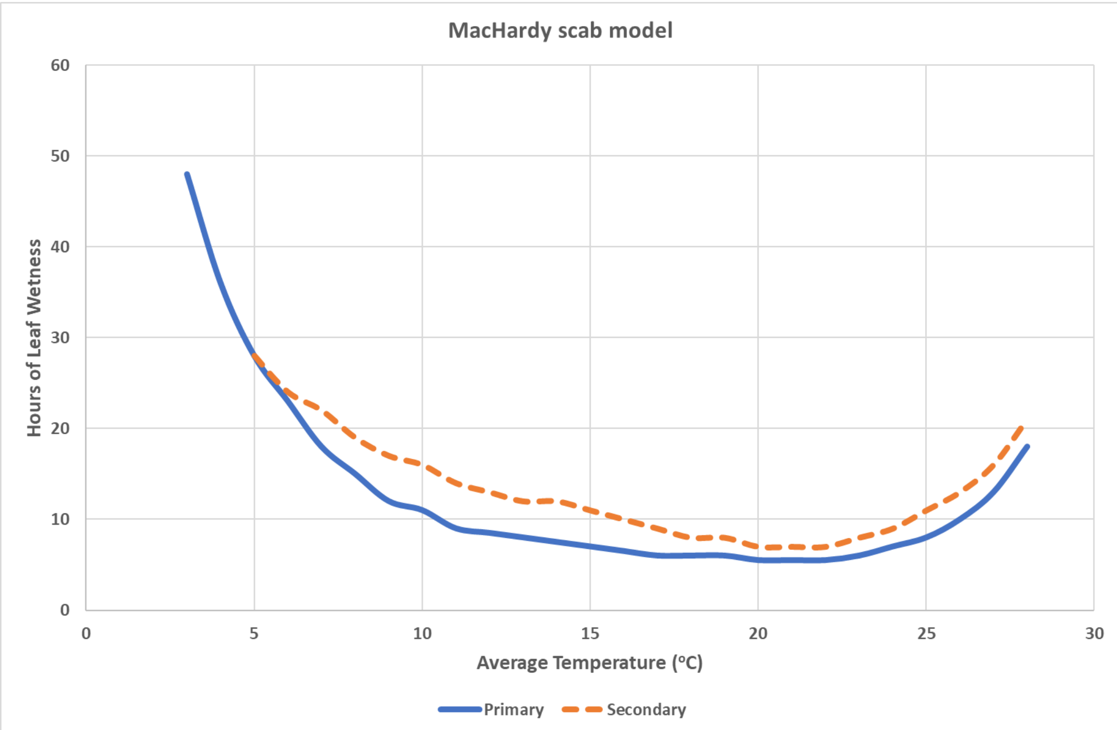


Figure 14: *Influence of temperature on hours of leaf wetness required for primary and secondary infections, based on the MacHardy scab model. Use this model only if you are confident scab carry over is low and block characteristics are not favourable to the disease.*

WARNING: It is IMPORTANT when using either model that when trees are dry less than 6 hours between wetness periods (e.g. during showery weather), the periods 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 after revisions conducted in Victoria.

STEP 2. Measure and record the information

No complex equipment is needed to use these simple models. Leaves are designated wet when free water is present on the foliage or fruit, usually indicated by droplets falling when the branches are shaken. The leaf wetness period is simply the time between when leaves are initially wet and when branches no longer shed water when shaken. Leaf wetness sensors measure electrical conductivity across electrodes due to water on simulated leaves.

A maximum – minimum thermometer is the basic equipment required to monitor temperature. This thermometer should be reset at the start of a wet period and the average of the high and low temperatures during the wet period calculated by adding the maximum to the minimum and dividing the result by 2. Although this is not strictly the average temperature, it is an acceptable approximation.

The thermometer should be placed in a sheltered position within the orchard or in a specially designed screen box. It is very important that thermometers are not placed in direct sunlight or excessively windy positions as this will lead to incorrect readings.

Alternatively, relatively inexpensive weather stations are available at most electronics retailers and rural supply outlets. These will record the time at which rain begins and finishes (but not dew or fog) and the temperatures during this period. This is useful if you are using the Mill's chart method where leaf wetness periods can occur in the middle of the night.

STEP 3. Determine if an infection period has occurred

Refer to a Mills Chart, MacHardy Chart (or use Figures 12 or 14 above) according to block disease pressure to determine primary (ascospores) and secondary (conidia) infection periods.

STEP 4. Use the information to decide if a spray is needed.

Once you have determined if conditions were right for an infection period you can refer to the degree days accumulated since August 22 and use Figure 11 above to assess the need to spray based on the ascospore maturity.

As soon as possible after a moderate or heavy infection period a curative fungicide should be applied if the residual activity of the previous spray is considered insufficient to protect susceptible tissue against infection. Consider all the factors that increase the risk of scab infection, and your IPDM experience, to determine if an application is necessary following a light infection period.

STEP 5. Decide which fungicide

Fungicides used after an infection period has occurred are considered to be curative fungicides that have a "kick-back" effect. The kick-back period is the length of time following infection that the fungicide can be applied and still control the disease so that no symptoms occur. Curative fungicides are also sometimes called systemic as they can penetrate plant tissue to control the developing pathogen after it has entered the plant. The kick-back period varies according to which curative fungicide you choose and is a factor in deciding which fungicide should be chosen.

In choosing a fungicide consider the history of fungicide use, including the activity groups of the products and how effective they have been in your orchard, and how long a kick-back period will need to be to prevent scab from developing. The required kick-back period is the length of time from the beginning of the infection period until it finishes + the time it will take until the application can be made.

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 which account for a greater number of factors which influence disease infection. They 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 have sensors with appropriate shields to allow accurate recording and be calibratable so that records are comparable to Bureau of Meteorology stations. The data collected should be able to be used for phenology models that forecast pest and disease events, provide records to satisfy regulatory requirements for spray applications, and be placed in locations that provide wireless transmission back to office computers or mobile phones. 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 etc.). 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. Orchards with a large range of topography, aspect, and altitude may require more than one electronic forecasting unit or the unit should be placed in the most vulnerable block to avoid under-estimation of infection periods.

Management

Responsible use of pesticides

Most commercial orchardists consider apple or pear scab to be the most serious disease affecting their crop. In most cases fungicide application strategies are built around scab control. Control of other diseases often occurs as a side effect of fungicides applied primarily to control scab. Some scab fungicides are also effective against Alternaria. *Venturia inaequalis* in Australia has developed resistance to triazole fungicides (Group 3) and is considered at high risk of developing resistance to other groups of fungicides. Fungicide resistance management strategies are in place and all fungicides sold in Australia are classified according to the chemical activity group of the active constituents. Many fungicide groups have limitations placed on the total number of applications that can be applied in a season and also as consecutive sprays, regardless of the target. Another consideration in the use of fungicides is the non-target impact of the chemical. Most fungicides are not directly toxic to insects, but many have sub-lethal effects such as reducing fertility of parasitoid wasps and predatory mites that are important biological control agents in orchards. The type, frequency and timing of fungicide applications therefore needs some thought. Over-application of pesticides wastes money and can create off-target and residue problems. By reducing pesticide use there is a risk of not only scab infection but other disease problems occurring. The key is to find a balance and to think carefully about the characteristics of the available fungicides and how and when they are best used. One of the major differences in this respect between Australian pome fruit production regions is the frequency, timing and magnitude of rainfall events and the consequent response by orchardists.

Spraying before or after rain?

Most Australian orchardists use forecasting and disease models as reassurance that their management options were correct. Scab fungicides are often applied in response to a rain event. The timing of this spray application varies largely on a regional basis with some regions preferring to apply a protectant fungicide prior to rainfall and others a curative after rainfall; if used correctly both strategies will result in good scab control. The choice of which strategy is correct for your farm comes down to some practical considerations.

- **Access:** If orchards are located on sloping ground, have heavy soils or the inter-rows have poor drainage it may not be possible to get spray equipment through the orchard following rain. Fungicide application prior to rainfall is the best option.
- **Cost:** In general protectant fungicides are cheaper than curatives.
- **Impact on beneficials**: Protectants such as mancozeb have a negative impact on beneficials. Always consider the off-target toxicity of all pesticides, especially where orchard blocks have a history of pest problems.

- **Chance of an unnecessary spray**. Occasionally rain which is forecast doesn't arrive or doesn't last long enough for an infection to have occurred. If a spray has been applied based on the forecast, the cost of the spray, tractor running costs and labour needed is wasted.

Leaf emergence and expansion can occur very quickly early in the growing season and also after harvest in autumn. The weather that drives this growth often exacerbates scab severity. Unprotected leaf surfaces at these times are susceptible to scab infection. Rainfastness is the ability of a pesticide to be retained on the plant surface in sufficient quantities to maintain its effectiveness following significant rain. Some rainfast fungicides are retained at their sites of deposition and are unlikely to protect leaves that emerge after application of the fungicide. Some fungicides can be re-distributed by rain onto young leaves during light rain.

Some forecasting models, such as RIMpro, can account for development of the tree in the period when young green leaves are present and at most risk of infection. The units often have models for a range of pests and diseases and in some cases can account for complex interactions between the pest or disease, its host, and the weather. Most have been developed overseas and may require recalibration for use in Australia to account for some minor differences in behaviour of the target pests and diseases.

Biological control, Biorational pesticides and Organics

Organic production usually relies on lime sulphur and sulphur application for the control of apple and pear black spot or scab.

Any technique which helps to hasten the breakdown of fallen fruit and leaves will help to suppress these diseases and the application of urea has already been mentioned. There is evidence that earthworms aid in control by speeding the breakdown and incorporation of the fallen leaves. Application of compost mulches will encourage worms and should consequently reduce the amount of overwintering disease inoculum. It is particularly important in organic production to focus on cultural methods that do not favour the disease. The hints in the sections above relating to site selection, establishing new blocks and selecting appropriate tree and canopy architecture, resistant varieties, and orchard hygiene will assist in reducing risk.

Acknowledgements

Some of the images in this chapter were obtained from Bayer Crop Sciences.

Useful References

Beresford RM 1999. Validation of an ascospore release prediction model for apple black spot (*Venturia inaequalis*). New Zealand Plant Protection 52 148-152.

Eikemo, H., Gadoury, D. M., Spotts, R. A., Villalta, O., Creemers, P., Seem, R. C., and Stensvand, A. 2011. Evaluation of six models to estimate ascospore maturation in *Venturia pyrina*. Plant Disease. 95 (3):279-284.

MacHardy, W.E., and Gadoury, D.M. 1989. A revision of Mill's criteria for predicting apple scab infection periods. Phytopathology 79:304-310

Reardon, J.E., Berkett, L.P., Garcia, M.E., Gotlieb, A., Ashikaga, T., and Badger, G. 2005. Field evaluation of a new sequential sampling technique for determining apple scab "risk". Plant Disease 89 (3): 228-236

Apple and Pear IPDM

Armillaria root rot, Armillaria luteobubalina and A. mellea

Felt-like fungus under the bark of a tree infected by armillaria root rot (left)

Shoe-lace like rhizomorphs of the fungus can spread the disease from tree-to-tree (right)

IPDM Quick facts

- The main cause of Armillaria root rot in Australia is a native fungal species
- The disease is common where bush blocks have been cleared to establish an orchard, or alongside remnant native vegetation.
- The fungus can survive in the soil for up to 20 years.
- Disease moves from tree to tree through root contact and growth of shoelace-like rhizomorphs.
- Cleared land should be planted to pasture for 2-3 years and then fumigated before planting orchard trees if there were any diseased trees detected during the clearance operations.

The disease and its impact

Armillaria root rot is mainly caused by a native fungal species, *Armillaria luteobubalina* whereas overseas the most common cause of this disease is the closely related fungus *Armillaria mellea*. Both species exist in Australia. 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 recently been cleared and an orchard block planted. Pome and stone fruit, native trees, ornamentals and other plants are affected. The disease causes a decline in tree health without being obvious until dieback starts to become evident. The fungus has the common names "Bootlace", "Shoestring fungus" due to the appearance of rhizomorphs, and "Honey toadstool" due to the colour and shape of the fruiting bodies.

Symptoms and life cycle

Growers will notice the above-ground symptoms of the disease first. The symptoms are like those of other root rot diseases: leaves yellow and fall prematurely and the tree shows ill-thrift, limbs dieback 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 mate of fungus is revealed. This is often fan-shaped in appearance and smells like mushrooms.

The wood is usually also discoloured. If the roots and the soil around them are closely examined dark brown to black shoe-lace-like rhizomorphs may be found spread along the roots or through the soil, forming a branched structure attached to the roots. The fungus moves from tree-to-tree largely through root contact, but rhizomorphs can also be responsible for movement of the disease.

The rhizomorphs can infect living trees but the spores that produce the rhizomorphs can only infect dead wood. The spores are produced by toadstools that grow at the base of dead or dying trees. The caps of the toadstools are scale-covered and a deep brown to honey colour, while the gills underneath the cap are whitish. The stems of the toadstools are a yellow-brown colour, have an obvious ring or collar at the top and may be up to 15 cm high. The toadstools appear in the dying stages of the host tree and usually during wet weather between May through July.

Olive brown to yellow clusters of toadstools are sometimes seen growing from the base 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.

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 of time (up to 20 years).

Control

When clearing and planting new ground

- Ring-bark native trees and leave them for at least six months before removing them, so that starch reserves in the tree are depleted. This lowers the chance of such trees becoming centres of infection.
- Rip the area thoroughly and remove and burn all stumps and large roots.
- Leave the area under pasture for at least two to three 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.

Treatment 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 plus 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 removal 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 which remain in the soil to rot down completely before replanting.
- Monitor carefully for any signs that disease is reappearing.

More information

Armillaria root rot. State of Victoria, Agriculture Victoria. https://agriculture.vic.gov.au/biosecurity/plant-diseases/fruit-and-nut-diseases/stone-fruits/armillaria-root-rot

Acknowledgements

Images in this chapter were obtained with permission from

- William Jacobi, Colorado State University, United States
- Joseph O'Brien, USDA Forest Service, United States
- Andrej Kunca, National Forest Centre - Slovakia, Slovak Republic

Apple and Pear IPDM

Bitter Pit

IPDM Quick Facts

- Bitter pit is a physiological disorder of apples which 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.which can be confused with feeding damage from stink bugs and Harlequin bug (*Dindymis versicolor*)
- Poor weather or choice of pesticides applied during bloom may impact on bee activity and result in low crop loads due to reduced pollination
- Lightly cropped trees are more prone to this problem

Bitter pit is a disorder 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 the major cause of bitter pit is a high leaf to fruit ratio. Lightly cropped trees are more prone to this problem.

Light cropping and bitter pit: causes

Poor pollination: Inappropriate pollinators or lack of bee activity due to rainy, windy or cold weather during bloom or use of insecticides which are toxic to bees. The number of seeds in fruit provides a rough index to the level of pollination; where fruit have only a small number of seeds 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, over watering and excessively hard pruning promote foliar growth at the expense of fruit production which boosts the leaf to fruit ratio.

Over-thinning*.* Over-thinning can occur as a result of poor management or naturally, because of hail, late frosts etc.

Other factors causing bitter pit

Variety and rootstock. Late in the season as fruit finalises its maturation it loses its connection to the xylem. The xylem is the tube which passes calcium from the roots to the fruits. Varieties which lose this connection earlier, accumulate less calcium and are prone to bitter pit. These varieties include Braeburn, Granny Smith, Gravenstein, Jonathon 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 which 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 phosphorous, compaction, low oxygen, cold conditions, root disease, replant or nematodes.

Preventative management

A soil analysis should be carried out on new blocks prior to planting and suitable varieties and variety/rootstock combinations planted. Where established blocks have been affected by bitter pit in previous seasons growers should determine the underlying cause (e.g. poor pollination etc.) and treat it appropriately. Up to six foliar calcium applications per season may be required. Late season foliar calcium applications are particularly important because late in the season there is reduced transport of nutrients from the soil to the fruit and foliar applications are the most successful way of boosting calcium.

More Information

Warner, G. 2008. Bitter pit causes are complex. Good Fruit Grower. April 15, 2008. †

Apple and Pear IPDM

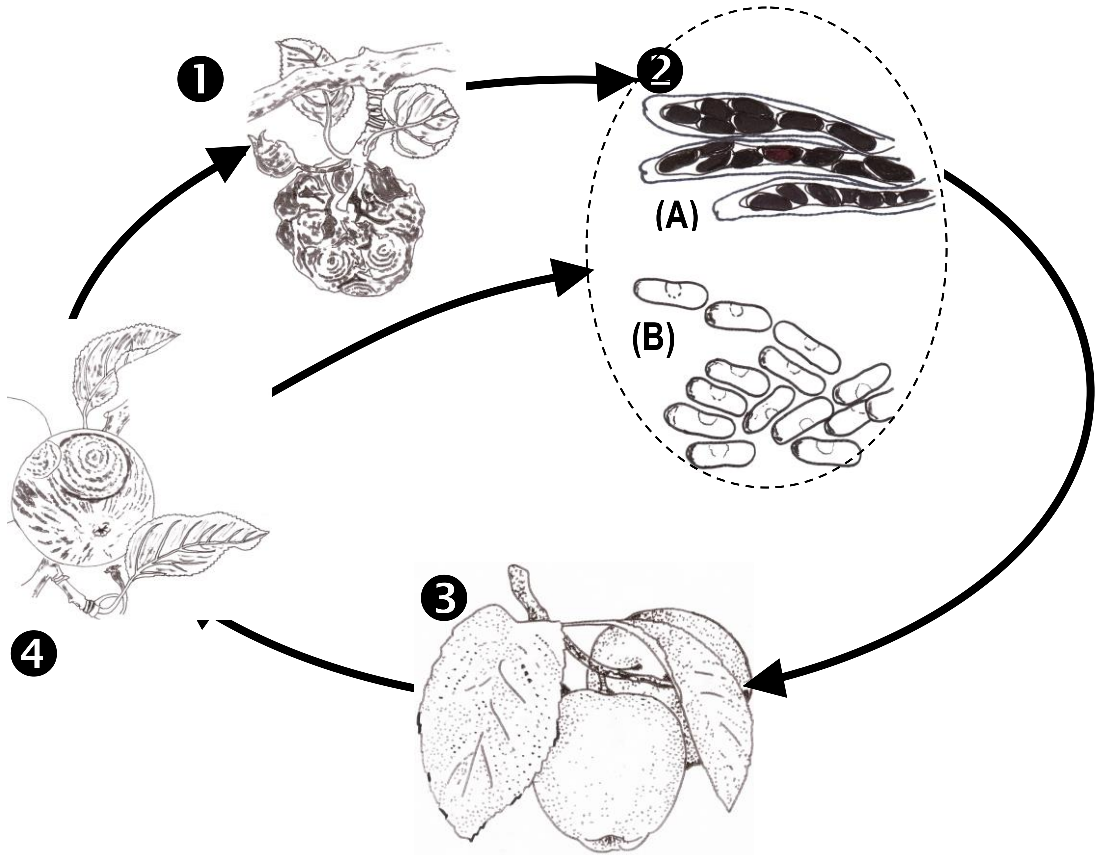
Bitter rot

IPDM Quick Facts

- Bitter rot is most likely to become a problem in areas with hot, humid summers.
- The first fruit infections can occur late spring-early summer when temperatures above 21°C coincide with rain or at night when fruit are wet.
- Symptoms can appear as early as three weeks after petal fall but are more common later in the summer.
- Most symptoms develop as the fruit approaches maturity.
- Bitter rot 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.
- Orchard sanitation is critical for the control of control this disease.
- Remove and destroy all diseased fruit whether it has fallen or is hanging in the tree.
- Remove all ‘mummies’ because most of those will be infected.
- Scab fungicides from groups M3 and M9 are effective against bitter rot and the timing generally suits incorporation into the scab program.
- Choose fungicides carefully to avoid disrupting predatory mites and other beneficial species that are providing biological control of secondary pests
- Can be confused with Target spot unless ooze is present. Bitter rot ooze is salmon pink whereas Target spot ooze is cream-coloured.

The Pest and its impact

Life cycle



The disease bitter rot is caused by a fungal pathogen previously known as *Glomerella cingulata* which was considered the sexual stage of *Colletotricum gloeosporioides*. Advances in fungal taxonomy have resulted in recognition of that *C. gloeosporioides* is a complex of similar species and the name *Glomerella cingulata* is no longer valid. Both apples and pears are affected. Orchardists may also have known this disease as summer rot or Glomerella rot. It is a member of a group of rots often called Anthracnose rots which includes target spot (caused by *Neofabraea alba*). *C. gloeosporioides* survives through winter on shrivelled infected fruit (mummies) on either the orchard floor or hanging in trees ❶ or in dead wood. 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 but *C. gloeosporioides* is unusual because it can penetrate otherwise healthy fruit ❸. Infected fruit develops characteristic lesions which produce many millions of spores ❹. Dependent on conditions, many disease cycles can occur in a single season.

Bitter rot is often the most serious fruit rot to effect apple orchards in warmer, more humid production regions such the Sydney Basin and Stanthorpe. However, most regions report that the disease can cause trouble given conducive weather (temperatures above 21°C with rain) and orchard conditions (mummified fruit, wet fruit on warm nights, rotting fruit left on the tree or orchard floor).

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 it may be because of industry's transition to more disease specific fungicides.

Damage

Damage in Australia is almost entirely confined to the fruit. Where infection pressure is extremely high leaves can become infected with the disease causing small, red flecks which 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 in Australia.

Fruit: Damage is of two types dependent on whether the infection was caused by a sexual or asexual spore (see 'lifecycle' above). 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 to pink in colour.

The lesions which 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 which 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.

WARNING: Infected fruit that have not yet developed symptoms are said to have latent infections. Bitter rot is a fungal disease that can develop in storage if fruit have latent infections at harvest. Postharvest fungicide treatments are usually not effective for controlling latent infections caused by this fungus. If your orchard has a history of Bitter rot in stored fruit, then orchard sanitation and green tip copper application followed by a concerted spray program should be considered.

Leaves: Damage to leaves is not common in Australia but could be confused with Alternaria leaf spot or damage caused by drift from desiccant type herbicides. If leaf symptoms are prevalent it would be wise to send specimens to a specialist diagnostic service for confirmation so that you can implement appropriate control measures

Glomerella leaf spot symptoms ranging from small purple spots to brown splotches

Similar Damage

Fruit which is damaged by hail or mechanical injury can develop sunken brown lesions which at first glance look like Bitter rot. Damage due to sunburn (pictured) can also look like Bitter rot especially when the sunburn has a red halo around it as with the early stages 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.

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 'lifecycle' above). 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 which will mulch them.

Remove and destroy all fallen fruit from the orchard floor both during the season and after harvest. It may also be possible after harvest 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 which 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.

Prevention of storage rots begins in the orchard. Millions of fungal spores are formed on a single hanging rotten piece of fruit. These spores are spread by wind throughout the orchard. Rotting fruit are best removed early in the morning when the air is relatively still.

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

Monitoring

In areas where bitter rot has been a problem in the past careful monitoring should occur during fruit development. Fruit are susceptible to infection from 3 weeks after petal fall until harvest. Infection early in the season becomes dormant soon after the spore penetrates the skin. Symptoms of infection do not show until resumption of growth is triggered by warmer weather and humidity. Relatively high temperatures (27°C to 32°C) and high humidity favour disease development. Fruit susceptibility increases as it matures. If anthracnose leaf spots appear be particularly vigilant, especially during summer. Monitors should pay particular attention to higher in the trees where spray applications for other diseases such as black spot may not have reached. The first symptoms will be small brown circular spots which become sunken by the time they reach a diameter of about 3mm. The fruiting bodies of the fungus will appear as small black dots arranged in concentric circles in the sunken lesion when its diameter reaches about 12mm.

Management

Responsible use of pesticides

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

Mancozeb, dithianon, ziram, and metiram are registered for the control of bitter rot on pome fruit, including apples and pears. These fungicides when applied for other diseases such as powdery mildew or black spot will also control bitter rot if the timing coincides with spore release. However, where monitoring indicates that bitter rot is present a thorough, early application will be needed.

IPDM Alert. In orchards using predatory mites to control plant feeding mites the application of mancozeb, ziram or metiram may lead to pest mite outbreaks because the fungicides are toxic to predatory mites.

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 have been developed commercially.

More information

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. The species, strains and lifecycles may not be the same as in Australia even if the common names are the same.

Shane, W.W. and Sutton, T.B. 1981. Germination, appressorium formation, and infection of immature and mature apple fruit by *Glomerella cingulata*. Phytopathology 71: 454-457

Velha, A.C, Stadnik, M.J., and Wallhead, M. 2019. Unravelling *Colletotrichum* species associated with Glomerella leaf spot of apple. Tropical Plant pathology 44: 197-204

Acknowledgements

Some images in this chapter were included in the first edition of this manual with permission from the University of Georgia, Plant Pathology Archive.

Apple and Pear IPDM

Codling moth

IPDM Quick Facts

- Orchard hygiene is a critical component of codling moth control
- Destruction of infested fruit, removal and burning neglected trees, cleaning empty fruit bins before storage, and not leaving unpicked fruit on trees after harvest will reduce the number of codling moth infesting the orchard.
- Burn piles of pulled trees before spring. Leaving them later means that any overwintering larvae under the bark will emerge and easily find mates, then mated females will move to nearby blocks of trees to lay eggs.
- Although codling moth numbers can be monitored using pheromone traps and the results can be used to optimise spray timing it is important to check for damage on a regular basis.
- Mating disruption can be an effective tool against codling moths. Mating disruption works best when used against low populations in large blocks of similar trees or where complementary tactics (such as trapping of females, egg parasitisation, applications of virus against newly hatched larvae, nematodes and/or parasitoid wasps against cocooned larvae and pupae) are used.
- Normal pheromone lures will not give accurate indication of moth populations in mating disruption treated blocks. High dose pheromone lures incorporating kairomones such as pear ester should be used in disruption treated blocks.
- Hanging traps high in the tree gives better results.
- A group of 3-5 traps, about 10m apart in a row, may give a more reliable indication of moth activity in a block than single, sparsely placed traps.
- Codling moth in most districts has two cohorts within each generation. Emergence of the first cohort in spring is erratic and results from individual blocks are required to set biofix dates, rather than using district forecasts.
- Emergence of the second cohort in spring is predictable using degree-days accumulated from the date when daylength reaches 13.5-14 hrs.

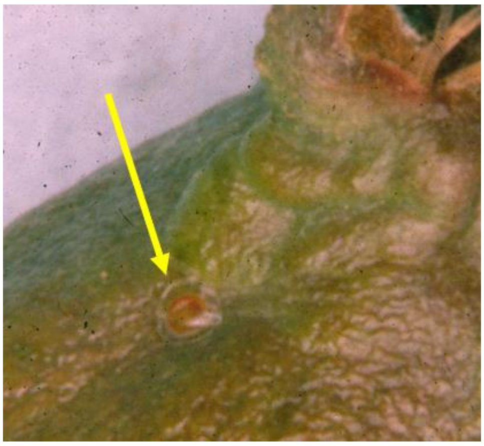
- Selection of pesticides for use against insect pests and fungal diseases needs consideration of the non-target effects of those pesticides so that the impact on biological control agents is minimised to prevent resurgence of minor/ secondary pests (see chapter 6).
- The age of larvae infesting fruit can be determined by measuring the width of the head capsule to identify the larval instar and then using the degree-day table to work backwards to when the larvae would have hatched. That allows you to identify possible problems with spray application or poor timing.
- The introduced parasitoid wasp *Mastrus ridens* has been released against codling moth in QLD, NSW, VIC, TAS, and SA.

The pest and its significance

Codling moth *Cydia pomonella* is the key pest in most pome fruit orchards, except in Western Australia, and some pesticides used in its control impact a range of secondary pests through effects on their biological control agents. Left uncontrolled it can damage up to 100% of the fruit crop but in most commercial orchards damage levels rarely exceed 1% of the crop for so-called conventional orchards but can be higher for organic orchards.

Codling moth originated in Eurasia and is now present in nearly all pome fruit growing countries. The adult moth has a wingspan of 12-19mm and body length about 9-10mm. The forewings are brownish-grey with patterns of lighter grey wavy crosslines and have a characteristic bronze or copper coloured spot at the tip. There is a relatively rare colour morph that has a gold coloured forewing. The hindwings are pale brownish-grey with fringed borders.

At rest the wings are folded over the back. Adult females are larger than males, that can be easily identified by the presence of a pair of claspers at the end of the abdomen.



The female lays flat, oval, 1mm long eggs singly on leaves and fruit. Newly laid eggs are opaquely white and develop a red ring towards maturity. Just before hatching the black head of the larva becomes visible in the egg. A newly hatched larva is white with a black head that is approximately 0.3mm wide across the head capsule. The young larvae move to the fruit where they chew through the skin on the side, stem end or calyx end and excavate a cavity just below the skin where they moult to the next instar (growth stage) and start eating their way to the core. On their way to the core they plug the excavated tunnel with excrement (frass) that initially appears as sawdust like material at the entrance to the tunnel but as the larva grows the frass becomes browner and has a syrupy consistency. There are generally five larval instars that can be distinguished by the width and colour of the head capsule. Average head capsule widths for each instar are 0.3, 0.5, 0.8, 1.2, and 1.7mm respectively. At the core they feed on the seeds until they reach the fifth instar. Fully mature larvae are about 15mm long and creamy pink with a dark

brown head. **Note:** Similar damage can be caused by oriental fruit moth, whose larvae look like codling moth larvae but do not generally feed on the seeds.

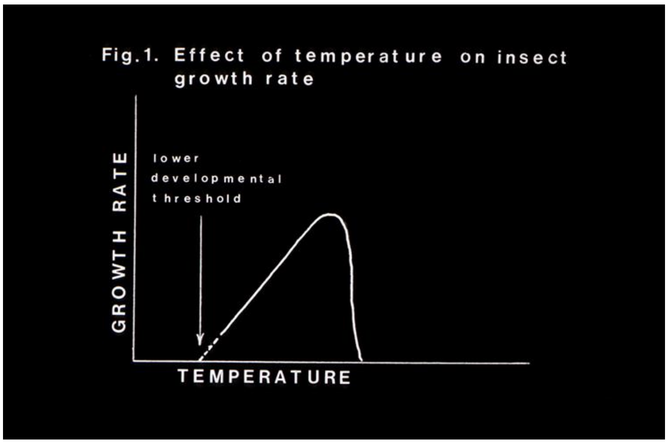
Mature larvae leave the fruit and form cocoons under loose bark on the trunk or amongst leaf litter on the ground beneath the tree. In summer most of the cocooned larvae form a pupa from which an adult emerges about two weeks later. A small percentage of the cocooned larvae in summer enter diapause (hibernation) until the following spring. As day length shortens progressively higher percentages of cocooned larvae enter diapause and all of the larvae cocooning in autumn diapause.

In spring, as daylength starts to increase and temperatures increase, diapausing larvae that have experienced sufficient chill break diapause and form pupae from which adults start emerging around pink bud on the apple trees. This first cohort of the over-wintered population emerge in one or more periods of peak activity referred to as flights. Diapausing larvae that have not had sufficient chill remain in diapause until daylength increases beyond 13.5-14hrs after which they pupate and eventually emerge as flights of a second cohort of the overwintered population. The eggs laid by these first and second cohorts produce the first generation of the season. Up to three generations a season can be produced in warmer areas. The first and second generations include the progeny of both cohorts as distinct but overlapping populations but generally the third generation only includes the progeny of the first cohort of the second generation. A small percentage of diapausing larvae can remain in diapause, missing an entire fruit season, to emerge in the next spring.

Most mating occurs around dusk when the temperature is around or higher than 16°C. If conditions are overcast in the afternoon and temperatures are high enough some mating can commence earlier than dusk. Female moths emit a sex pheromone in a process known as “calling” to attract males for mating. The pheromone components have been identified and synthetic versions are used in pheromone lures for trapping males and in mating disruption dispensers to delay mating and therefore reduce the number of eggs laid by female moths.

Effect of temperature

The growth rate of an insect increases with temperature until the optimum temperature (31°C for codling moth) is exceeded, after which the growth rate rapidly decreases, and death can occur if the temperature is high enough for long enough (thermal death point). At the other end of the growth curve the growth rate decreases as temperatures decrease until the growth rate becomes so slow that it appears to stop (so-called lower developmental threshold).



These characteristics are used to develop physiological time units called degree-days that better describe insect age and allow phenology models to forecast timing of lifecycle events such as egg hatch and subsequent generations. Degree-days for codling moth are denoted by the symbol DD_{10C} where the subscript "10C" identifies the base temperature of 10°C which is used as the practical equivalent of the lower developmental threshold. Sometimes they are denoted as "°D (10°C)". Other insects have different base temperatures used to calculate degree-days. The eggs, larvae, and pupae each have specific physiological time requirements to complete their development before transforming to the next life stage. Temperature also affects activities such as flight (>13°C) and mating (>16°C).

For practical purposes these temperatures are ambient air temperatures rather than the actual temperature experienced by the insect in its microclimate, which is not practical to measure.

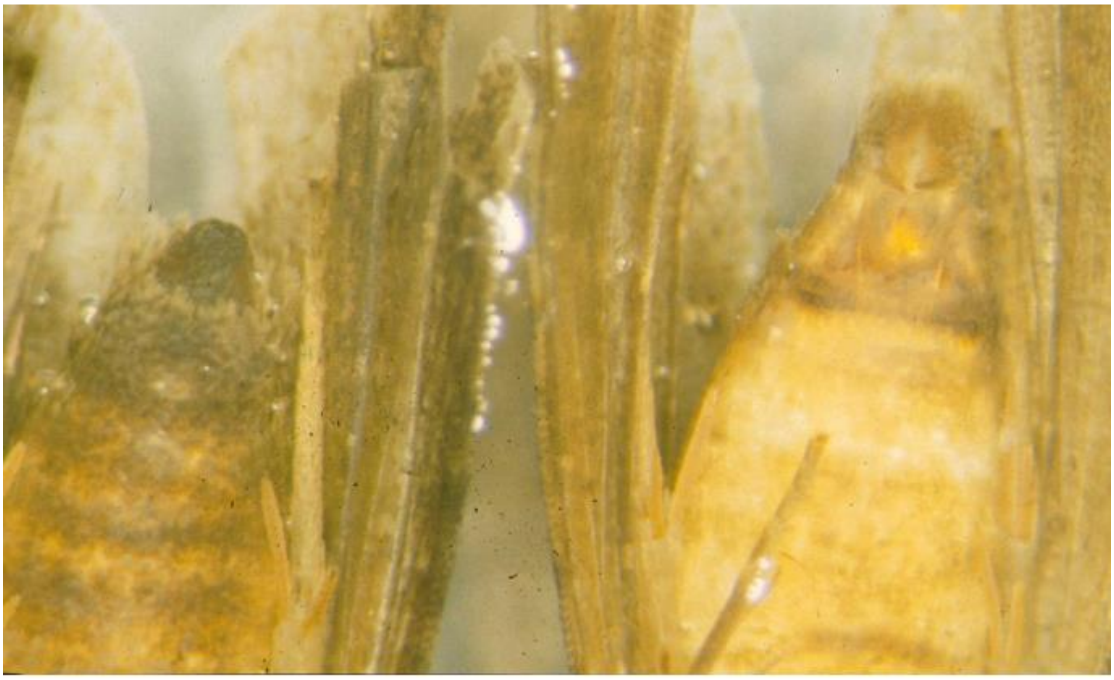
Note: In countries such as the USA, that use Fahrenheit temperatures the degree-days for codling moth are often quoted as "^{0}D (50°F)" and the values are much higher because the conversion factor is ^{0}D (F)=1.8 x ^{0}D (C). This must be considered when using reference material from overseas or even the early Australian references before we changed from using Fahrenheit.

Monitoring

Pheromone traps baited with lures containing a synthetic version of the female sex pheromone are used to monitor population trends and assist in decisions about management of the pest. Several trap types are available, and the most common type is a delta trap, usually made of coreflute. All non-automatic pheromone trap types have one component in common: the base of the trap contains an insert treated with a sticky substance that traps the male moths when they land on it. It is important that the sticky insert be replaced when it becomes heavily soiled with moth scales, dust and debris over time and therefore loses its effectiveness. Delta traps come in a range of colours. White traps are common but tend to attract bees and other insects during the flowering period. Red coloured traps do not attract bees and are easier to see than white traps during flowering. The traps capture more moths if placed higher in the tree because that is where moths are more active at dusk as they seek mates. The traps come with a wire that can be hooked over a branch but for trees taller than 2m the wire can be attached to a thin pole (bamboo is ideal) that allows the trap to be placed higher in the tree, from the ground, and also makes it easier to bring the trap down to inspect the contents. .

In orchards that are not using pheromone-mediated mating disruption the standard lures contain 1mg of Codlemone (the codling moth pheromone). In large blocks use about 1 trap for every 2 ha but never rely on just one trap in a block regardless of how small the block is. The single trap may have inadvertently been placed in a "hotspot" of codling moth, in which case it will give bias decisions towards spraying the whole block when perhaps only the hotspot needs to be sprayed, or conversely it may have been placed in an area of low moth density or the lure may be faulty and the low capture rate may lead to not spraying when spraying was needed. The more traps you deploy the more moths you will capture but rather than make decisions on the total number of moths captured it is better to calculate the average number of moths captured per trap in the block. Early recommendations for placement of traps required the traps to be separated by at least 30m to remove competition or interference between traps. More recent research suggests that it may be better to place 3-5 traps in a line, spaced 10-20m apart and use the array as a single "super trap". This layout takes account of the dispersal and flight behaviour of the moths and increases the probability that they will intersect the pheromone plume.

In orchards treated with mating disruption pheromone dispensers the 1mg lures used in standard traps will not give reliable results. High dose lures containing 10mg of pheromone were developed to improve performance in disrupted orchards. More recently lures loaded with a combination of pheromone and a kairomone, such as pear ester, have been shown to be more effective monitoring tools because they attract both male and female moths. If using these "combo lures" it is useful to distinguish between male



male   female and female moths (see below for images of the tips of the abdomen of each sex) as the females are generally mated females searching for an oviposition (egg laying) site.

Traps in mating disruption treated orchards should be placed high in the trees and at least 1 m away from any hand applied pheromone dispensers. The line trapping method mentioned above is also recommended in blocks treated with mating disruption.

Most of the lures available in Australia should be changed every 6-8 weeks.

Traps should be in place by pink bud to detect early flights. There is no need to inspect the traps more frequently than once per week early in the season because low temperatures mean any eggs laid by moths will take a few weeks to hatch and setting of biofix dates to initiate phenology models can be done by using the day after the last zero catch as the biofix. This provides enough flexibility to allow a timely spray if needed and it is better to be a bit early rather than too late.

Advances in technology have produced prototype automated pheromone traps that use various techniques to detect, count and identify insects captured in the trap and then wirelessly transmit that data to a website. These traps can provide instantaneous counts but are currently expensive and are usually leased as part of a service contract that includes access to the remote database. The comments above regarding setting and placement of traps hold for automated and non-automated traps.

Calculating degree-days

If you have an automated weather station it may also come with software to calculate leaf wetness periods, ascospore maturity, and degree-days.

If your weather station does not come with relevant software but you can download the daily maximum and minimum temperatures to a computer, you may be able to access a web-based degree-day model that can use your temperature data.

Most models that use maximum and minimum temperature data calculate degree-days using a sine-wave approximation fitted to the max-min data to provide a more accurate estimate than that obtained by using the simple average temperature minus the base temperature calculation presented below. The sine-wave calculation is useful early in the season because it more accurately calculates degree-days at times when the minimum temperature is below the base temperature. Once the minimum temperature is higher than the base temperature there is not much difference between the two methods.

To estimate degree-day values from daily maximum and minimum temperatures simply add the maximum and minimum temperatures and divide the result by 2 to get the "average" temperature then subtract 10 (being the base temperature) to get the degree-days for that day. This basic calculation is easy to program into a computer spreadsheet:

$((\max + \min)/2) - 10 = DD_{10C}$

For example: Max = 25, Min = 15

((Max + Min)/2) -10 = ((25+15)/2) – 10 = (40/2) -10= 20-10 = 10

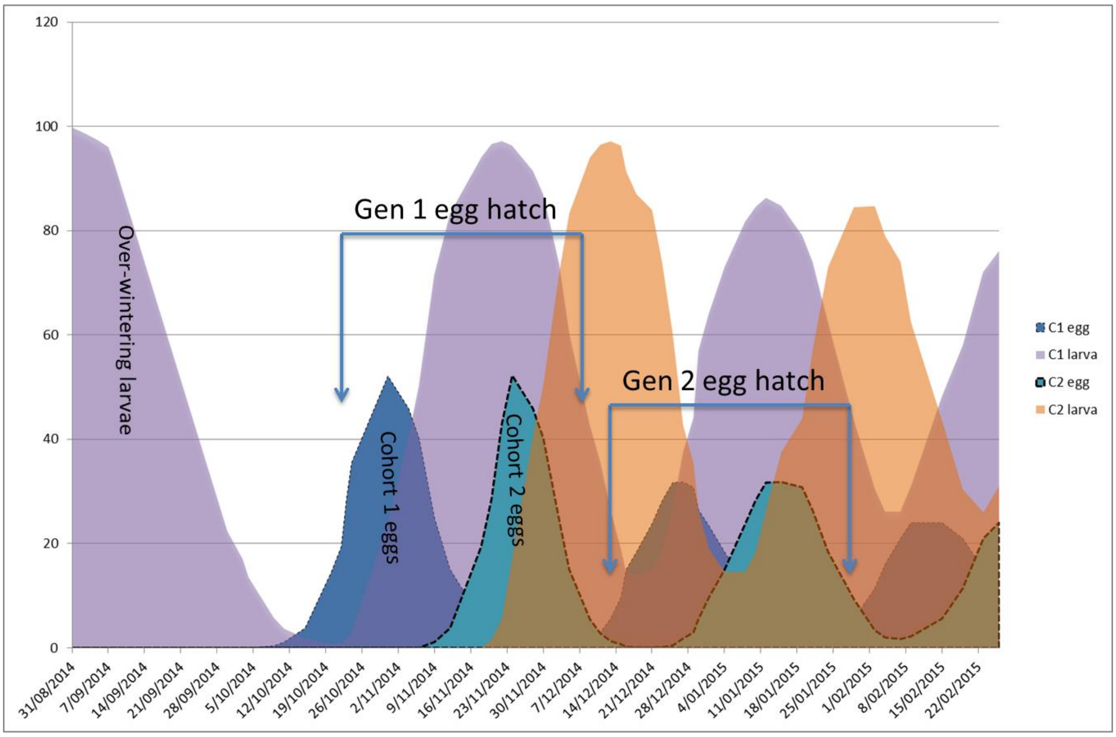
Use of degree-days to time spray applications.

To predict when the eggs laid by moths of the first cohort that emerged in spring will start to hatch you set a biofix based on the results of trapping the adult moths. In Australia, unlike many northern hemisphere countries, spring emergence is erratic and difficult to predict using arbitrary calendar dates. There is usually great variation in emergence dates even between blocks on the same farm. For this reason, it is more appropriate to set biofix for individual blocks. Provided traps have been in place before moths have started to emerge, there will be a period in which no moths are trapped, followed by either the odd catch then nothing and eventually consecutive periods when moths are captured. Experience has shown that weekly trap inspections are adequate for determining biofix. More frequent inspections run the risk that cool dusk periods that limit flight will result in underestimates of emergence dates because moths can emerge at lower temperatures but not fly much until dusk temperatures are around 16°C. Two or more consecutive weeks in which moths were captured triggers setting of the biofix. Once again, experience has demonstrated that setting the biofix as the day after the last inspection date that recorded zero catch accounts for the possibility that moths emerged but didn't fly, or if they were flying they were trapped on the first day after the traps were inspected. It is always better to be a little bit early than late with a spray application.

Once biofix has been set and you start accumulating degree-days the start of egg hatch will begin at around 140 DD_{10C}. Many ovicides require application at 80-100 DD_{10C} to be effective. Egg laying will continue while moths are still present so cover may be required for about 6 weeks depending on the size of the population.

Each generation takes about 560 DD_{10C} which means that the start of egg hatch for the first cohort of the second generation will be due at 700 DD_{10C} from the original biofix and the third generation at 1260 DD_{10C}.

In many pome fruit areas in Australia codling moth exhibits two distinct cohorts in each generation. The emergence of the second cohort, and therefore setting of its biofix, is based on degree-day accumulation after the daylength reaches 13.5-14.0 hrs. The date at which this occurs varies a little from year to year and by latitude. Emergence of the first moths of the second cohort in spring, and therefore expected biofix for that cohort, occurs about 100 DD_{10C} after daylength reached the critical photoperiod. Thereafter the calculations for egg hatch and subsequent generations of the second cohort follow the same pattern as the first cohort but using the biofix dates appropriate to the cohort.



Fruit damage assessments

Pheromone traps indicate moth activity and phenology models can predict egg hatch to assist with timing of sprays if considered necessary. The phenology models can also predict when the next generation of moths is due to appear. Many factors impact on efficacy of control measures. Codling moth larvae are not susceptible to pesticides while they are feeding inside the fruit. Egg laying occurs over a sustained period, so it is important that periodic checks are made to detect problems in time to take corrective action.

The monitoring program provided in Chapter 3 of this manual includes details of two sampling methods useful for assessing codling moth management. The first is a 1-minute inspection of a tree to check for obvious signs of infection by disease and infestation by pests. This involves walking around a free standing tree, or along a panel of trellised trees, for one minute looking for scab lesions on leaves and fruit, rolled leaves that indicate LBAM, chewed leaves that indicate loopers and weevils, and the tell-tale signs of sawdust-like small piles of frass on fruit, indicating early stage infestations of codling moth. You should also easily see the larger piles of brown syrupy frass indicating deeper

entries of codling moth larvae. This one- minute inspection should be repeated at least 5 times in the one session, selecting trees (or panels) at random throughout the block. It can be done at the same time as leaf samples are inspected for presence of mites and traps are inspected for moths. If signs of codling moth are detected they should be recorded and then take a knife and gently cut into the fruit, at first just under the skin if it is an early entry and look for the larva. You may have to follow the tunnel to the core if the entry is more than a few days old. If you use a linen tester type hand lens it will have a mm scale on the base. Once you find the larva you can use the scale on the base of the linen tester to estimate the width of the larval head capsule. Make a note of the head capsule width and the colour of the head capsule, and then kill the larva if you haven't already done so. The head capsule colour and width can be used to identify the instar and degree-day range for that instar can be read from the table below. By checking either your codling moth phenology model output or calculating degree-days from your weather records you can estimate when the larva would have hatched from the egg. You can then check your spray program for any issues around the time of egg hatch.

Instar	**1**	**2**	**3**	**4**	**5**	**pupa**
HCW (mm)	0.3	0.5	0.8	1.25	1.6	
HC colour	Black	Brown	Brown	Black	Brown	
DD egg hatch to end of stage	72	117	173	241	330	558

The second method is a more detailed inspection of fruit which is normally done at the end of natural fruit shed in late December and again just before the second and third generations are predicted to start, or harvest is starting. This inspection involves selecting at least 5 trees (or panels) at random in the block and, using a picking ladder if necessary, inspecting 100 randomly selected fruit on each of the sample trees. If you detect signs of codling moth infestation, follow the process mentioned above for extracting and identifying the age of the larva.

If more than two codling moth infested fruit are detected in any of the early inspections, you are heading towards economic damage of greater than 1% of your crop and you should intensify your sampling to confirm the situation before taking corrective action.

Biological and cultural control

Mating disruption is a technique in which the orchard air is saturated with pheromone emitted by slow-release dispensers or aerosol puffers (Chapter 7). The disruption in moth communication makes it difficult for males to find females and the resultant delay in mating reduces the number of eggs a female can lay in her lifetime. The dispensers need to be in place before the first moths emerge in spring but once in place they operate for the entire season. The technique works best against low populations but when used in conjunction with other techniques such as orchard hygiene, release of biocontrol agents, application of entomopathogens and use of selective pesticides sustainable control can be achieved without the side effects of less selective insecticides.

Orchard hygiene practices such as removal and destruction of infested fruit and reducing the amount of fruit left behind on trees after harvest of early maturing varieties limits build-up of codling moth after harvest is especially important for organic producers. Leaving as few as 3 fruit per tree hanging after harvest can potentially result in an extra 400 female codling moth per hectare overwintering. Selection of rootstocks and scion cultivars with smooth bark reduces the number of cocoon sites on the trees and forces the codling moth larvae to cocoon amongst leaf litter on the orchard floor and in the soil beneath the trees where they are prone to predation and entomopathogens.

Codling moth eggs are preyed upon by earwigs and mirid bugs but neither gives significant control. Egg parasitoids such as Trichogramma wasps parasitise codling moth eggs and are available as natural populations and from commercial suppliers of biological control agents.

A larger parasitoid wasp *Mastrus ridens* that attacks cocooned larvae was imported and released into nursery sites on orchards in QLD, NSW, VIC, SA and TAS with impressive early results. Further work is underway to develop ways of assessing establishment and enhancing its survival and distribution. *M.ridens* is particularly adept at reducing overwintering populations of codling moth to low levels. Its use in conjunction with mating disruption to reduce egglaying, Trichogramma to reduce the survival of eggs and hatching of first instar codling moth larvae, and spraying of entomopathogenic codling moth granulosis virus to kill neonate codling moth larvae provides an integrated system of biocontrol with potential to greatly reduce reliance on synthetic pesticides.

Chemical control

Most of the insecticides currently registered for codling moth control have specific guidelines on timing of sprays based on degree-day accumulation from a moth catch related biofix. The mode of action of the insecticide and the targeted insect stage are what determines the timing.

Most of the ovicides (chemicals that kill eggs) target eggs that are less than 3 days old. They need good coverage of the surface on which the moth lays her eggs, because it is neither practical, safe nor legal to spray at frequencies and volumes required to hit widely spaced individual eggs.

Many larvicides can kill larvae about to hatch from the eggs, and as the larvae move from the eggs to the fruit. The labels of these products usually contain statements requiring the first application at certain accumulated degree-days from biofix. Once the larvae have penetrated the flesh of the fruit they are no longer accessible to pesticides until they leave the fruit as mature larvae looking for cocooning sites.

Codling moth is adept at developing resistance to insecticides and all new products come with resistance management statements on the label that must be obeyed. Incorporating behaviour modifying treatments like mating disruption into the codling moth management program and protection of predators and parasitoids by choosing IPDM compatible pesticide options is a cost-effective strategy to prevent resistance while controlling the pest.

IPDM warning: Many insecticides and fungicides have detrimental effects on biocontrol agents. See Chapter 6 for information about these effects and **READ the PRODUCT LABEL**

Apple and Pear IPDM

Fruit flies

IPDM Quick Facts

- Two species of fruit flies have a major impact on pome fruit production in Australia.
- Queensland fruit fly (QFF or Qfly), *Bactrocera tryoni*, is a native tephritid whose natural range has expanded southwards in the eastern states where it is now officially considered endemic to the Northern Territory, Queensland, New South Wales and Victoria although not all pome fruit areas in Victoria are infested. Sporadic outbreaks occur in other states.
- Mediterranean fruit fly (MFF or Medfly), *Ceratitis capitata*, is currently restricted to areas in Western Australia from Esperance in the south to Derby in the north, although sporadic outbreaks occur in parts of South Australia.
- Trapping to detect presence of adult flies and prediction of key periods in their life-cycle will improve the timing and efficacy of control measures.
- Monitoring traps for QFF use Cue-lure as the attractant for male flies.
- Trimedlure- Extended is used as the attractant for male MFF.
- Methyl-eugenol is used in surveillance traps to detect presence of other exotic fruit fly species.
- On-farm quarantine, orchard hygiene, monitoring and surveillance traps, and area-wide co-operation to manage host plants are critical to good fruit fly control.
- Protein is important for freshly emerged fruit flies to mature sexually and for females to develop eggs.
- Protein baits attract both sexes of immature fruit flies.
- Protein baits are not attractant to sexually mature flies except for older females that have laid eggs and need a protein feed to develop another batch of eggs.
- The effectiveness of protein baits depends on the type of protein, the toxicant added to the protein, the formulation (liquid, gel, etc) of the bait, placement, and timing of the baiting.
- Protein baits are short-range attractants so traps need to be placed no more than about 6m apart and bait sprays should be applied as coarse drops.

- Male annihilation technique uses is an attract-and-kill technique for male fruit flies and is based on combining pheromone and a suitable registered toxicant in blocks or pads placed at medium to high density in orchard trees.
- Traps baited with lures containing host plant volatiles are available for monitoring and mass-trapping.
- Recent legislation is some states require traps with sticky surfaces to be enclosed in mesh or another device to prevent access by small vertebrates such as lizards, native mice, birds etc.
- Sterile Insect Technique (SIT) uses mass-release of sterile flies to suppress wild fly populations.
- Cover sprays against fruit flies can decimate beneficial predators and parasitoids

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.

Queensland fruit fly

The Queensland fruit fly, (*Bactrocera Tryoni;* QFF) has a red-brown thorax with distinct yellow markings, a dark brown abdomen and is around 6-8 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

Its natural range has expanded southwards in the eastern states and it is now officially considered endemic to the Northern Territory, Queensland, New South Wales and Victoria although not all pome fruit areas in Victoria are infested. Sporadic outbreaks occur in South Australia, Western Australia and Tasmania.

Mediterranean fruit fly

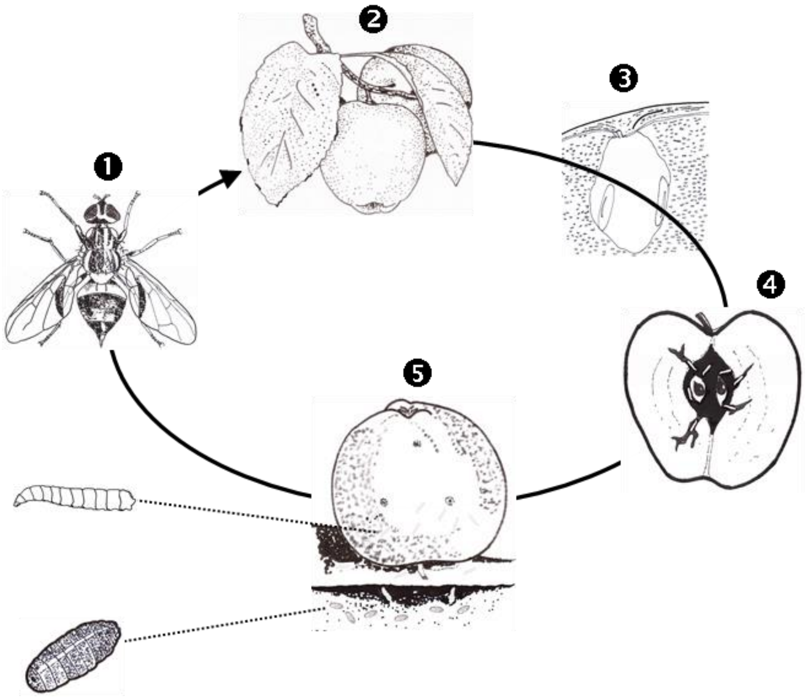
Mediterranean fruit fly (*Ceratitis capitata*; Medfly) can tolerate cooler climates better than most tropical fruit flies. It is currently restricted to areas of Western Australia as far south as Esperance and as far north as Derby but the main pome fruit infestation is in the Perth Hills.

Medfly has an extremely large host range and can infest over 200 fruit and vegetable species.

The adult fly is 3-5 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, encircled by two light coloured rings. The thorax (middle) has irregular patches of black and silver.

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

Life cycle



Although there are significant differences between QFF and Medfly in terms of development the similarities in the life cycle are presented in the above diagram. During warm weather in spring or early summer adult fruit flies feed and mate ❶. Adult flies feed on sweet exudates from plants including nectar as an energy source and feed on protein from yeasts and bird droppings on leaf surfaces to mature sexually and for females to develop eggs. Mated 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 lifetime. The eggs and larvae of QFF and Medfly are almost identical. Eggs are white, 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 two to four days. Development of larvae (maggots) takes six to eight days in summer. The larvae of QFF and Medfly are so alike they need to be identified under a microscope or by DNA testing. Rapid test kits (loop-mediated isothermal amplification, or LAMP kits) suitable for field application have been developed to allow relatively quick identification in field responses. Maggots have cutting jaws which allow them to cut fruit into pieces small enough to swallow. They tend to chew and create tunnels which lead toward the centre of the fruit. This chewing introduces bacteria and fungi which in turn result in the fruit developing 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, larvae become inactive and develop into oval, brown pupae in which the adult fly develops. Medfly but not QFF may be able to survive through winter in this pupal form. The activity of fruit flies depends on temperature. Although development and lifecycles slow, both medfly and QFF can exist as adults during winter in warmer regions.

Medfly:

In South West Western Australia medfly is active late spring, summer and autumn, and becomes inactive in winter in cold areas. Medfly can overwinter as eggs and larvae in fruit, as pupae in the ground, or as adults in sheltered areas. Adult medflies become active in winter when temperatures exceed 12°C. With rising temperatures in spring adults emerge from overwintering pupae in the soil and adults that overwintered in sheltered sites also become active. In WA the succession of ripening deciduous fruit tree hosts is apricots and peaches in late spring, nectarines and plums in summer, and pome fruit in autumn, with citrus and unpicked apples being overwintering hosts that provide the flies that infest stone fruit in the following spring.

Each life stage of Medfly has a different lower temperature threshold for development. Egg maturation in adults requires 12.8°C, egg hatch 9.3°C, larval development 11.1°C, pupal development 8.4°C and 298 DD to complete one life-cycle according to studies completed in WA (De Lima 2008).

QFF:

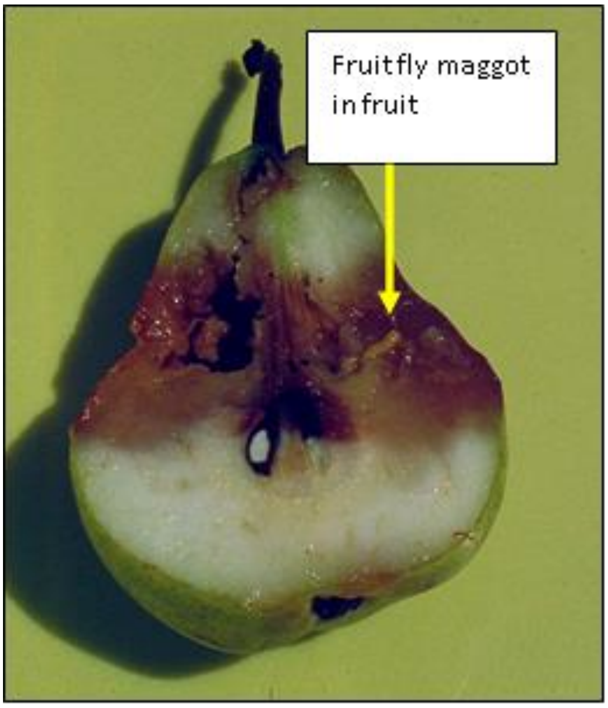
Adult QFF can survive through winter in protected sites although 5-7 consecutive days with minimum temperatures below -7°C will kill them. Female QFF may resorb eggs during extended cold periods. Although they cease producing eggs when daily maximum temperatures are below 18°C, in areas with relatively warm winters QFF can lay eggs into ripe fruit if the temperatures during the day are above 5°C. QFF is more active in warm humid conditions and after rain. Although they are most active from October to May hot dry conditions in summer affect their survival. However, microclimates in irrigated orchard trees are less severe than ambient air temperatures and humidity. Males tend to be more active in the morning and then later in the afternoon. Both males and females need a protein feed to become sexually mature and they use honeydew and nectar as a sugar source to provide energy.

There are considerable differences in published lower developmental thresholds, possibly due to the methods used or locations from which the flies were sourced. Most use different threshold temperatures for each life stage but Jessup (2020) proposed a simplified model based on degree-days base 12.4°C ($DD_{12.4C}$). This model uses 82 $DD_{12.4C}$ from 1st July for egg maturation, mating and oviposition, Eggs hatch after another 17 $DD_{12.4C}$ and larvae pupate after another 81 $DD_{12.4C}$ .The pupal stage lasts 224 $DD_{12.4C}$ and the first generation of new adults after winter begins to emerge 404 $DD_{12.4C}$ after 1st July. These adults take 82 $DD_{12.4C}$ to mature, mate and begin oviposition.

Damage

Both species do similar damage on pome fruit. The egg laying sites are indicated by punctures called stings because the female has a needle-like ovipositor that she inserts into the fruit to lay her eggs. Stings are more obvious on pale, smooth skinned apple cultivars such as Golden Delicious, Granny Smith, and Cripps Pink apples or green skinned pears such as WBC and Packham. The type of damage caused by fruit fly larvae varies with the type and maturity of the fruit, the number of larvae in it, and the weather. As the larvae feed on the flesh of the fruit various yeasts and bacteria develop and cause further breakdown of the flesh. If the flesh is hard or immature the larvae form a network of feeding channels that eventually leads to internal decay. Heavily infested fruit will eventually fall to the ground and the mature larvae will crawl out and burrow into the ground to pupate.

Vinegar flies (*Drosophila* spp.) and sap beetles (*Carpophilus* spp.) are also associated with rotting fruit but they generally only attack pome fruit that is very close to harvest maturity or was damaged by other means such as codling moth, hail, or mechanical punctures. *Drosophila* larvae look superficially like small fruit fly larvae but have a projection from the rear end that looks a bit like an exhaust pipe whereas fruit fly larvae have a blunt rounded rear end. *Carpophilus* larvae are not wedge shaped, have 3 pairs of legs, an obvious brown head and two small brown pointed projections at the rear.



Note: Presence of *Drosophila* larvae does not automatically implicate *Drosophila* as the cause of damage. *Drosophila* are attracted to rotting fruit and may have entered after fruit fly larvae or other pests have left the fruit.

Management

The main means of fruit fly dispersal is through transport of eggs or larvae in infested fruit. Fruit flies are often transported over large distances by travellers. Domestic quarantine limits the distribution of pests between states and excludes fruit flies 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. Specific details on the quarantine measure relating to individual states can be found on the websites of their departments of agriculture and primary industries.

Orchard hygiene

On-farm quarantine protocols to prevent visitors, contractors and staff bringing potentially infested fruit onto the property is a good first step in management of any pests or diseases. Obvious signage at all entry points will reinforce the message. Businesses that pack or store fruit for other growers need to ensure that they have strict guidelines in place that either impose standards for delivery of fruit or deal with ways to process substandard and/or infested fruit, including disinfection of bins.

It is important to remove and destroy waste fruit which is, or could become, infested with fruit fly. Fruit which has fallen or is left hanging after harvest should be removed and destroyed. Remember that even fruit which appears perfect may harbour infestations so be conservative and treat all unharvested fruit in this way.

Burying waste fruit is not a practical option for commercial orchards but if it is attempted the fruit must be buried deeply (>1m) to prevent any flies emerging from pupae from finding their way to the surface. Do not dump untreated fruit in or near the orchard because this can become a source of flies to infest other fruit. Cold storage at a core temperature of 1°C or below for 3 weeks or more will kill maggots in the fruit, so pome fruit rejected from the packing line is low risk because it is usually subjected to a long period of cold storage before sale. Be aware that it may take several days for fruit in the middle of a stack of full bins to reach a core temperature of 1°C or below. Cold storage of fruit collected from the orchard floor or left on the trees after harvest is not a practical option for commercial orchardists. In-field pest management approaches to control the pest prior to the fruit becoming susceptible to attack are essential.

Any host plants that are unwanted or regularly remain unharvested should be removed and destroyed. This includes trees from around sheds and houses, along boundaries and irrigation channels, and roadsides (if permitted by local by-laws). These measures will also help with management of other pests such as codling moth, oriental fruit moth, carpophilus beetles, and diseases such as scab.

Recommendations to freeze, boil, or puree waste fruit and feed it to livestock are only applicable to home gardeners, small lot owners, or small scale organic producers. Livestock used for meat, milk, or egg production should not be fed fruit that has been sprayed unless label instructions are strictly followed.

Monitoring fly populations

Adult fruit flies can be present in the orchard throughout the year. The one-minute tree inspection technique described in Chapter 3 is suitable for detecting adults on the tree and damaged fruit. The flies often rest on the undersides of leaves and can fly quite quickly if disturbed. Around the middle of the season monitoring for stings should commence. The mid-season and pre-harvest fruit damage inspections described in Chapter 3 can be used to quantify fruit fly damage. 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 and inspect with a hand lens. You should be able to see fly eggs.

Fruit flies are mobile pests that have wide host ranges and, because each host species generally provides only a relatively short period in which the fruit is suitable for sustaining growth of maggots, they disperse in search of successive suitable hosts. This means that area-wide co-operation amongst a range of stakeholders to manage susceptible host plants is critical to good fruit fly control.

While visual monitoring provides useful information, earlier detection is likely with traps which use pheromone or food baits.

Trapping to detect presence of adult flies and prediction of key periods in their life-cycle will improve the timing and efficacy of control measures. The most common traps used for this purpose use male attractants as lures and a toxicant to kill the insects that enter the trap. Cue-lure is used as the attractant for male QFF and Trimedlure- extended is used as the attractant for male MFF. Government surveillance programs also use traps baited with Methyl-eugenol to detect presence of other exotic fruit fly species and other endemic species that do not respond to either of the other lures.

Traps based on protein baits are available to detect immature flies. Protein is important for freshly emerged fruit flies to mature sexually and for females to develop eggs. Protein baits are not attractant to sexually mature flies except for older females that have laid eggs and need a protein feed to develop another batch of eggs.

Traps containing coloured sticky surfaces and lures based on host plant volatiles to attract egg-laying females are also available. The exposed sticky surfaces need regular maintenance to remain effective because dust and debris that accumulates on the surface reduces its ability to capture the insects. They also tend to capture a range of non-target flying insects. In addition, new animal welfare regulations require traps with sticky surfaces to have mesh or other design elements that prevent small vertebrates from becoming stuck. Considerable effort worldwide, including Australia, is being expended in development of user-friendly female traps.

Traps should be hung in the tree canopy at about head height and about two-thirds of the way out from the trunk, in semi-shade and clear of foliage to allow easy access for the flies through the entry holes in the trap. The traps should be in place in time to detect early activity of overwintered flies. For QFF this should be before 82 $DD_{12.4C}$ from 1st July. There is no value in placing traps in pome fruit trees before flowering. Traps should be placed in evergreen trees or early fruit hosts such as citrus, loquats, and apricots to get an indication of early population trends for prediction of when subsequent generations are likely to occur.

Bait spraying

The effectiveness of protein baits depends on the type of protein, the toxicant added to the protein, the formulation (liquid, gel, etc) of the bait, placement, and timing of the baiting. An organic certified bait is registered and available. Bait sprays should be applied as coarse drops. Bait spraying will only kill adult flies that are foraging for the protein required for the males to become sexually mature and for the females to mature eggs in preparation for mating. It is therefore important that bait spraying is conducted early in each generation before fruit is being stung. Bait spraying does not kill eggs or maggots but by killing adults before they mate it does reduce the number of eggs being laid and therefore the number of maggots produced. Bait spraying is more effective when conducted in the morning because this is when flies are actively foraging. Bait spraying involves application of coarse droplets of protein solution, laced with a pesticide registered for that use, to leaves of trees likely to be harbouring flies. Entire tree coverage is not required and should be avoided so that pesticide residues and phytotoxic effects do not become issues. **DO NOT APPLY BY ORCHARD AIRBLAST SPRAYING EQUIPMENT.** Bait spraying in commercial orchards requires application of about 30L of the bait spray/ha. This can be achieved using 12volt operated spray equipment mounted to quad bikes, gators, utes, or small tractors. The fine spray nozzles usually fitted to the hand lance should be replaced with a nozzle that gives a coarse spray so that large droplets can be applied. About 60-100mL should be applied to the foliage of each tree (or panel of trellised trees), preferably avoiding spraying of fruit. Flies are attracted to the protein bait by smell. Bait sprays need to be re-applied if there is more than 5mm of rain. Where sprinklers are used for irrigation, they should be set so that they do not spray water into the tree canopy but if that is not avoidable then bait sprays must be applied higher in the canopy than where to irrigation water will hit. **IPDM note:** Sprinklers set up to wet the canopy will redistribute any pesticide residues and could lead to loss of effectiveness in those parts of the tree. This could lead to establishment of fungal diseases such as scab and allow build up of insects such as woolly apple aphid in lower parts of the tree.

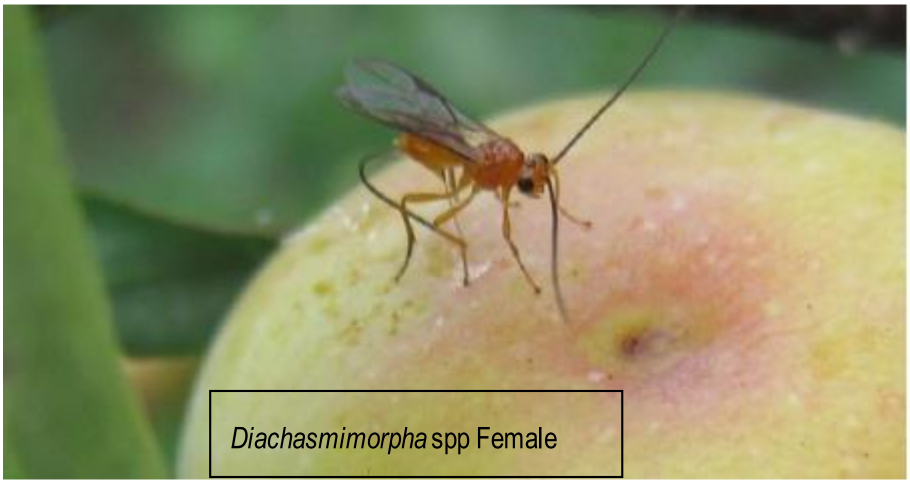
Lure and Kill

Bait spraying is a form of lure and kill, a technique in which insects are attracted to a pesticide-laced lure or bait and are killed when they feed on or contact the lure. Although protein baits can be used in traps for monitoring immature flies the main tool for lure and kill of fruit flies is the Male Annihilation Technique (MAT) which uses the lure solution from monitoring traps (cue-lure for QFF or Trimedlure-Extended for Medfly mixed with a toxicant and impregnated into either a block or pad of porous material like canite fibreboard, cardboard, or felt. Some MAT products simply use the lure/toxicant pad from the standard monitoring traps placed inside an inverted waxed paper cup hung in a tree as a cheap alternative. These MAT devices do not retain the killed flies, and if placed too close to monitoring traps may compete with the traps and give a false indication of fly activity. MAT devices should be placed no closer than 36m to a monitoring trap. Because of this potential interference, some export protocols may forbid use of MAT. Depending on fly pressure the MAT devices may need to be applied at 10-30/ha. They only attract and kill male flies so should be used in conjunction with other female targeted treatments such as baiting and Sterile Insect Technique.

Biological control

Fruit flies have several natural predators and parasitoids. Ants and ground beetles feed on larvae in infested fruit and pupae in the ground. Birds like choughs, poultry including guinea fowl and turkeys, and small vertebrates are generalist predators of insects on the ground.

There are eight species of Braconid wasps that are known to attack QFF in Australia and four of those have a wide Tephritid fly host range which includes Medfly and several other exotic species that are on the Australian quarantine watch list. *Diachasmimorpha kraussii* and *D. tryoni* are native wasps that attack 2nd and 3rd instar fruit fly maggots and have been recorded from far north Queensland down to southern inland NSW. Two parasitoids native to SE Asia were introduced into Australia from Hawaii. *D.longicaudata* has established from North Qld to Lord Howe Island. *Fopius arisanus* has spread from far north Qld to Sydney. *D.tryoni* has successfully established against Medfly in other countries.



Diachasmimorpha spp Female

The parasitoids are susceptible to many pesticides and pesticide-laced baits containing sugars as well as protein may be attractive to the adult parasitoids, leading to mortality. Combination of parasitoid releases and Sterile Insect Technique (SIT) is likely to be successful.

SIT involves the use of mass-reared flies that are sterilised prior to release. The technique has been used in Australia for many years against QFF and Medfly. The flies used in Australia for SIT are sterilised by irradiation in the pupal stage and transported to rear-out facilities where they mature and are distributed to release sites. The sterile flies are released in large numbers and the mating of sterile male flies with wild females produces sterile eggs and no offspring. SIT is a useful technique for use over urban areas which cannot be sprayed, or baited, and works well against low populations of the pests.

Cover sprays

The use of cover sprays against fruit flies often leads to severe disruption of the biological control agents that form the basis of your IPDM system and leads to mite flare and many other secondary problems. If you feel the need for a cover spray choose the registered chemical that has the least disruptive impact on the beneficial species in your orchard. There are tables in Chapter 6 that indicate the impact of chemicals on beneficial species.

Apple and Pear IPDM

Grasshoppers and Katydids

IPDM Quick Facts

- Wingless grasshoppers (*Phaulacridium vittatum*) tend to be pests in areas such as the Granite Belt, NSW Central West, NE Victoria, Perth Hills, and Donnybrook / Manjimup.
- Grasshoppers move into orchards from December to February and feed on tender young shoots and leaves. Fruit can also be chewed in bad years.
- Katydid s feed on the surface of young fruit. As feeding wounds dry a white-grey scar is formed which expands as the fruit grows and matures.
- Stone fruit is more likely to suffer katydid damage than apples and pears.
- Katydids are active insects and only a small number can result in substantial damage.
- Weeds such as capeweed and flatweed provide for emerging and developing nymphs, as well as supporting thrips and LBAM.
- Poultry in the orchard such as guinea fowl and chickens can be an effective option for grasshopper control in organic orchards or smaller orchards that can provide secure housing safe from foxes. Use of poultry in orchards requires strict attention to pesticide choice so that residues in meat and eggs do not become issues.
- A range of predators, parasitoids and entomopathogens generally keep grasshoppers under control.

Wingless grasshopper image S. Learmonth.

Katydid image NSW DPI

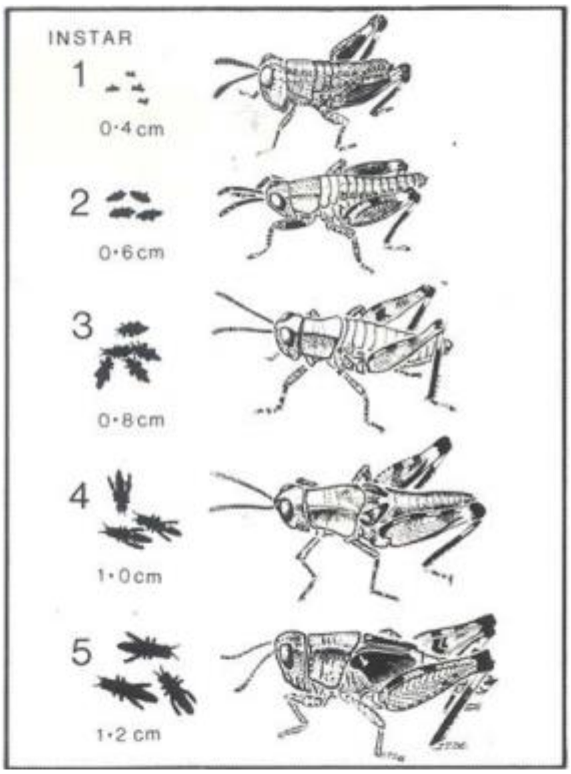
The pests and their impact

Wingless grasshoppers (*Phaulacridium vittatum*) are native to Australia and tend to be pests in areas such as the Granite Belt, NSW Central West, NE Victoria, Perth Hills, and Donnybrook / Manjimup.

Adult wingless grasshoppers are about 20mm long, generally brown with orange hindlegs and about 6% of adults have a distinct white lateral body stripe on top of the thorax. There is a short winged form that makes up about 60 % of the population and gives the insect its common name

Short winged morph of an adult Wingless grasshopper

Long winged morph of an adult Wingless grasshopper



There are five nymphal instars of wingless grasshopper that can be sorted by size and morphological characteristics based on antennae and wing bud development. Although wingless grasshoppers do not form large migratory swarms, they often congregate in large numbers that look like swarms in herbage around the margins of young non-bearing blocks of fruit trees. Therefore, the source of grasshoppers is likely to be close to the orchard (e.g. an adjacent paddock used for grazing). Wingless 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 move into orchards from December to February and feed on tender young shoots and leaves, and in bad years can damage fruit. The problem is worse along boundary rows, where they can completely defoliate young trees.

Katydids 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 40-50 mm long are green to brown. There is one generation per year with eggs 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 which 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. Weeds such as capeweed and flatweed provide for emerging and developing nymphs and support thrips and LBAM but at the same time support predators and parasitoids. Grass sward will deter wingless grasshoppers because they do not eat grass but prefer forbs.

Poultry such as guinea fowl, chickens and turkeys in the orchard can be an effective option for grasshopper control for organic orchards and smaller orchards provided suitable secure housing is available to protect the poultry from predation at night, and choice of pesticides is based on prevention of chemical residues in meat and eggs.

Pesticides should be a last option to be used where monitoring indicates the likelihood of significant damage. If pesticides are applied to egg-beds, the orchard floor or trees the pesticides are likely to disrupt IPM for other pests. Baiting using pesticide laced grains is not appropriate if poultry are being used to control the hoppers. If the decision has been made to use pesticides the poultry should be removed and kept out of the orchard until the with-holding period for stock feeding has been achieved. Because grasshoppers infest only a portion of the orchard it should be possible to leave the majority of the orchard untreated.

Pesticide should only be applied for katydids when there is potential for serious crop damage and 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 wasps., bee flies and flesh flies can have a substantial impact on egg survival. For katydids egg parasites include tachinid flies and wasps while predators of nymphs and adult katydids include assassin bugs, praying mantises, sphecid wasps and birds. Orchards in which IPM is practiced are likely to contain more of these beneficial organisms.

Apple and Pear IPDM

Helicoverpa and Loopers

IPDM Quick Facts

- **Budworms** are larvae of Noctuid moths in the genus *Helicoverpa* (which used to be called *Heliothis*). The two species of budworms that attack apples and pears are *Helicoverpa armigera* and *Helicoverpa punctigera*.
- *Helicoverpa* moths can invade orchards from neighbouring pastures and other crops in spring and have usually mated before arriving in the orchard when apple trees are blossoming.
- Pheromone traps indicate presence of male moths but not female moths. Mated females lay eggs on flower buds, flowers, or leaves near flowers.
- Budworm larvae bore into and through the flower buds, bore into the newly formed fruitlets, and feed on expanding new leaves. Single, deep, clean holes are an indication of budworm activity.
- Early indicators of impending budworm attack are the presence of noctuid moths attracted to house lights at night in spring, and the presence of distinctive ribbed eggs on blossoms and buds.
- **Loopers** are the larvae of Geometrid moths and get their common name from their distinctive looping or 'inching' action. Loopers attacking pome fruit are apple looper *Phrissogonus laticostata*, pome loopers *Chloroclystis testulata* and *C. approximata*, and twig looper *Ectropis excursaria*.
- Loopers feed on the leaves and, when feeding on fruit, generally graze the fruit surface making shallow damage distinguished from LBAM damage by occuring on exposed rather than protected surfaces of the fruit.
- Early indicators of looper attack are distinctive pellets of faecal droppings on leaves. Leaves higher in the tree will be chewed and caterpillars present.
- Eggs and small larvae of budworms and loopers can be controlled by *Trichogramma* wasps and *Bacillus thuringiensis* sprays, and larger larvae by codling moth sprays.

The pests and their impact

The native budworm *Helicoverpa punctigera* and the cotton bollworm *Helicoverpa armigera* (also known in Australia as tobacco budworm, tomato grub, corn earworm) can attack pome fruit from pink bud through to early fruit development. These are larvae of noctuid moths.

Corn earworm can vary substantially in colour but can be distinguished by the 'saddle' on its fourth body segment (Source: **cesar**).

Around the head region, corn earworm has white hairs (left), whereas native budworm has black hairs (right) (Source: **cesar**).

H. armigera has developed resistance to a wide range of pesticides and is generally more difficult to control. In southern Queensland *H.armigera* overwinters as diapausing pupae in the soil under late summer crops and emerge in spring during October but do not become the dominant species until mid-summer and autumn. *H.punctigera* breeds on flowering plants in inland Australia and in southern parts of Australia overwinters as pupae from which moths emerge in spring. In Victoria *H.punctigera* emerges before *H.armigera*. Both species are capable of long-distance migration on high altitude winds that precede cold fronts. Migrating *H.punctigera* arrive in southern fruit growing states in August and start laying eggs.Pheromone traps can be used to monitor activity of both species separately because they have different pheromones, requiring use of separate traps.

In pome fruit growing regions, the moths can invade orchards from pastures and other crops. Often this means that the moths have mated before arriving in the orchard around the time fruit trees are starting to flower. Pheromone traps only capture male moths, not females, and capture of males indicates females are likely to be present and laying eggs. Because the eggs are laid during the time that bees will be active it is important to make careful choices of control measures.

Heliothis (Helicoverpa) larva and damage

Budworm larvae bore into developing flower buds, flowers, developing fruitlets and unfolding leaves, and can cause considerable damage and fruit drop. Damaged fruit that remains on the tree may become deformed by deep depression with scar tissue. These scars are larger than those caused by apple dimpling bug and the deformities are distortions rather than dimples. Some chemical control choices will affect bees and therefore pollination, biocontrol agents that prey on the eggs of Helicopverpa and other pest species may be affected, and the costs of counteracting the side effects may outweigh the benefits of controlling the budworms.

Loopers are the larvae of Geometrid moths and get their common name from their distinctive looping or 'inching' action. Loopers attacking pome fruit are apple looper *Phrissogonus laticostata*, pome loopers *Chloroclystis testulata* and *C. approximata*, and twig looper *Ectropis excursaria*. Loopers feed on the leaves and, when feeding on fruit, generally graze the fruit surface making shallow damage distinguished from LBAM damage by occurring on exposed rather than protected surfaces of the fruit.

Occasionally loopers create crescent shaped series of small deeper single holes when the caterpillar anchors itself with its hind prolegs while it bores a hole and then pivots sideways, like a mechanical excavator, to make other feeding holes while anchored to the same spot. As fruit matures the wounds caused by the loopers become corky and sometimes develop into small lumps but generally they remain shallow and concave.


Female apple looper moth (photo courtesy Tasmoths)


Male apple looper moth (photo courtesy Tasmoths)

The adult looper moths are rarely seen because they are well camouflaged when resting on bark. The larvae have a habit of remaining still if they sense the presence of a predator (or human). Larvae have 3 pairs of true legs on the thorax and, unlike budworms, have only two pairs of abdominal prolegs that are at the end of the body. Budworm larvae, like most moth larvae, have prolegs on each abdominal segment. The looping action of the looper larvae is the result of having prolegs only towards the rear of the abdomen.

Apple looper larva

Apple looper larva damage to apples

Management of budworms and loopers involves a combination of weed management, biological control, entomopathogens, early season monitoring, and careful selection of pesticides to avoid disrupting predators and parasitoids that would otherwise manage to keep other pest below economic thresholds. Apple looper has a range of hosts including Acacia. Budworms feed on a wide range of weeds such as deadly nightshade, Noogoora burr, thistles, capeweed, dock, fat hen, and marshmallow. Management of those weeds prior to flowering of pome fruit will not only reduce incidence of budworms but will also help reduce populations of LBAM and harlequin bugs. This does not mean creating bare earth in the inter-row! Biological control agents such as parasitoid wasps require access to flowering plants for energy sources like sugar, so it is important to maintain a balance of plants in the inter-row without promoting the weeds mentioned above.

Trichogramma wasps parasitise budworm eggs and probably also looper eggs. A small black wasp *Microplitis demolitor* parasitises young budworm caterpillars. The predatory shield bugs *Cermatulus nasalis* and *Oechalia schellenbergii* attack Helicoverpa and other caterpillars. Green lacewing larvae, lynx spiders, and red and blue beetles are known to prey on budworms. Small caterpillars can be controlled by applying sprays containing the entomopathogenic bacteria Bacillus thuringiensis (Bt). Once the larvae have grown beyond the third instar, they are probably beyond control by Bt alone and a registered chemical insecticide may be required. Choose carefully to minimise impact on other biocontrol agents. Refer to Chapter 6 for information about side effects on beneficial species.

Monitoring for eggs during the fruit tree flowering period can be done at the same time you are doing blossom tapping to detect dimple bugs and thrips. Small loopers may be dislodged into the container and if that occurs then it would be prudent to look for eggs and other small larvae amongst the flowers. If the orchard is surrounded by pasture or field crops you may want to position some pheromone traps along the border to detect movement of moths into the orchard.

After petal fall the one-minute tree inspection described in Chapter 3 should be used to search for larval feeding activity. Pears are particularly attractive to twig looper and the first signs of activity are usually presence of small cylindrical pellets of faecal matter on the upper surface of leaves. These leaves may not have been eaten but the larvae producing the pellets are likely to be detected feeding on leaves on twigs or branches above where the pellets were found. Twig loopers are sensitive to movement and will become immobile while imitating a small twig (hence the name). Once you detect the pellets stand quietly and do not make any sudden movements but cast your eyes over the leaves. Often you will detect slight movement in your peripheral vision which then allows you to home in on the larvae.

Budworm and looper damage can continue through the season so maintain awareness while you conduct weekly tree inspections.

Insecticide applications should be a last resort because some of the suitable pesticides may also be registered against codling moth, and leafrollers like LBAM, and have restrictions on the number of applications permitted per season. The most likely timing for control of loopers will usually coincide with sprays against codling moth, therefore negating the need for additional sprays to control either pest.

Apple and Pear IPDM

Leafrollers

IPDM Quick Facts

- Lightbrown apple moth (LBAM) and Western fruit moth (WFM) are leafrollers that attack pome fruit, and many other plant species, in Australia. LBAM is found in all pome fruit growing regions but is considered to be native to the eastern states and introduced accidentally into Western Australia. WFM is native to Western Australia and appears to be confined to the lower south-west of that state.
- LBAM has a very wide host range and has spread to New Zealand, New Caledonia, UK, and the USA (Hawaii and some western states).
- LBAM and WFM adults are almost indistinguishable but respond to different pheromones, which makes it relatively easy to assess if you have one or both species present and are using separate traps for each species.
- Eggs and larvae of both species are indistinguishable without special laboratory techniques. Both species lay masses of flat overlapping eggs and the larvae of both species are green and roll leaves to construct feeding shelters.
- Pheromone mediated mating disruption is an effective control for LBAM, but the pest continues to feed and breed over winter. Mated females may lay eggs on the new flush leaves after the green tip stage of pome fruit trees. If large numbers of male LBAM are captured in pheromone traps in late winter- spring it indicates potentially high numbers of mated females will also be present and the mating disruption treatment may need to be supplemented by release of egg parasitoids or spraying with the entomopathogen *Bacillus thuringiensis* (Bt).
- Despite responding to different pheromones, limited research in Western Australia suggests that WFM may be disrupted by the LBAM mating disruption products. Use of mating disruption may affect the traps used for monitoring the activity of adult leafrollers. Regular inspection of trees for signs of larval feeding is important.
- In Western Australia the threshold of 5 or more leafroller moths/trap/week in a non-disrupted orchard triggers inspection of leaves and fruit. The threshold for spraying is when 5% of leaves and/or fruit clusters are infested with larvae.

The Pests and their Significance

Light brown apple moth (LBAM) *Epiphyas postvittana* is a serious pest infesting over 250 crops (e.g. apples, pears, citrus, grapes),broad leaved weeds (capeweed, mallows, docks, fat hen, blackberry), native plants such as Acacia, and a wide range of ornamental plants including roses,

LBAM is present in all Australian pome-fruit production regions but numbers are greatest and damage more severe in cooler regions such as Southern Victoria and Tasmania. Damage is also likely to be more severe where conditions promote good growth of host plants, and by the extension of cool conditions well into summer. In cool seasons it can cause damage from spring until harvest in autumn.

LBAM is an Australian native species but has become naturalised in New Zealand, New Caledonia, the United Kingdom, Hawaii and some western states of USA. It is considered a quarantine pest by many of Australia's trading partners.

Western fruit moth (WFM) *Epiphyas pulla* is another native species and occurs only in Western Australia where it appears to be limited to the south-west. It is almost indistinguishable from LBAM in the egg, larval, pupal and adult stages. However, the two species respond to different pheromones and, since those pheromones are species specific, pheromone traps can be used to determine which species is present. Separate traps labelled with the type of lure should be used for each species. Use of the wrong pheromone will give misleading monitoring results. WFM is generally more abundant than LBAM in production areas around Manjimup, while elsewhere LBAM is generally more abundant.

Orchardists in the Manjimup area should install monitoring traps for each species. In other Western Australia production areas, the LBAM pheromone should be used but if no moths are captured and damage is occurring then WFM traps should also be installed. Place a minimum of three of each species trap per block, Traps for the same species should be spread evenly over a block, separated by 10-30m between any two traps. Lures for WFM are available from one supplier only and DPIRD should be contacted for details.

Damage

Leafroller larvae prefer sheltered feeding sites such as between fruit in tight clusters, under leaves webbed onto fruit, or inside rolled leaves. In each case there will be presence of webbing under which the insect feeds.

Three main types of damage occur on fruit:

- **Extensive shallow wounds** on the fruit surface are common on short-stalked varieties that tend to form tight clusters. The larvae spin webbing between the fruit and feed on the fruit surface under the webbing. Varieties that do not form tight clusters can also be attacked if leaves close to the fruit, usually near the stalk end, are webbed to the fruit surface to shelter the feeding larvae. The fruit responds to the damage by producing a layer of corky material over the wound. This damage is mostly cosmetic but makes the fruit unmarketable. This damage can look like looper and weevil damage, but those pests tend to damage exposed areas on the fruit whereas leafrollers damage sheltered sites.

- **Small holes in the fruit surface** made by young larvae biting through the skin of the fruit and dying before progressing further. These are similar to the holes made by loopers but are made in sheltered sites and tend to be more random whereas the holes made by loopers are generally in exposed sites and are often arranged in a crescent shaped pattern.

- **Internal damage** is much less common than surface damage and occurs when immature larvae feeding in the shelter of the calyx encounter an opening in the calyx end and work their way into the fruit. The calyx cavity often extends to the core of the fruit, giving the impression of damage by codling moth or oriental fruit moth. If caused by leafrollers the damage is accompanied by extensive silk and any excrement produced is ejected as discrete pellets scattered around the fruit surface. Codling moth and oriental fruit moth excrement appears as a sticky mass at the entrance hole and in the feeding tunnel. Codling moth feeds on the seeds in the core whereas oriental fruit moths usually feed around the core without eating the seeds.

Leaf damage occurs when young first instar larvae settle on the underside of a leaf, usually near the mid-vein, and spin a protective covering of silk under which they feed until they moult to the second instar. This early damage appears as small windows in the leaf surface. The larvae then move to another feeding site where they construct a more substantial shelter by either webbing together two sides of a leaf, two adjacent leaves, or leaves to one or more adjacent fruit. Fruit calyxes, especially in pears, are also frequently used. The larvae prefer softer leaf tissue and rarely feed on the leaf veins. Leaf damage is rarely of

economic significance, but it is a good indicator of the presence of larvae that will become the next generation of moths laying eggs in the crop.

Life cycle

Neither of these leafrollers enter hibernation (diapause) but they are tolerant of cold conditions. Eggs laid in autumn produce larvae that continue to feed and slowly develop through winter on weeds and native plants. Trapping studies conducted year-long in Harcourt, Victoria found moth captures fluctuated over winter but that moths were present throughout. Male moths emerge earlier than females and mating begins around dusk soon after female emergence. At the end of winter moth numbers peaked and began to subside before apple trees had reached green tip. The next rise in moth captures occurred after petal fall and the start of that rise was used as biofix for a model to predict egg hatch. The developmental base used in degree-day calculations for LBAM is 7.0 ^{o}C and although generation times vary according to food quality and daylength, a rough guide to the number of $^{o}D_{7.0C}$ after biofix in spring for commencement of egg hatch for each generation in apple orchards is given in the table below.

Degree-days ($^{o}D_{7C}$) from biofix at start of season in spring in Victoria	
Egg hatch 1st generation	130
Egg hatch 2nd generation	772
Egg hatch 3rd generation	1534

Eggs are laid in batches of about 30-35 eggs. The eggs are flat, translucent aqua in colour and laid in an overlaid pattern that makes the batches look like fish scales. They are laid almost exclusively on the upper surfaces of leaves and are difficult to see unless the light is at the correct angle. The black head of the developing larva becomes apparent in the egg a day or so before it hatches. Freshly laid eggs are at risk of parasitism by Trichogramma wasps and other insects. Parasitised eggs turn black as the parasitoid larva develops in the egg. Unparasitised eggs take about 130 $^{o}D_{7.0C}$ to hatch. The neonate larvae are pale yellow, about 1mm long, with a black head. They disperse by crawling or by dropping on silken threads which sometimes are blown in the wind to other trees. They settle near the mid-rib on the underside of a young leaf where they spin a silken protective cover and commence feeding as described above in the damage section. Male larvae develop through 5 instars and females 6 instars.

All instars after the first have lightbrown coloured heads. Mature larvae are pale to medium green, with a darker green central stripe, and wriggle actively out of their shelter and drop to the ground if disturbed by someone trying to open the rolled leaf to check what is in it. Experienced pest monitoring scouts develop the habit of cupping the rolled leaf in the palm of their hand in a way that allows them to catch the caterpillar before it escapes. Pupation occurs in the feeding shelter and the adult moth emerges about 130 $^{o}D_{7.0C}$ later. The number of generations depends on latitude and food quality with 4 generations common at latitude 38°S, 3 at 40°S, and 2 at 43-47°S. In areas with hot dry summers, such as Sunraysia, LBAM can suffer from outbreaks of a nuclear polyhedrosis virus that reduces population build-up until autumn.

Management

There are regional variations in thresholds for leafrollers and additional constraints may be placed on export blocks to ensure compliance with phytosanitary requirements. The recommended action threshold for LBAM and WFM in Western Australia is 5 or more moths caught in one trap in one week. When this threshold is reached check trees for larvae. Consider applying control once infestation of shoot/fruit clusters by larvae reaches 5%. Management for LBAM and WFM is the same. In Victoria the threshold is generally 8 moths/trap/week with timing of sprays guided by the prediction model.

Pheromone mediated mating disruption is an effective control for LBAM but since the pest continues to feed and breed over winter mated females may lay eggs on the new flush leaves after the green tip stage of pome fruit trees. If large numbers of male LBAM are captured in pheromone traps in late winter- spring it indicates potentially high numbers of mated females will also be present and the mating disruption treatment may need to be supplemented by release of egg parasitoids or spraying with the entomopathogen *Bacillus thuringiensis* (Bt).

Despite responding to different pheromones, limited research in Western Australia suggests that WFM may be disrupted by the LBAM mating disruption products. Use of mating disruption may affect the traps used for monitoring the activity of adult leafrollers. Shutdown of traps is only one measure of the success of mating disruption. Regular inspection of trees for signs of larval feeding is important because mating disruption works by delaying mating, not stopping it completely, and if moth populations are large enough significant egg laying can still occur.

Many chemicals registered against codling moth are also registered against LBAM. The timing of critical stages in the life cycles of these two pests means that there is often little synchrony with respect to spray timing but sometimes the timing of a second spray for codling moth coincides with the need for a spray against LBAM and you can use one chemical to kill both pests. Modern pesticides have resistance management strategies on their labels, restricting the number of applications against each generation or for the entire season. Where two pests with slightly different lifecycles are being targeted it is important to understand that the last spray against one pest may be the second or third spray against the other and the risk of resistance is increased. Because leafrollers feed in shelters there is a short window of opportunity in which to apply a spray. Ovicides generally need to be applied onto fresh eggs less than 3 days old or onto leaf surfaces on which either the moth will deposit eggs, or the larvae will walk over on their way to a feeding site. Insect growth regulators can be applied close to egg hatch to either prevent the egg from hatching or prevent the surviving larvae from moulting to the next stage.

Biocontrol

Leafrollers are subject to a wide range of native and introduced biocontrol agents which can keep the pest population below damaging levels if they are not impacted negatively by use of pesticides that either kill them or reduce their fitness and fertility. Included in this category are not just insecticides but also fungicides. **Refer to Chapter 6 for information on the side effects of pesticides on beneficials**.

Organic growers can utilise the same mating disruption products, naturally occurring parasitoids and generalist predators such as spiders and earwigs, and commercially available biocontrol agents and entomopathogens such as Bt available to conventional growers.

Weed control is particularly important for control of leafrollers because of their broad host range. Replacing broad leaved plants in the inter-row with suitable grasses will reduce overwintering hosts for the leafrollers but will also reduce habitat and energy sources for some biocontrol agents, so consideration should be given to establishing nearby "insectary plantings" to maintain populations of beneficials. Alternative host plants near the orchard boundaries or along watercourses in the property should be considered for removal if it does not contravene local by-laws.

Crop thinning

Damage by leafrollers, weevils, and codling moth is most severe where fruit clusters are allowed to remain. Thinning to singles or at most doubles will reduce the number of sheltered sites that favour these pests and also allows better spray penetration, reduces bruising and fruit punctures, and usually also decreases biennial bearing.

Monitoring

Pheromone traps can provide an indication of male moth activity throughout the year or just throughout the fruit season. In the eastern states only LBAM traps are required. In WA, especially around Manjimup, separate traps are required for LBAM and WFM.

Male LBAM

The pattern of distribution for the traps depends on the size and shape of the block being monitored and the ease of getting to the trap. A long narrow block would suit a set of three traps 30m apart along a row parallel to the long axis if that is the way the rows are running. If the rows run parallel to the short axis then one trap near the middle of each of three rows separated by 5-6 rows would be a practical option. LBAM traps and WFM traps can be placed on opposites of the same interrow so long as they are at least 10-15m away from the traps on the opposite side. Traps should be cleared once per week and the sticky base replaced before it becomes coated with dust, debris or remains of trapped moths. The lure should be replaced at intervals recommended by the manufacturer. Do not discard used lures in the orchard because they may still attract some moths. Pheromone traps for leafrollers do not need to be placed high in the tree because the moths usually fly closer to the ground. Hanging traps at about 1.5-1.8m above the ground, on the edge of the canopy, is sufficient. In general, delta traps are better than wing traps for leafrollers. White coloured traps are difficult to see during blossoming and tend to attract and trap bees. Red traps are easy to see most of the season and attract fewer beneficial species.

Checking for eggs and larvae

The one-minute per sample tree monitoring technique described in Chapter 3 is a cost-effective way of monitoring leafroller larvae. This should be complemented by the in-season damage assessments also described in Chapter 3. The most obvious symptom of leafroller activity, apart from use of pheromone traps, is the presence of rolled leaves. Once you have trained yourself to recognise these you will find it easier to develop the situational awareness and peripheral vision to detect problems before they get out of hand. Monitoring is a structured process where you follow set procedures that allow standardised assessments. Situational awareness gives you and your staff the ability to pick up on mild symptoms while doing their normal duties, in time to investigate them further through your monitoring program.

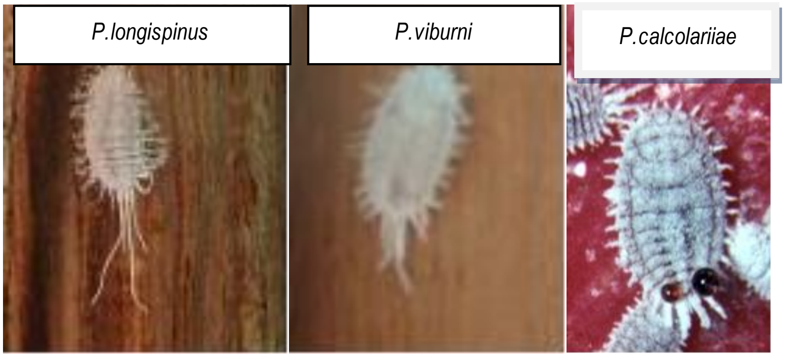
Mealybugs

IPDM Quick Facts

- Mealybugs are small insects covered in whitish mealy wax protuberances.
- The mealybugs attacking pome fruit in Australia are worldwide pests.
- There are differences in the life cycles of each species of mealybug.
- Longtailed mealybugs overwinter as late instar nymphs and adults under bark on the trunk and limbs.
- Obscure mealybugs overwinter under bark but also on the roots.
- Longtailed mealybug eggs hatch as they are being laid and the crawlers stay under the female until they are ready to disperse to the leaves and fruit.
- Obscure mealybugs lay eggs into a silky egg sac. Egg hatch depends on temperature. The crawlers disperse onto the branches and into the calyx or stem ends of fruit.
- Several generations occur per season.
- If spraying is required, it should be timed for when most of the 1st instar (crawlers) have departed from their shelters under the bark and 2nd instar nymphs are apparent on the leaves and limbs. This is the time that the bulk of the population is vulnerable to pesticides. Spraying before then is a waste of time, money, and pesticide.
- Biological control agents are effective at controlling mealybugs if they are allowed to survive pesticide applications in the orchard. Several species of naturally occurring biocontrol agents exist and some are also available from commercial suppliers who can advise on release rates and chemicals to avoid.
- Effective scouting for mealybugs involves a multi-technique approach utilising artificial shelter bands as monitoring traps as part of the trapping run for other pests, checking for crawlers on leaves during mite sampling, looking for honeydew and sooty mould on leaves, limbs and fruit while conducting timed inspections of trees for diseases and other pests, and checking the calyx and stem ends of fruit during damage assessments.

The Pests and their Significance

Mealybugs are small insects 3-5mm long that are covered in whitish “mealy” wax, which helps prevent desiccation and gives them their common name. The mealybugs attacking pome fruit in Australia are worldwide pests. The three most common mealybugs are longtailed mealybug, obscure mealybug (also known as tuber mealybug), and citrophilous mealybug. Mealybugs have high reproductive capacity and produce multiple generations per year, with peaks in spring and summer. Mealybugs suck the sap of their host plants and secrete large amounts of honeydew that causes sooty mould to develop. The sooty mould can inhibit photosynthesis in leaves, is a cosmetic contaminant on fruit, and its stickiness is an annoyance to pickers and other orchard staff. Longtailed mealybug females can be distinguished from those of other species by the length of waxy ‘tails’ that are at least as long as the body whereas with obscure mealybug they are shorter than the body and citrophilous mealybug has short waxy ‘spines’ and ‘tail’ but also exudes a dark coloured body juice when prodded.



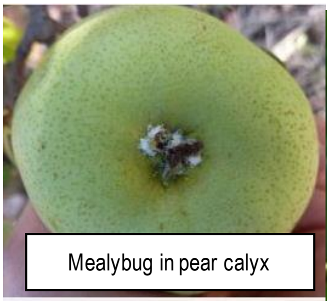
Longtailed mealybug *Pseudococcus longispinus* eggs hatch inside the body of the female as the eggs are being laid, giving the appearance of live birth. The first instar nymphs (crawlers) occur as batches that remain under the body of the female until ready to disperse. The crawlers are about 0.3 mm long and disperse to feeding sites in the leaf axils, the near the main vein on the underside of leaves, and in the calyx and/or the stem end of fruit by crawling. Longer distance dispersal to other trees can occur by ballooning in the wind. The emergence of crawlers within generations of longtailed mealybug is relatively synchronised, which helps with the timing of sprays. The only opportunity to contact the pest with pesticide is when it is present on the leaves. Once the crawlers settle on the leaves, they moult to the 2^{nd} instar and start developing the waxy covering. After they reach 3^{rd} instar, they are ready to move back to sheltered sites under the bark where the females continue to develop while the males spin cocoons and pupate. The best timing for sprays is the period between when 2^{nd} instars started to increase and before 3^{rd} instars start to move off the leaves. At this stage most of the population will be exposed. Once the third instars have returned under the bark it is very difficult to get spray to penetrate the shelter. Crawlers that settled in the calyx will generally complete development in the calyx where they are protected from sprays and predators have difficulty accessing them. There are 3-4 generations, depending on temperature and humidity, and some overlap of generations, Hot dry conditions, especially in spring, reduce population increase.

Obscure mealybug *Pseudococcus viburni* has been an important pest in the Queensland Granite Belt but in recent years longtailed mealybug has become established there and mixed communities appear to be complicating control efforts. Obscure mealybugs spend most of their lives in sheltered sites under bark, in the calyx or stem cavity of fruit, or on the roots of their host trees, with a short period when crawlers may be exposed on the leaves. The eggs are laid into a fibrous white egg sac, which helps distinguish this pest from longtailed mealybug. Once the eggs hatch the crawlers move out in search of feeding sites. Because of its more cryptic habits lack of crawlers on leaves is not an accurate indicator of crawler activity. The crawlers should be visible on the bark and wood of branches and twigs as they make their way towards the fruit. Once they access the fruit calyx, they will be very difficult to control with sprays.

Citrophilous mealybug *Pseudococcus calceolariae* is not present in WA but is present in TAS, SA, VIC, NSW, and QLD where, although it has been recorded on pears and quinces, citrus, grapes, a range of ornamentals, and vegetables, it is not considered to be an important pest of pome fruit.

Damage

Severe infestations may reduce the vigour and growth of foliage and weaken trees, but it is unusual for populations in commercial orchards to get large enough for this to happen. The production of honeydew that drips onto leaves allows sooty mould to develop and can reduce photosynthetic activity of leaves. Sooty mould caused by honeydew on fruit requires removal before the fruit can be marketed. Mealybugs feeding in the calyx of pears can cause premature softening and ripening. Feeding in the stem end of apples results in sooty mould which is difficult to remove. Mealybugs that settle in the calyx are extremely difficult to remove without using targeted high-pressure water sprays. Contaminated consignments are rejected by canneries and the fresh market.



Mealybug in pear calyx

Clean (left) and mealybug infested apple stem (right)

Management

Mealybugs prefer shaded conditions and higher humidity, which means that they are suited to orchards under netting.

Pruning to allow more open canopies that provide better air movement and improve spray penetration may help with control.

The narrow window in which mealybugs are in exposed conditions makes timing of sprays critical. Good timing relies on good monitoring.

Choice of pesticide is also critical because of potential interaction with control of other pests, resistance management considerations, and off-target impacts on beneficial species (refer Chapter 6)

Monitoring

The use of corrugated cardboard bands, wrapped around branches at about head height, will provide sheltered sites in which females will produce eggs and crawlers. Regular inspection of these bands to detect changes in crawler populations, in combination with leaf inspections to detect movement of 3rd instar nymphs off the leaves, will assist timing of sprays. Maintaining the bands throughout the season will allow detection of each generation. The bands will also help in detection of parasitoid activity because mummified mealybugs will be present under the bands if parasitoids are active. To establish the bands, select 10 trees at random in an infested block. Tag the trees with surveyor tape because you will need to return to these trees on a regular basis. (Note: This is one of the few times that sentinel trees are recommended and scouts need to understand the risks associated with this approach. The mite sampling guidelines described in Chapter 3 will allow an additional opportunity to detect mealybug activity if the sentinel trees were poor choices.) Select 2 easily accessible limbs at chest to head height and use a rasp to smooth away rough bark in a 15 cm band around the limb, being careful not to go so deep as to ringbark the limb. This prevents mealybugs from hiding under the bark after they move beneath the band. Cut a band of corrugated cardboard to a width that fits the rasped area and wrap it around the limb, overlapping by about a third. Attach two Velcro strips, about 20mm in from either edge of the band, at the end of the band. Make the Velcro strips long enough to reach around the limb over the band and have about 150mm overlap for attachment. Velcro makes it easier to open and close the bands for inspection.

When inspecting the bands, use a 10x hand lens to identify and count the life stages of mealybugs that are present. If it is too onerous to count them it is acceptable to note when crawlers have left the shelter and when 3rd instars and adults become present.

In areas where obscure mealybug is an issue the techniques used for sampling Bryobia mite on limbs will allow you to observe the mealybugs if they are not evident on leaves.

The one-minute per sample tree technique described in Chapter 3 provides an opportunity to look for signs of honeydew that indicates mealybug feeding activity.

Fruit damage inspections during the season, as described in Chapter 3 should be used to examine fruit for mealybug in the calyx and stem ends of the fruit.

Biological control

The predatory ladybird beetle *Cryptolaemus montrouzieri* is known as the mealybug destroyer. Both the adult and larval stages feed on mealybugs. Although the adult *C.montrouzieri* feeds on all stages of mealybug it seems to prefer feeding on mealybug eggs, which makes it useful for controlling obscure and citrophilous mealybugs. The larvae of C.montrouzieri look superficially like large mealybugs, a disguise that may confuse ants that often protect colonies of honeydew producing mealybugs. The larvae are voracious predators of mealybug crawlers, 2nd and 3rd instar nymphs, including those of longtailed mealybug. The mealybug destroyer is available from biocontrol agent suppliers in Australia and successfully controls mealybugs in greenhouses and should be effective under netting in orchards. It is probably more effective to introduce it as both larvae and adults. Larvae do not fly and therefore continue to search for prey on the release trees after they clean up each colony, whereas the adults are likely to fly off looking for new colonies once they have cleaned up localised colonies. Some pesticides that are relatively harmless to other beneficials appear to be detrimental to *C.montrouzieri* and have long residual effects so it is important to refer to Chapter 6 for known effects of pesticides and to discuss, with the supplier, susceptibility of the strain of beetles you are purchasing before ordering them.


Mealybug destroyer larva amongst mealybug crawlers


Adult mealy bug destroyer

Several parasitoid wasps prey on mealybugs and can provide good control if not killed by inappropriate pesticide usage. *Leptomastix dactylopii* is mentioned in the literature but appears to be specific against another mealybug *Pseudococcus citri* that attacks citrus. Mealybugs capable of providing good control of mealybugs in pome fruit orchards are *Anagyrus fusciventris* and *Tetracnemoidea sydneyensis* against longtailed mealybug, and *Pseudaphycus maculipennis* against obscure mealybug.

Lacewing larvae, particularly those of the green lacewing *Mallada signata* are voracious predators of mealybugs, aphids and mites. Likewise, syrphid fly larvae prey on mealybugs and woolly apple aphid.

The wasps, lacewings and syrphids are naturally occurring in orchards but some are also available commercially to supplement wild populations if required. Note: If you wish to purchase biocontrol agents they should be purchased from Australian suppliers because there are strict quarantine laws and regulations governing importation of live organisms from overseas.

Apple and Pear IPDM

Mites

IPDM Quick Facts

Two mite families, Tetranychidae and Eriophyidae, attack pome fruit in Australia.

Tetranychid mites are the more damaging and include European red mite (ERM), two-spotted mite (TSM), and Bryobia mite.

- ERM and Bryobia overwinter as red eggs on the upper and outer parts of the tree near buds and spurs. ERM eggs are onion shaped with a spine coming from the top of the egg. Bryobia mite eggs are spherical and do not have a spine.
- TSM overwinter as orange females in sheltered sites under bark, in trash in the crotch of trees, in cracks in trellis poles and in masses of webbing between scaffold limbs and the trunk. Males do not survive winter.
- TSM summer form is yellowish-green with 2 dark spots, eggs are spherical, translucent to opaque. ERM adult form is dark red with hairs coming from 4 lines of white spots on the back. Bryobia adult form is red-brown, flat and has two very long front legs
- Feeding by Tetranychid mites causes stippling, bronzing and, on pears, leaf burn when severe.
- The actual number of mites per leaf is less important than the percentage of leaves infested and how long they are infested. Thresholds calculated as cumulative leaf infested days (CLIDs) depend on the variety, with WBC being most sensitive and apples least sensitive.
- A wide range of biocontrol agents, including several species of predatory mites, feed on and control Tetranychid mites. Predatory mites are the most reliable biocontrol agents, are resistant to many of the pesticides used in orchards and can persist in orchards even when prey numbers are low.

Eriophyid mites attacking pome fruit are pear leaf blister mite and apple rust mite.

- Eriophyid mites rarely cause significant damage.
- Apple rust mites provide prey for predatory mites early in the season before TSM becomes active

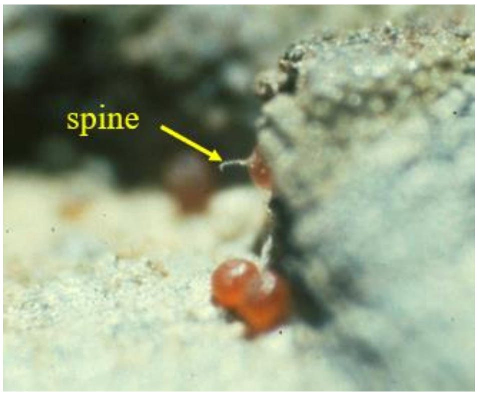
The Pests and their Significance

Two main mite families attack pome fruit in Australia. The **Tetranychidae** are commonly called spider mites because of their appearance and the habit of some members to spin webbing. This family includes Bryobia or brown mite *Bryobia rubrioculus*, European red mite (ERM) *Panonychus ulmi*, and Two-spotted mite (TSM) *Tetranychus urticae*. The **Eriophyidae** includes pear leaf blister mite *Eriophyes pyri* (previously called *Phytoptus pyri*) and the apple rust mite *Aculus schlechtendali*.

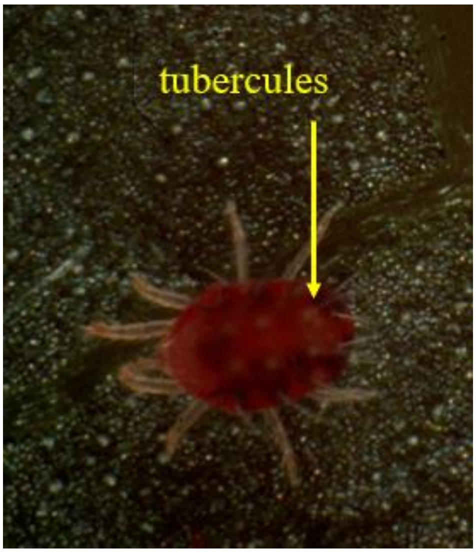
Bryobia mite is the largest mite that feeds on apples and pears and may be the first to appear in spring. It is usually more common on home garden trees, roadside 'feral' trees or organic orchards but with changes to some practices in more 'conventional' commercial orchards Bryobia is starting to become evident. Bryobia overwinter as red spherical eggs (not onion-shaped) laid near spurs and buds. These eggs hatch around green tip stage of the host tree. The newly hatched mites (larvae) have six legs, are bright red, and feed on the underside of unfurling leaves. They become brown 8-legged nymphs after their first moult and resemble smaller versions of the adults. The nymphs feed mainly on the underside of leaves. The adults are about 0.7mm long and have an oval, flattened dark reddish-brown body that has a pair of very long front legs (as long or longer than the body) and feed mostly on the upper surface of the leaves.

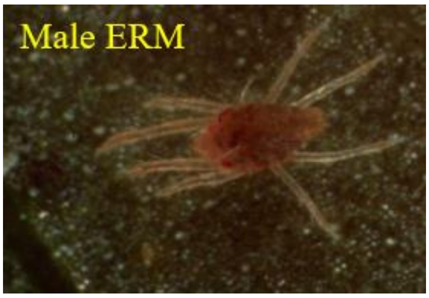
There are no known males of this species and reproduction occurs without mating. The mites spend a lot of their time during the warmer part of the day on the bark rather than the leaves. They also cluster around beneath shoots and branches to moult. This presents some challenges for scouts because leaf damage is often seen but very few mites may be seen on the leaf. If that is the case, inspection of the twigs and branches will usually reveal the mites and/or cast skins. There are 3 overlapping generations on some hosts with most summer eggs laid on the shoots but, on apples and pears, they can continue reproducing until late autumn when they start laying winter eggs near the junction of 2-year old wood and the current season growth. Leaves developing from injured buds are often smaller and misshapen. On larger leaves the damage starts with lots of small pale spots like leaf hopper damage and leading to a silvery appearance that, in severe cases, turns brown, brittle and distorted. In commercial orchards damage is rarely bad enough to affect fruit growth.

European red mite overwinters as red onion shaped eggs that have fine longitudinal grooves and a thin spine coming from the top. They are laid in much the same places as Bryobia eggs and, although close to the same colour, can be distinguished from Bryobia eggs by the presence of the spine. Overseas there are early and late hatching strains but in Australia they seem to hatch at about the same time, just after green tip, as Bryobia and they tend to out-compete the Bryobia for feeding spaces.



Adult female ERM are about 0.4mm long with a strongly convex, dark red oval body that has 4 longitudinal series of whitish coloured raised 'pimples' from each of which a long hair protrudes. Males are smaller than females, yellowish green to bright red, and tapered to the rear.





There are a few behavioural differences between ERM and Bryobia. ERM immatures and adults remain on the leaves during moulting between stages and the cast skins accumulate amongst the colonies on the leaves. Summer eggs are paler than winter eggs and are generally laid on the lower leaf surface. There are at least 5 overlapping generations per season. Mated females produce both male and female offspring while unmated females produce male offspring.

Damage starts as light speckling on the leaves and progresses to dull green leaves with a bronzed appearance on the underside of the leaf, and then the leaves take on a silvery bronze appearance. Apple trees, except for Golden and Red Delicious, are rarely defoliated by ERM damage but high numbers of heavily infested leaves can reduce both the number and size of fruit in the following season. Pears on the other hand, are more sensitive to mite damage and prolonged feeding by high populations can lead to leaf burn and premature defoliation in hot dry weather. Leaf burn is not as severe if the mite populations gradually build up so that the leaves become conditioned. If leaf burn causing severe defoliation occurs in late summer the trees may flower in autumn, causing a loss of yield in the following season. Williams Bon Chretien (WBC) pears are more sensitive than other varieties.

Two-spotted mites are web-spinning mites that are most abundant on apple and pear trees in summer. They overwinter as orange females in sheltered sites such as under bark scales, in trash in the crotch of the tree, in cracks on branches and trellis posts, in the calyx of fruit left hanging on the tree, and in severe cases in or under webbing spun between the scaffold limbs and the trunk. In spring, as the weather warms, the overwintering females begin to feed and their colour changes to light yellow-green and two large patches of black develop. The spherical translucent eggs laid by these females become opaque before hatching to produce males which mate with the surviving females to produce male and female offspring. Females are about 0.6mm long and oval. Males are smaller and taper towards the rear giving them a 'broad-shouldered' appearance. As with ERM and Bryobia the larvae have 6 legs and the nymphs and adults have 8 legs. Infestations usually start in the lower centre of the tree and expand upwards and outwards whereas infestations of ERM and Bryobia begin in the outer and higher parts of the tree.

Damage by TSM on apples produces pale green stippling that progresses to light yellow stippling and bronzing of the undersides. Feeding sites on the leaves are often protected by webbing spun over the veins onto the leaf surface. Very severe infestations result in copious amounts of webbing being spun over the shoot terminals and the mites start to turn orange and disperse on the wind. As with ERM, pears are more sensitive to mite feeding but conditioning can occur with gradual build up of the population. Water stressed trees can suffer leaf burn and drop leaves. The next season's crop of pears can be affected even if leaf drop and autumn flowering does not occur. In autumn, as the quality of the leaves diminishes and temperatures start to drop, the mites stop feeding, the females change to their orange overwintering form and the males die.

Pear leaf blister mites are so small they cannot be seen without a hand lens. They are about 0.2mm long with a white to pale brown coloured narrow elongate body. Male and female mites overwinter beneath the outer scales of fruit and leaf buds. In the UK bud swell triggers feeding activity in which the adults penetrate deeper into the buds and lay eggs at the base of the inner scales. In California all stages of the mite are present in the buds over winter and can reproduce. In both cases the mites attack emerging leaves from green tip through flowering and developing fruit by feeding below the skin. This feeding causes blisters in which eggs are laid and the young mites are protected by the blister while they feed on the tissue. The blisters have a small hole in the raised top of the blister, through which the mites exit to move to another site where they initiate a new blister. Three distinct types of damage are caused on pears. Feeding on buds over winter can desiccate the buds which then fail to develop. Feeding on developing pears results in oval russet spots about 6-12mm in diameter and if they run together the developing fruit may become deformed. WBC pears are most susceptible to this type of damage but varieties with naturally russeted skin do not show the symptoms. Leaf blisters 3-6mm in diameter begin as red raised areas that later blacken can impair leaf function if the attack is severe. Damage by pear leaf blister mite is rarely seen in commercial orchards in Australia.

Apple rust mites are smaller than pear leaf blister mites, being 0.16- 0.18mm long with a wedge shaped yellow-brown body having the head at the larger end. Females that overwinter beneath bud scales and bark near spurs, emerge at bud burst in spring to feed on the unfolding leaves. Breeding continues throughout spring and summer with generations completed in less than 2 weeks over summer and populations of several hundred rust mites per leaf can occur. Damage consists of patchy felt-like formations and yellowing of hairs on the underside of the leaves and dull, faded, silvered appearance of the upper surface. Severe damage leads to folding or cupping of the leaves. In most cases apple rust mites are more beneficial than pestiferous, because they are an excellent food source for predatory mites early in the season and allow the predatory mite population to build up before ERM populations explode and/or TSM are active.

Management

Limit Dust

Mites infestations are often worse near dust sources such as dirt tracks or roads. Consider using salamander or road base on high traffic tracks or investigate dust suppressants. Encourage staff, contractors and visitors to drive slowly.

Ground cover and weeds

Maintaining healthy, green ground cover discourages mites in two ways. It reduces dust (see above) and provides an attractive alternative habitat for generalist biocontrol agents that feed on a range of pests. Of the pest mites discussed above, two-spotted mite is the only one with a wide range of hosts that includes broad-leaved weeds. Some predatory mites feed on grass pollen when no prey is available, so maintaining a grass sward is preferable to an inter-row full of capeweed, fat hen and mallows. However, a balanced inter-row that provides nectar for parasitoids, shelter and food for generalist predators, and pollen sources can potentially be more appropriate.

Irrigation

Trees under water stress and trees suffering from waterlogging and salinity are more likely to become infested with mites than those which are well irrigated. Stressed trees have leaf microclimates that are above ambient air temperatures and the higher temperatures can be in the optimum range for pest mite development. A combination of mite feeding damage and changes to leaf chemistry due to stress can alter the plant response to mites and accelerate damage development. Keep trees appropriately irrigated. Overhead irrigation for cooling should be conducted carefully to ensure that foliage dries quickly because the cooling effect requires evaporation. Leaving foliage wet for long periods also encourages scab and other diseases, and acts like heavy rainfall by redistributing and potentially reducing pesticide residues to ineffective levels.

Varieties

Leaves on European pears are more sensitive to mite feeding than those on apples or Asian pears. WBC and Comice pears are particularly prone to mite damage whereas Packham Triumph and the new blush pears are more tolerant and Red Sensation are virtually resistant. Golden Delicious, Red Delicious, and Fuji apples are more sensitive to mites than other apples but are more tolerant than WBC pears.

Delaying the damage to 'condition' leaves

The theory that both apples and pears are able to withstand higher populations of mites if mite populations have built up slowly allowing the leaves to become conditioned to their feeding is based on assessments of the numbers of mites/leaf. There is a good relationship between numbers of mites/leaf and the percentage of leaves that are infested. As the number of mites/leaf increases so does the percentage of leaves infested but it is not a linear relationship with a constant rate of increase. Thresholds based on the Cumulative Leaf Infested Days (CLIDs) concept utilise this relationship, and the period of time that leaves have been infested, to measure the rate of increase in risk of damage. Plotting CLIDs over time produces a graph whose slope can be used to estimate when the threshold will be exceeded and gives growers guidance on when they should intervene to reduce the slope. The threshold is a seasonal threshold, not an instantaneous threshold, and the mite management strategies need to ensure that the threshold is not exceeded. This is critical in orchards where ERM and TSM are both present because ERM infests leaves earlier than TSM but the effects are additive. It is generally easier, and less disruptive to predators, to control ERM using green tip oil sprays than to require mid-season use of miticides when predators of TSM are just getting started.

Monitoring

Monitoring mite infestations early in the season is critical, especially in areas with either Bryobia or ERM because these mites overwinter higher in the trees and start infesting leaves between green tip and petal fall. If TSM is the only pest mite of interest then early season monitoring should concentrate on the inner, lower part of the tree where TSM infestations often begin.

Monitoring and sampling once a fortnight is frequent enough until mite infestations begin to develop. In the lead-up to Christmas the monitoring should become weekly because by then ERM populations should be starting to peak and the TSM population would be starting to expand. Predator populations should be noted during mite monitoring. The most cost-effective sampling procedure involves presence/absence recording rather than counting every mite and predator on a leaf. This gives data for calculation of the percentage of leaves that are infested, which can be used to determine one form of instantaneous threshold, or it can be used to calculate CLIDs for use in a seasonal threshold. The slope of the CLIDs graph also indicates how well the predator populations are managing the mite infestations and should also flatten dramatically after an effective miticide application. Being a cumulative graph, it will flatten but never go back towards zero.

Presence/absence sampling can be easily done in the field with a hand lens whereas counting mites requires a microscope in order to get accurate counts. Presence/absence sampling is discussed in Chapter 3, along with templates for recording results. Mite monitoring is potentially the most onerous task in IPDM and in Chapter 3 we have presented practical monitoring methods that allow blocks to be monitored for the suite of common pests and diseases in ways that do not require multiple sampling techniques for each pest or disease.

Calculation of CLIDs

To calculate the leaf infested days (LIDs) between two sample dates (Day 1, Day 2) you add the % leaves infested recorded at day 1 to the % leaves infested recorded at day 2 and divide the answer by 2 to get the average. Then multiple the average by the number of days between day1 and day 2.

For example: If day 1 had 0% leaves infested and day 2 (7 days later) had 30% leaves infested:

The average is (0+ 30)/2 = (30)/2 = 15 and because there were 7 days between samples LID=15x7=105.

If day 3 is another 7 days later and there are 40% leaves infested then LID between Day 2 and day 3 is calculated as (30+40)/2 multiplied by 7 = (70/2) x7= 35x7=245.

The cumulative leaf infested days (CLIDs) between day 1 and day 3 is therefore 105 + 245 = 350

The CLID figure is a 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 well ***before*** it occurs and allow appropriate control to be applied ***only if necessary***.

- 1% leaf scorch will develop at approximately 1000 CLID
- 5% leaf scorch will develop at approximately 1500 CLID. This is the recommended threshold for WBC pears
- 10% leaf scorch will develop at approximately 2400 CLID
- 20% leaf scorch will develop at approximately 3000 CLID

Remember that % 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 which they are willing to tolerate.

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. 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. All miticides have activity groups and resistance management guidelines listed on their labels. These are legal documents and must be followed. Further information on resistance management is provided in Chapter 6.

Naturalised biological control agents

A large number of types of predatory mites and insects are likely to be present in orchards without deliberate introduction. While 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.

Stethorus beetles. Stethorus is a tiny (2mm 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.

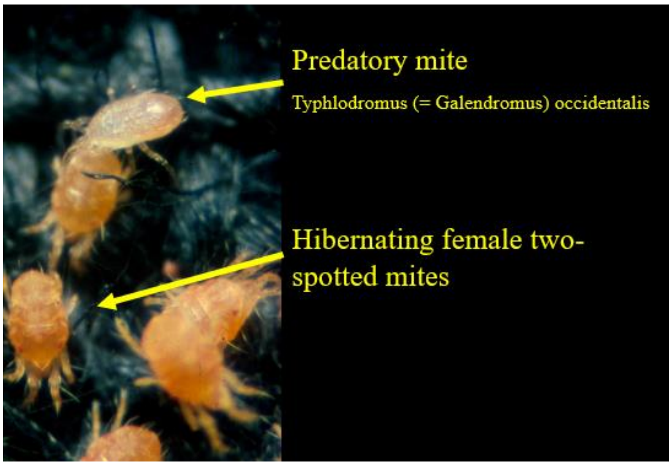

Stethorus adults feeding on two-spotted mites

Lacewings. Both green and brown lacewings are common in Australian apple and pear orchards; particularly those using IPM. Adult lacewings are approximately 15mm long and feed on nectar and pollen. Female green lacewings lay their eggs on long stalks. Brown lacewing eggs do not have stalks and are laid on the leaf surface. A single female lacewing can lay up to 600 eggs during her 3 to 4-week adult life..

Lacewing larvae are generalist feeders and consume a wide range of orchard pests including mites. .

Predatory mites

Predatory mites resistant to organophosphate insecticides were introduced to Australian orchardis to control pest mites during the 1970s and 1980s. Several species are sold commercial insectaries producing biocontrol agents. Effective use of biological control agents reduces the need for pesticide applications which, in turn, slows the development of resistance and reduces the amount of pesticide residues present at harvest.



The four main predatory mite species are the western predatory mite *Galendromus occidentalis* which prefers TSM but also preys on ERM and rust mites; *Galendromus pyri* that prefers ERM but also preys on TSM, Bryobia and rust mites; *Neoseiulus californicus* that feeds on a range of pest mites, other small invertebrates and pollen; and Chilean predatory mite *Phytoseiulus persimilis* that feeds mostly on TSM.

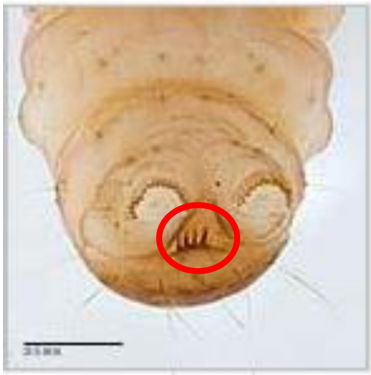
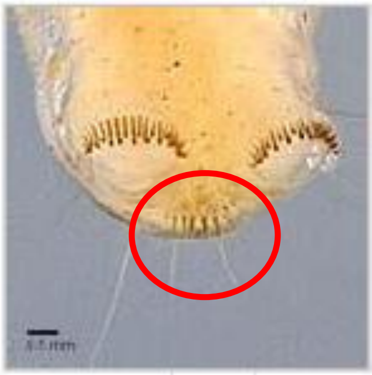
Oriental fruit moth

IPDM Quick Facts

- Oriental fruit moth (OFM) is a minor pest of pome fruit in Victoria
- OFM can have up to 6 generations in stone fruit but less in pome fruit.
- OFM overwintering in pome fruit blocks will emerge as adults in late winter-early spring, mate and disperse to nearby stone fruit.
- OFM in stone fruit blocks nearby pome fruit may disperse into the pome fruit after the stone fruit has been harvested and infest the pome fruit.
- OFM damage to pome fruit looks like codling moth damage but feeding around the core by OFM does not usually involve the seeds.
- OFM adults can be monitored with pheromone traps or traps with lures based on terpinyl actetate.
- OFM egg hatch and timing of generations can be predicted using degree day models using 7.5oC as the base temperature, 110 degree days for egg hatch and 540 degree days for the generation time.
- No thresholds have been determined for OFM infesting pome fruit.
- Good orchard hygiene in stone fruit blocks near pome fruit will reduce dispersal of moths to pome fruit.
- Good orchard hygiene in pome fruit blocks, especially pears, near stone fruit will reduce availability of fruit remaining on trees after harvest and therefore inhibit extra generations of OFM and reduce populations of OFM overwintering in the pome fruit blocks.
- Dual formulations of mating disruption are available for treating both codling moth and OFM in one pass.

The Pest and its Significance

Oriental fruit moth (OFM) *Grapholita molesta* was mostly a pest of stone fruit in Australia but is known to also attack pome fruit overseas. It now also attacks pome fruit in Northern Victoria and could do so in other regions where stone fruit and pome fruit are grown nearby. It is a quarantine pest in Western Australia. On stone fruit trees larvae of the early generation bore into tips of shoots, causing them to distort and dieback. Later generations attack the fruit. This has not been seen on pome fruit but occasionally larvae have bored into the base of shoots. The damage to pome fruits tends to occur later in the season when fruit symptoms look like those caused by codling moth, with a tunnel towards the core but feeding does not usually include the seeds. The larvae look like codling moth larvae but mature larvae can be distinguished from codling moth larvae, with the aid of a hand lens or the camera on a mobile phone, by the presence of an anal comb in OFM larvae but not codling moth larvae. The photographs below have the anal comb, as seen from different angles, within the red circles.

OFM overwinter as diapausing larvae under the bark in the same sort of places as codling moth. OFM emergence and flights begin much earlier than codling moth flights, starting in August when stone fruit trees are beginning to flower but well before pome fruit trees have reached green tip. OFM emerging after overwintering on pome fruit trees mate and then disperse to nearby stone fruit blocks to lay their eggs. This is the most likely reason that little damage to shoots occurs in pome fruit. The third generation of OFM coincides with harvest on early peaches, and presence of apples and pears on pome fruit trees, and some OFM disperse from harvested stone fruit blocks into pome fruit blocks to infest the fruit. OFM adults look like small versions of codling moth but without the coppery spot and dark patch at the end of the wings.

OFM activity can be monitored using pheromone traps, food lure pots using a combination of fermenting brown sugar solution and terpinyl acetate (which are messy to use, need a lot of maintenance, and captured moths are difficult to identify because they lose their scales), and recently lures based on terpinyl acetate have become available for use in sticky traps. Pheromone traps catch only the males and catch can be inhibited if the traps are used in blocks treated with mating disruption. Terpinyl acetate based traps capture both males and females and are unaffected by mating disruption treatments.

Mating disruption dispensers that treat both codling moth and OFM in pome fruit blocks are available.

OFM have a lower developmental threshold of 7.5°C and can produce more generations per season than codling moth. Degree day models are available to forecast timing of these generations. To get a rough approximation of OFM degree days add the maximum and minimum temperatures for the day and divide the result by 2 to estimate the average temperature and then subtract 7.5. Each generation takes on average 540 $^oD_{7.5C}$ and up to 6 generations can occur in a district. Degree day models use first sustained capture of moths in traps as a biofix to initiate accumulation of degree days. The table below summarises the degree day accumulation, after a biofix derived from the time of first moth capture at the start of the season, that is required to forecast commencement of egg hatch for each generation.

Start of egg hatch for egg generation	**$^oD_{7.5C}$ from biofix**
Generation 1	110
Generation 2	650
Generation 3	1190
Generation 4	1730
Generation 5	2270
Generation 6	2810

No thresholds have been developed for OFM in pome fruit. The timing of sprays for OFM in pome fruit will often overlap with sprays against codling moth, starting with the 2nd cohort of the 1st codling moth generation. If mating disruption is used for codling moth in blocks near where stone fruit have a history of OFM damage, consider also using mating disruption for OFM in the pome fruit block.

Apple and Pear IPDM

Pear blossom blast

IPDM Quick Facts

- Pear blast is a disease caused by the bacterium *Pseudomonas syringae*.
- The disease can become a serious problem in regions which commonly have cool, wet weather that persists during long, extended bloom periods.
- The pathogen can live on a wide range of plant types without causing symptoms.
- During winter the pathogen survives in the buds and leaf scars of pear trees.
- In warm spring weather populations of the pathogen increase without causing disease but can spread to neighbouring trees by wind-blown rain.
- The pathogen invades blossoms through natural openings within the flower.
- The bacterium can promote ice formation which makes frost more likely to form. The bacterium then uses the subsequent frost damage to spread through the flower and cause disease. The bacterium then survives on and in fruit and aborted blossom through the growing season
- Infections seldom progress passed 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 than European pears as they often bloom earlier and are subject to more frost damage. Green-fruited varieties may be more susceptible than red or blush varieties. Corella in Australia is susceptible.
- If bacterial blast is seen it is too late to do anything about it during the current season. The one-minute whole tree sampling technique should detect blossom blast symptoms
- Bacterial diseases are difficult to control and there are no products currently registered for the control of this disease on pear.
- Application of various copper products at green tip for the control of pear scab may also help to manage bacterial blossom blight.

The Disease and its Significance

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

The most obvious damage caused by the disease is blossom death which 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. While 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 weather becomes warmer populations of the pathogen increase without causing disease. During this time and subsequently, the bacteria are spread to neighbouring trees by wind-blown rain. It is only when the weather becomes cool and wet that conditions favour disease development.

Blossom infection is favoured by cold, wet periods during bloom because the pathogen invades blossoms through natural openings within the flower. The bacterium can promote ice formation, using a process called ice nucleation, which makes frost more likely to form. The bacterium then uses the subsequent frost damage to spread through the flower and cause disease. The bacterium then survives on and in fruit and aborted blossom through the growing season.

The number of bacterial cells required to be present for ice nucleation to occur depends on temperature. At minus 2.2 ^{o}C one in a million bacterial cells initiate ice nucleation. At minus 2.8 ^{o}C it is one in 10,000, and at minus 3.9 ^{o}C it is one in 10.

Damage

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

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 (right).

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 without the pathogen being present. The blackened, water –soaked appearance of frosted flowers looks the same as those killed by bacterial blast.

Blossom blast symptoms can be distinguished from fireblight, which is not present in Australia and is a serious quarantine issue, because blossom blast does not spread into larger limbs and is not associated with bacterial ooze. Blossom blast occurs earlier in the season than fireblight would be expected and healthy leaves are often found just below flower clusters killed by blossom blast but leaves below fireblight affected clusters will usually be blackened.

Varietal susceptibility

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

Although all pear varieties are infected, susceptibility varies between varieties of European pear. Research conducted in the USA suggests that green-fruited pear varieties may suffer a higher incidence of blossom blight than red-fruited varieties. 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. Avoid planting susceptible varieties such as Nashi in frost-pockets. Consider installing wind machines if you are in a frost prone area.

Pruning

Pruning and destroying affected tissue helps in lowering 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

If bacterial blast is seen it is too late to do anything about it during the current season. The one-minute tree sampling technique described in Chapter 3 should detect blossom blast symptoms and by recording the location of affected trees you will be able to pay more attention to those areas next season if and when cool, wet weather persists during long extended blossom periods. Extra management e.g. (frost protection) can then be applied to this area.

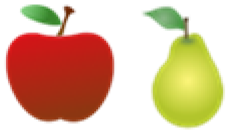
Management

Responsible use of pesticides

Bacterial diseases are difficult to control. Australian orchardists do not have access to agricultural antibiotics and there are no products currently registered for the control of this disease on pear. Application of various copper products for the control of 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.

Apple and Pear IPDM 

Pear and cherry slug

IPDM Quick Facts

- Pear and cherry slugs *Caliroa cerasi*; are not slugs but are the larvae of a sawfly.
- They cause most damage on pears and cherries but also feed on plums, apples, quinces, cotoneasters and hawthorns
- Monitoring and detection in early spring is important
- Monitoring using the one-minute per sample tree technique is cost-effective
- There are usually two generations per season. The 2nd generation usually matures more rapidly because of the warmer weather and tree damage is more evident late summer.
- While 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 blossom in the following season
- The first signs of damage are yellow spots on the upper leaf surface. Continued feeding results in skeletonised leaves.
- Natural biological control agents such as lacewings and hover flies are usually responsible for keeping pest populations low.
- Pear slugs are easy to control with almost any insecticide which means that spraying for other pests will probably kill the slugs as well.
- Choice of insecticide should consider impact on non-target organisms such as the predators and parasitoids of other pests

The pest and its significance

Pear and cherry slugs *Caliroa cerasi*; are not slugs but are the larvae of a sawfly. They cause most damage on pears and cherries but also feed on plums, apples, quinces, cotoneasters and hawthorns.

The sawfly overwinters as a pupa in a cocoon underground beneath the host tree. Adults (small shiny black wasps about 5mm long) emerge in spring, mate and lay an oval shaped, slightly flattened, very small egg (about 0.5 x 0.9 mm) on the lower surface of a host plant. After the egg hatches larvae make their way to the upper surface of the leaf to feed. These young larvae are pale, free from slime, and have a light brown head. As they begin to eat they grow rapidly and secrete a coat of slime, giving them a translucent yellow-black appearance. Older larvae turn olive green, may be lighter in appearance, and reach a maximum length of 5-10mm. They skeletonise foliage by removing fleshy, green leaf tissue from the upper surface, leaving a network of fine leaf veins and paper-thin epidermis (the outer covering of the leaf). Fully mature larvae drop to the soil and burrow in to pupate in fragile cocoons. There are usually two generations per season. The 2^{nd} generation usually matures more rapidly because of the warmer weather and tree damage is more evident late summer.

While 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 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 light brown apple moth and reduce the number of broad-spectrum insecticide applications.

Damage

Leaves

Following the emergence of larvae leaf damage occurs quickly. The first signs of damage are yellow spots on the upper leaf surface. Continued 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 and in this case, entire trees may appear scorched. Severe infestations can cause premature leaf fall.

Although the damage looks unsightly, trees which 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
- Weather is conducive to a rapid build-up of larvae 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 hover flies 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.

The one-minute whole tree inspection technique described in Chapter 3 is designed for early detection of pests like pear slug. Eggs are very small and almost impossible to detect so it is therefore vital to detect larvae on the top surfaces of leaves as early as possible. Adults are active from October and larvae in November through to the end of March. 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.

Responsible use of pesticides

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

Pear slugs are easy to control with almost any insecticide which means that spraying for other pests will probably kill the slugs as well. Choice of insecticide should consider impact on non-target organisms such as the predators and parasitoids of other pests. Refer to Chapter 6 for information on these side-effects.

Biological control, Biorational pesticides and Organics

There is some evidence that covering young larvae with wood ash is an effective control technique. Early reports from the 1890s indicated that slaked lime mixed with sulphur, and the use of dry sand was effective. Abrasive desiccants such as kaolin used for sunburn protection may be an alternative. These methods may be practical for small scale or organic producers.

The use of poultry under infested trees during winter is not practical for most conventional orchards, issues of pesticide residues need to be considered, and protection from predation by cats, foxes and raptors may be required.

IN both Europe and New Zealand there has been some work carried out 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.

Apple and Pear IPDM

Phytophthora root and crown rot

IPDM Quick Facts

- Three species of Phytophthora (*P. cactorum*, *P. cinnamomi* and *P. cambivora*) cause the disease root and collar rot in Australian orchards.
- The disease commonly infects relatively young trees and occurs in patches of 1-5 trees throughout the orchard block. Phytophthora is more likely to kill young trees as their root and crown areas are small compared to mature trees
- The disease is usually well established before above-ground symptoms are noticed and infected trees are almost always beyond cure.
- The disease is more common in trees with herbicide guards or where there is a lot of weed growth in the row
- When conducting monitoring in *Phytophthora* infected blocks take care to not spread the disease to other clean blocks. Restrict vehicle access and disinfect footwear
- Where *Phytophthora* is present it impossible to eradicate. It is therefore important to avoid bringing *Phytophthora* in from outside of the orchard block. Only buy trees from reputable nurseries and talk to other growers about the health of recently purchased nursery stock
- Improving soil drainage and increasing soil organic matter will help to control this disease
- Finding ways to reduce waterlogging are critical to managing *Phytophthora* problems
- Choose rootstocks and varieties to match growing systems, soil types and consumer preferences. Where *Phytophthora* is likely to be a problem extra thought should be given to the disease resistance of planting material.

The Disease and its significance

The significance of Phytophthora in Australian apple and pear orchards varies between 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 Phytophthora (*P. cactorum*, *P. cinnamomi* and *P. cambivora*) cause the disease root and collar rot in Australian orchards. The disease commonly infects relatively young trees and occurs in patches of 1-5 trees throughout the orchard block. Phytophthora is more likely to kill young trees as their root and crown areas are small compared to mature trees.

Remedial treatment is labour-intensive and often unsuccessful. More commonly orchardists choose to remove trees and soil and replant. This is costly and makes orchard management more difficult as blocks 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 they are commonly watered at the same rate as other trees, leading to over-watering, water-logging and re-infection.

Damage

Roots

Following infection there is an overall reduction in the number of roots, especially the fine secondary roots responsible for much of the tree water and nutrient absorption. This affects the above-ground growth of the tree. Leaves drop giving the canopy an 'open' appearance, there is a lack of terminal growth and leaves wilt and yellow. Infected trees lodge during high winds if they are unsupported. Eventually terminal shoots die, 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, the bark is loose and there may be dark lesions which 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 soil-level. Trees with crown rot (also known as collar rot) die very quickly. The infection begins with one or more 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 colour.

Similar damage

Above ground symptoms can be confused with several other root diseases. These include White root rot (caused by *Rosellinia necatrix*) and Armillaria root rot

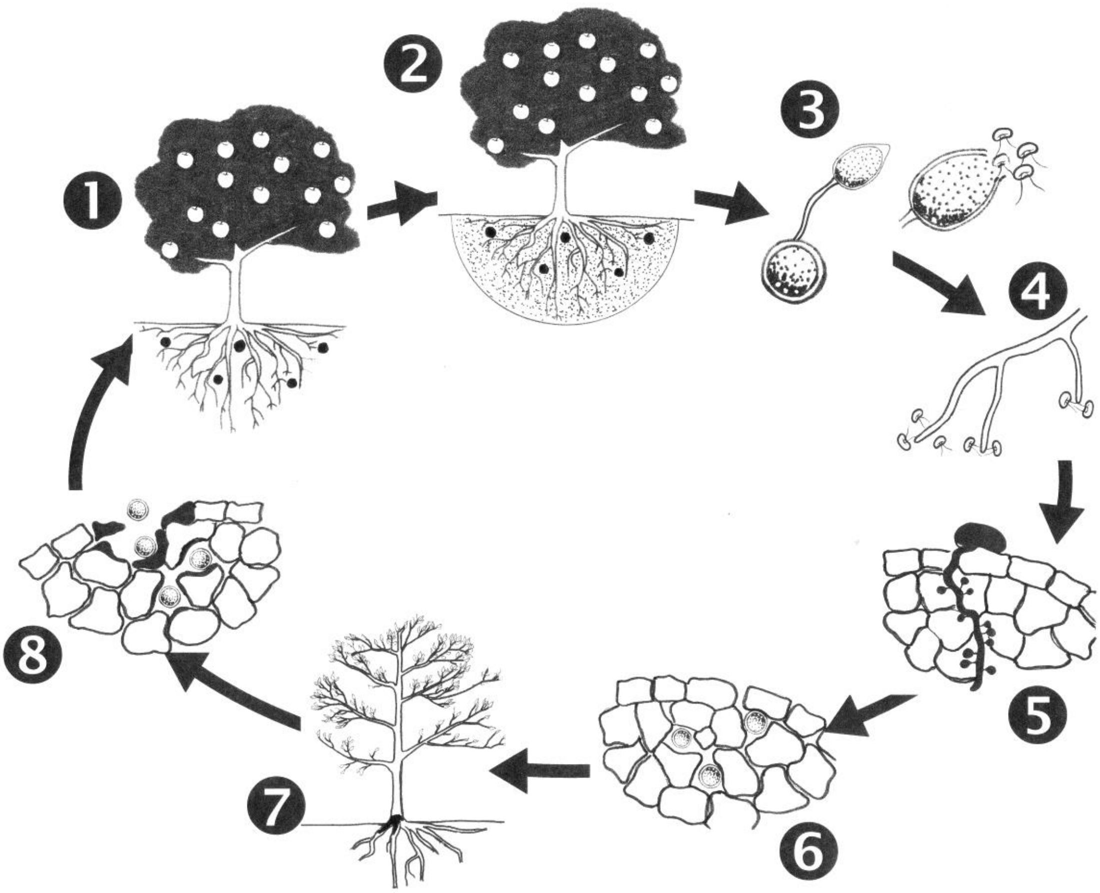
Monitoring

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.

Where early signs of the disease are seen action must be taken to minimise further losses (see the section on management below). Bear in mind though that there is often a lag time between disease infection, symptoms being seen 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 only protect the trees which have not already been infected.

When conducting monitoring in *Phytophthora* infected blocks take care to not spread the disease to other clean blocks. Restrict vehicle access and disinfect footwear.

Life cycle



The species of *Phytophthora* infecting pome fruit have slightly different lifecycles to each other. This is a simplified life cycle which 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 around 2 seasons under ideal conditions➊. When the soil becomes saturated with water ➋, the oospores germinate and form sac-like structures called sporangia which, in turn, germinate releasing small swimming spores called zoospores ➌. These spores are unusual in that they have an ability to move freely in soil moisture. They are attracted by chemicals given off by fresh young roots➍. When they reach these roots, they attach and send a thread like infection structure into the root. These structures bud off small round bodies which will mature to form oospores➎. Within the roots, the oospores are protected and continue to grow➏. As the fungus develops and gains nutrition the roots begin to breakdown and are less efficient at providing water and nutrients for tree growth. Above-ground trees at first appear wilted, unthrifty and stunted. Fine root hairs are gradually broken down➐. As the roots rot, the oospores are released into the soil and become available to continue the disease cycle when soil moisture and temperature are appropriate➑

Prevention and good orchard management

IPDM requires consideration of what the tree requires from an agronomic point of view as much as from a pest and disease context.

In Chapter 1 we emphasised that:

- Soil biodiversity is important for plant health and nutrition, and supporting biocontrol agents
- Improving biosecurity is more cost-effective than attempting to eradicate all pests and diseases
- Cultural practices are effective preventative measures

In Chapter 2 we emphasised that IPDM starts well before problems are observed. A well-developed IPDM plan involves 4 major steps:

5. Prevention by strategic planning to avoid problems
6. Preparation to counter adverse conditions
7. Planting healthy quality trees into well prepared sites
8. Pest, disease and weed management planning

Dealing with root and collar rot is a good example of why the principles of IPDM are so important.

Nursery stock and soil movement and improvement

Where *Phytophthora* is present it impossible to eradicate. It is therefore important to avoid bringing *Phytophthora* in from outside of the orchard block. Only buy trees from reputable nurseries 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, poorly drained, cool soils where water tends to pool and stay in contact with the crown and roots. It can also spread quickly through a block on lighter soils if there is a hard pan underneath that prevents deep drainage and increases lateral water movement. 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 20-25cm in height 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 drainage and increasing soil organic matter will help to control this disease. Incorporation of organic material (commercially available compost) into the soil encourages beneficial soil micro-organisms which protect the tree roots from infection by pathogens. 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. Soil testing for pathogens prior to commencing development of the orchard block could allow corrective action to be taken prior to major earthworks. Consider design and surfacing of farm tracks to reduce risks associated with vehicles becoming contaminated. Installing subsoil drains, improving soil organic content and perhaps seeding with mycorrhizal fungi may be required. Planting expensive fruit trees into substandard and infected soil is asking for trouble.

Infected trees may not be exhibiting symptoms. In most cases the infected area is several trees bigger than the area showing symptoms. Rather than removing trees and large volumes of soil and then filling the holes with 'better training' soils consider cutting your losses and removing more trees so that drainage problems and soil organic matter can be addressed for longer term benefits. Filling holes with 'better draining' soil actually creates a sump that collects water and drowns the new tree.

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

Avoiding root and crown damage

Damaged roots release more chemicals into the soil and therefore attract more zoospores (see lifecycle). The wounded roots also allow these disease spores to enter the roots more easily. Any practice which damages either roots or crowns will allow higher phytophthora infections.

Ripping to prune roots on vigorous rootstocks should be avoided in soils which are prone to waterlogging or where phytophthora has been a problem in the past. Choosing dwarfing rootstocks which restrict scion vigour needs to be considered before planting.

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 crown of the trees and to make sure that foraging does not damage or expose roots. Fencing may be necessary.

Water management

Movement and development of the disease depends on water. Water allows zoospores (see the lifecycle above) to swim through soil pores and infect root tips. As a rule of thumb, these spores need soil to be saturated for 24 hours or more to infect (though this varies with temperature and species). Finding ways to reduce waterlogging are critical to managing Phytophthora problems.

Symptoms of the disease reflect damage under the ground. Root damage reduces the ability of the tree to respond to drought and waterlogging. Both affect the ability of the tree to take in water and nutrients. Roots need both oxygen and water. Waterlogging makes the soil anaerobic and therefore affects the supply of oxygen. Drought affects soil moisture and increase tree demand for water. 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 fewer roots, but irrigation has allowed the tree for survive for a period. During extremely hot, dry weather the tree can no longer cope and dies.

Rootstocks

Choose rootstocks and varieties to match growing systems, soil types and consumer preferences. Where *Phytophthora* is likely to be a problem extra thought should be given to the disease resistance of 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 between *Phytophthora* species, growers are encouraged to trial small numbers of a particular rootstock before planting widely.

Apple rootstocks for Phytophthora prone areas[1]		
Plant		**Avoid**
M9	M7	MM104
M2	M26	MM106
M4	MM111	

1 These are generalised recommendations. Note warnings in text.

Controlling weeds

Do not allow excessive weed growth under trees. The above-ground portion of weeds slows evaporation and the crown and soil surface stay wet for longer. The roots of weeds slow water drainage through the soil profile and 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 of herbicide guards encourages *Phytophthora*

Pay extra attention to the general health (particularly the canopy density and colour) of trees in low-lying and water-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.

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 of where other trees have died as a result of the disease it may be advisable to adopt a routine schedule of sprays.

Fosetyl as Al 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 only be undertaken for high value trees in the very earliest stages of infection. It may be a useful precautionary treatment for young trees in very high density plantings which 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.**

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. While no products are specifically registered as soil adjuvants overseas research has shown common soil inhabiting fungi such as *Trichoderma* and *Streptomyces* reduce the effect of *Phytophthora* on a range of crop plants.

Apple and Pear IPDM

Powdery mildew

IPDM Quick Facts

- Powdery mildew is caused by a fungus *Podosphaera leucotricha*.
- Many important commercial apples are susceptible to powdery mildew.
- The fungus requires living plant tissue to survive and by infecting flower and leaf buds, shoots, leaves and fruit it reduces tree productivity and fruit quality
- The pathogen overwinters as mycelium on dormant fruit and leaf buds infected the previous season
- The first symptoms are seen on infected buds a few days after they open. Infected expanding leaves have small white-grey powdery lesions. The lower leaf surface is usually colonized first. Infected flowers appear covered with the powdery growth.
- Only new leaves are susceptible to infection and only for a few days after emergence. Fruit can be infected between pink and bloom. Severe infection during flowering can result in failure to set fruit or russetting of fruit, seen as a maze of fine lines often appearing as a solid patch.
- By mid-summer, infected leaves turn brown and senesce prematurely. On less susceptible cultivars, symptoms may appear as pale spots with reddish borders on the underside of the leaf.
- Leaf wetness is not necessary for infection. Optimum conditions are RH >70% and temperatures between 19-25ºC. The risk of infection decreases as summer temperatures increase but further outbreaks can occur in autumn.
- Monitor buds, flowers, leaves and shoots from green tip to petal fall to determine presence of primary infection, especially on susceptible varieties. Continue scouting until terminal shoot growth stops.
- At harvest monitor foliage and fruit on trees to determine effectiveness of IPM program and assess potential overwintering inoculum.

The Disease and its Significance

Powdery mildew, caused by the fungus *Podosphaera leucotricha*, is a major disease and many important commercial apples (e.g. Cripps Pink, Bravo etc) are susceptible to powdery mildew. The fungus requires living plant tissue to survive, infecting flower and leaf buds, shoots, leaves and fruit. The disease reduces tree productivity and fruit quality. Although the disease has been reported on pears and quince it is rarely seen on these hosts in Australia.

The disease affects apple trees in several ways, all of which have economic impacts. Fruit with russet caused by 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%.

The first symptoms are seen on infected buds a few days after they open. Symptoms appear on expanding leaves as small white-grey lesions that have powdery fungal growth. The lower surface of leaves is usually initially colonized by the fungus. Infected flowers appear covered with the powdery growth.

Severe infection during flowering can result in failure to set fruit, or russetting of fruit seen as a maze of fine lines often appearing as a solid patch.

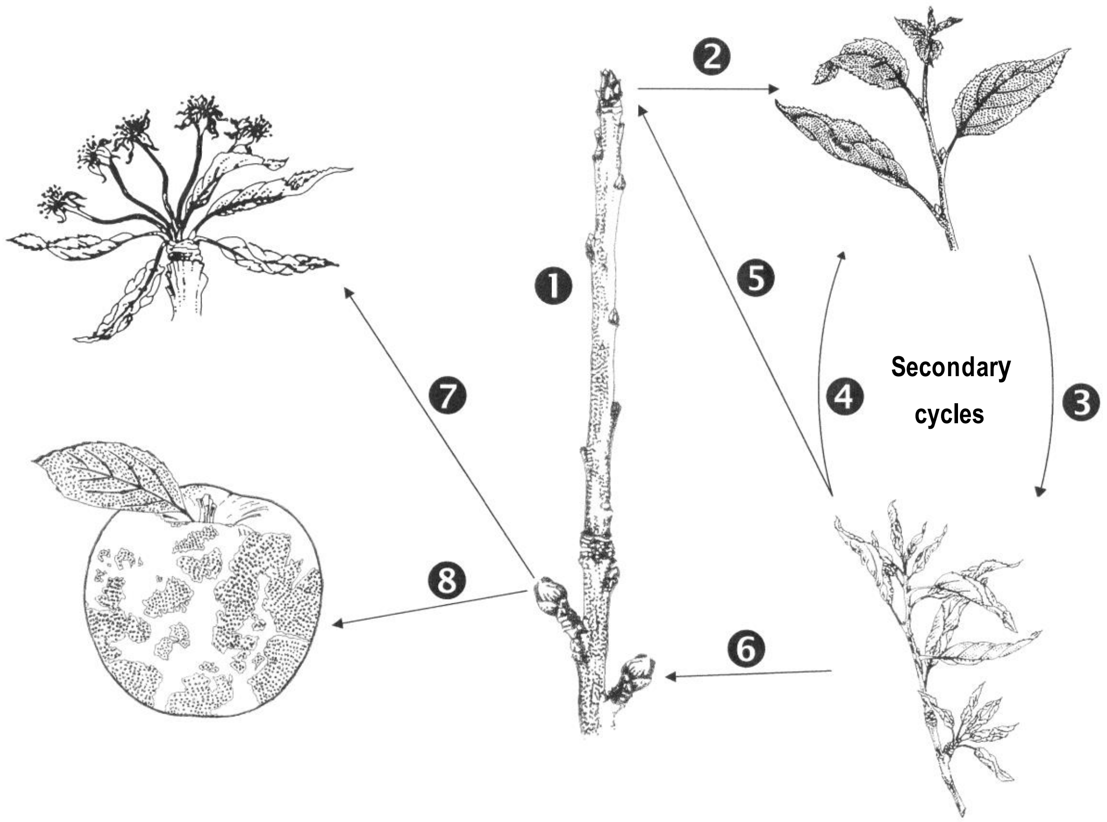
By mid-summer, infected leaves turn brown and senesce prematurely. On less susceptible cultivars, symptoms may appear as pale spots with reddish borders on the underside of the leaf.

Similar damage

Damage due to powdery mildew is quite distinctive. At first glance webbing and distortion of leaves 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 cupped, pale leaves and distorted growth. Again, the presence of dust or powder-like spore is diagnostic for powdery mildew.

Life cycle



During winter the powdery mildew pathogen remains sheltered in floral or vegetative buds ❶. As leaves expand in early spring the pathogen becomes active and infects the new growth. Early infections appear as small white-grey lesions which 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 trees lose their leaves. As 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 formed❼. Where fruit does form from infected buds it is usually russetted❽. The pathogen does not form spores on either aborted buds or russetted fruit. Secondary disease cycles can only occur where leaves are infected.

One aspect of powdery mildews life cycle is unusual when compared to other disease and this has an effect on managing the disease. Powdery mildew does not require rain to develop (as do other diseases). In fact, rain is harmful to the fungus and suppresses suppression 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.

Scouting Notes

Monitor buds, flowers, leaves and shoots from green tip to petal fall to determine presence of primary infection, especially on susceptible varieties. This can be done at the same time and on the same trees being used for scouting insects and scab. The one minute/tree inspection technique described in Chapter 3 should detect powdery mildew incidence because as you walk around the tree you will be looking at more than 20 shoots. Inspect the top 5 unfolding leaves per shoot for mildew and record the incidence of mildewed shoots. Continue scouting until terminal shoot growth stops.

Healthy (left) and infected (Right) shoot at pink stage

Early symptoms on upper leaf surface

Severely infected extension shoot.

Monitor weather to determine when conditions for infection occur and need for application of fungicide with activity against powdery mildew to prevent disease and inoculum build-up.

The pre-harvest fruit inspection technique described in Chapter 3 will allow incidence of powdery mildew affected fruit to be recorded. Assess foliage in autumn to detect potential overwintering inoculum.

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 where 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 further 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 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 this disease. Burn all prunings.

Wind breaks, netting and tree planting should also be managed to optimise air flow, particularly in regions where this disease is a problem.

Varieties

All commercial varieties of apple grown in Australia are susceptible to powdery mildew. The worst affected varieties include Cripps Pink, Bravo, Jonathon, Bonza, Jonagold, and Granny Smith. In regions where powdery mildew is a problem, growers should consider the risk associated with planting those varieties. 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. Red delicious and Fuji are less susceptible. The University of California investigated relative susceptibility of cultivars grown in the USA and the results are available on-line at https://doi.org/10.1094/PHP-2009-1119-01-RS but cultivars developed after 2009 were not investigated, not many on the list are grown in Australia, and the susceptibility varied with location.

Responsible use of pesticides

Almost all the pesticides used to manage powdery mildew are also registered for, and effective against black spot. In regions where apple black spot is a problem powdery mildew control may be coincidental because of fungicide applications made principally for black spot. However where 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 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 10-14 day intervals, but this practice is not sustainable and should be reviewed every season. In any case, sprays for powdery mildew should only be necessary on the most susceptible of varieties beyond the blossom period. When applying fungicides for powdery mildew it is important to consider that:

- The white cottony growth 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 young trees and control is critical for those being trained as central leader or palmette types where lateral tipping is undesirable.

Managing resistance

Almost all of the fungicides registered for use against powdery mildew belong to chemical groupings which 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 sulphur 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) which are present in the orchard during blossom and this may result in pest mite problems later in the season.

Thresholds

No economic thresholds or action thresholds have been developed for powdery mildew in Australia. In some apple growing areas in USA a threshold of 20% of leaves infected is used but, although there is a reasonable relationship between the percentage of leaves infested and the amount of leaf area affected, there is no reliable relationship between the incidence or severity of leaf infection and fruit damage.

The period between tight cluster and petal fall is when the crop is at the greatest risk for infections. Factors that influence infection risk include amount of shoot growth, unprotected tissue and warm temperatures. Spraying before infection occurs critical to managing powdery mildew.

Apple and Pear IPDM

San José scale

IPDM Quick Facts

- San José scale (*Quadraspidiotus perniciosus*) is difficult to control with conventional insecticides because it spends most of its time under a protective waxy covering.
- Pesticide applications must be precisely timed to when the highly mobile but unprotected crawlers are exposed on the branches and fruit.
- Crawlers are difficult to see and are only exposed for a short time before they produce the protective scale covering.
- Prediction of critical timing can be assisted by use of phenology models that use daily temperature data to calculate insect growth units (degree days) to forecast when crawlers will be exposed.
- The models can predict crawler emergence by accumulating degree days from the middle of winter (1st July) or be initiated by a biofix based on capture of males in pheromone traps.
- There are several generations per season.
- Applications of horticultural oil formulated for dormant applications are important for management of this pest but need to be coordinated with treatments for other pests.

The Pest and its Significance

San José scale (*Quadraspidiotus 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 habit of forming dense encrustations (>100 / cm^2) on the bark of their hosts has a gradual debilitating effect on branches. Branch death usually takes several years of continuous infestation and affects tree training efforts. The overall reduction in tree vigour and health reduces fruit yields and direct feeding on fruit affects fruit quality and marketability.

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 and a trend away from dormant treatments this pest is making a comeback in commercial plantings.

Damage

Fruit. San José scale injects a toxin while feeding, which results in a distinctive red halo around the feeding site on fruit and 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.

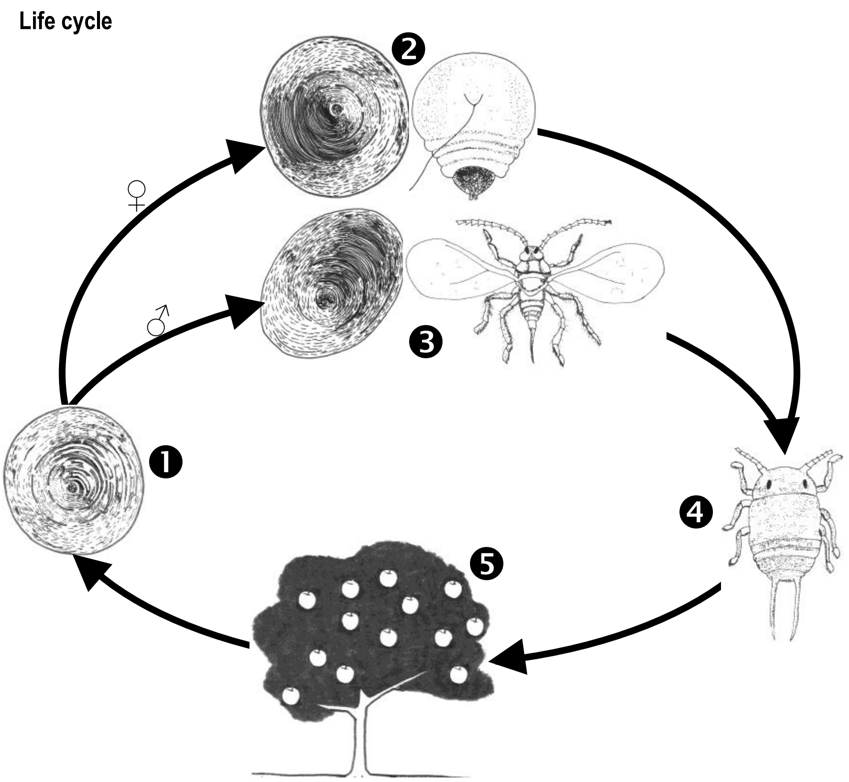
© NSWDPI

Limbs and branches. Unmanaged infestations result in an overall decline in tree vigour, growth and productivity due to death of twigs, limbs and eventually tree death. Damage is usually more severe and occurs more rapidly on younger trees because they provide easier access to succulent green tissue and thinner bark. Young trees can be killed in 1-3 years. 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.

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.

Life cycle



Scales are often not completely dormant during winter and all stages (except adult males) can be found throughout the colder months attached to the larger branches of trees. About 80% of the overwintering scale insects are immature and growth resumes in spring as temperatures increase❶. This usually coincides with the beginning of blossom but because development is dependent on temperatures 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 which 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 which also has a raised knob. Males emerge as minute (1mm long) yellow, two-winged insects ❸. Females remain under their scale and do not move throughout their entire lives.

Following mating females give birth to live young; they do not lay eggs. The young nymphs emerge from the cover of the scale as bright yellow crawlers ❹ that disperse throughout the tree and to nearby trees ❺. Crawlers find a suitable feeding site within 24-hours, insert their slender thread-like mouthparts through the bark, or 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 is dependent on temperature, but typically they reach maturity in six to eight weeks and there are two to four generations per year.

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

San José scale monitoring is targeted at detecting the crawler stage of the life cycle because this is one of the few stages where it is not protected by its waxy scale and can be effectively killed using insecticide and; the crawler stage is responsible for spreading infestations. Controlling crawlers effectively stops infestations spreading in the orchard. However, there is only a short window of time in which the crawlers are unprotected. Degree day models are available to predict when the crawlers can be expected to emerge. These models either use the first detection of males in pheromone traps, or a set starting date in winter, as the biofix for initiating accumulation of degree days. The lower development threshold temperature used to calculate degree days in the model is 10.6^{o}C. A rough approximation of degree days for a single day is the average temperature minus the developmental threshold. The Californian model suggests that emergence of males is expected about 111 degree days after 1st July in Australia and crawlers start emerging 225 degree days later. The optimal time to treat crawlers is between 333-389 degree days after male capture or 444-500 degree days after 1st July. Each subsequent generation takes 583 degree days. The model needs to be tested more widely in Australia and may require some minor modifications to adjust for conditions in each growing area.

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 the forks of branches, tiny cracks and crevices in the bark and 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.

José scale infestation on apple twig. Photo: Anne-Sophie Roy, EMPPPO

Responsible use of pesticides

Where careful monitoring of the crop indicates that application of dormant oil and other management has failed to control San José scale it may be necessary to apply an insecticide. Almost all the registered products available for use against San José scale in-season have an adverse effect on predators of orchard pests (Refer to Chapter 6 for details). Application of these products should be as a last resort and orchardists should expect problems with other pests.

Fenoxycarb is registered as a product which will suppress San José scale when applied to control codling moth and/or Light brown 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. This spray should be carried out even if no scale has been seen recently. Scale can be difficult to detect, and heavy infestations can come from relatively low starting populations. Oil sprays during dormancy are particularly effective as most of the scale population will consist of younger individuals who are particularly susceptible to this treatment. Orchardists who have a regular European red mite problem generally delay application of oil until close to green tip. Although this timing is not as effective in controlling scale, and to avoid phytotoxic effects on trees there should be at least 4 weeks between two applications of oil, orchardists in this situation have to decide which pest is more important. Information from winter assessments as well as records from previous seasons will help orchardists to decide which pest is likely to cause the most serious problem and apply oil accordingly.

Lime sulphur

Dormant application of lime sulphur in combination with oil sprays will help to control San José scale but may affect overwintering predatory mites. 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 sulphur 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 pulchellus (*syn*. lindi)* is an important predator of immature stages of San José scale.

Silver Leaf

IPDM Quick Facts

- Silver leaf disease caused by the fungus *Chondrostereum purpureum* occurs on both apples and pears.
- The disease occurs in temperate regions throughout the world but in Australia it is more common in cooler regions, like the Adelaide Hills and the Dandenong ranges, that experience damp, humid conditions.
- The fungus infects only the woody tissue of the trees but exudes toxins that cause breakdown in the leaf structure, creating air pockets.
- The disease is characterised by the leaves developing a silvery sheen.
- In storage, fruit from infected trees is predisposed to infection by other fruit-rotting fungi.
- The fungus enters through damaged bark and pruning wounds and spreads rapidly into the heartwood and sapwood.
- As the tree dies the fungus produces bracket-like fruiting bodies.
- There are no chemicals for control of this disease.
- All diseased wood from around the orchard should be removed and burned.
- Fresh pruning cuts should be sealed immediately to prevent infection

The Disease and its Significance

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 between 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)

The disease is characterised by the leaves developing a silvery sheen. This sheen is caused by light shining through leaf cells which are damaged by toxins exuded by the pathogen, which is located only in the wood. Overall, the tree becomes unthrifty with reduced leaf area, poor root growth, poor quality fruit which does not store well, and lower yields. 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 several factors which can lead to an increased incidence of water core.

External (left) and internal symptoms (right) of water-core caused by the disease silver leaf

Management

The disease can be controlled by careful pruning in conjunction with wound dressings.

Avoid winter pruning 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 help the pathogen to colonise.

The disease is not easily transmitted on pruning tools, and you don't need to sterilise your tools between cuts.

All prunings must be buried or burnt. 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; preferably immediately after making large cuts. The pathogen produces more spores in the dark, and leaving wounds unprotected is a recipe for disaster. If for some reason wound dressings aren't applied quickly, it is often best to leave wounds unprotected. Infection is likely to have already occurred. The pathogen is likely to have penetrated some depth into the tree 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.

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.

Many fungicides are toxic to trees when applied at the wrong rates. Therefore, avoid 'home-made' mixtures of paint and fungicides. Use of copper-based products is especially dangerous, as they may increase susceptibility to silver leaf. A commercial wound dressing formulation is available that contains the fungicides cyproconazole and iodocarb. Use this formulation if silver leaf has been a serious problem.

Apple and Pear IPDM

Snails

IPDM Quick Facts

- Snails can damage leaves, bark and fruit
- Snails sheltering in tree guards can create conditions that promote collar rot
- Snails are more prevalent in blocks under netting
- Snails are mor active at night
- Snails cluster together during the day in sheltered sites
- Common garden snail is the most prevalent snail in pome fruit orchards
- Eighty percent of snail eggs are laid over winter
- Weeds in the tree-line shelter snails, provide food, and are ladders into the crop.
- Snails do not like abrasive surfaces or copper
- Poultry can provide good control of snails but need to be properly managed to prevent predation, parasitic mites, pesticide poisoning, pesticide residues in meat and eggs, and disease such as Avian Influenza spread by wild birds.
- Baits are a last resort and must be applied correctly to avoid poisoning wildlife, livestock, companion animals, and children
- A buffered copper complex formulation is registered as a snail repellent for use in orchards

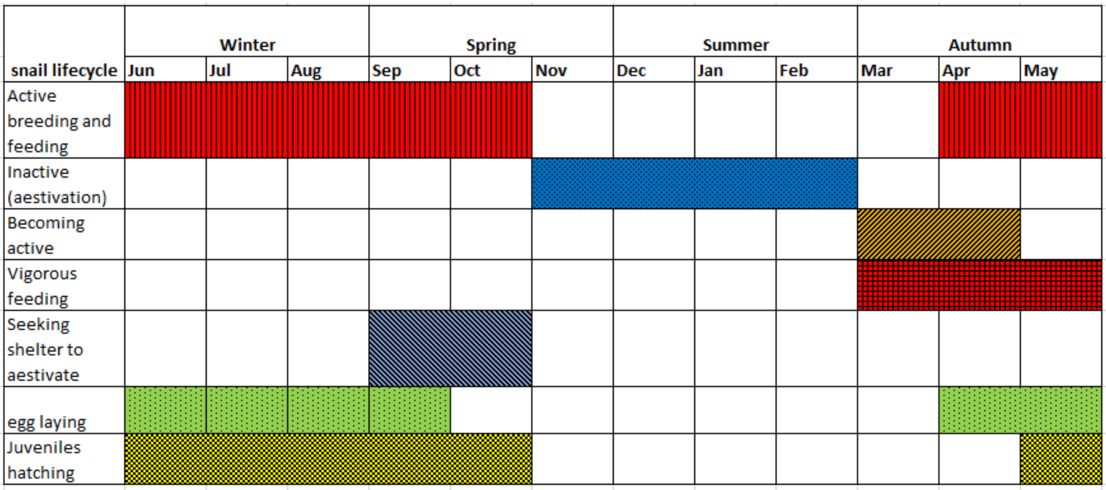
The Pest and its Significance

Snails are voracious feeders and can damage leaves and young fruit. Losses of 5-10% in Gala apple blocks have been recorded. Damage is worst in blocks under netting. Orchards in Stanthorpe, The Goulburn Valley, Perth and the Adelaide Hills are often severely affected. Snails are generally nocturnal feeders and most damage occurs at night, although they venture out on cool rainy days. Snails tend to cluster together in sheltered humid places such as in tree guards, under piles of leaves or prunings, around the base of trellis poles, and in vegetation near irrigation drippers, sprinklers, and leaking pipes or hoses. When a lot of snails take shelter in tree guards their excrement can build up and completely fill the guards to above the graft union with a rich, moist organic substrate that can encourage adventitious roots to develop from the scion. It also creates ideal conditions for crown rot.

The most common snail species in orchards is the common garden snail *Helix aspersa* which is also edible and widely used in European cookery. Snails are hermaphroditic, meaning 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 egg laying. The eggs are laid into shallow depressions or crevices in moist earth, often beneath piles of leaves fallen from the trees in autumn. After hatching it takes immature snails about 2 years to reach sexual maturity.

Lifecycle



Adult snails are most active from late autumn through to late spring, but this will vary depending on temperature, humidity and availability of food. Snails become inactive (aestivate) over hot dry weather such as late spring through summer. They become active again in autumn after substantial rain and commence vigorous feeding in preparation for breeding, which starts in mid-autumn and continues through winter into mid-spring. Egg laying starts in mid-late autumn through winter to early spring, with most eggs laid over winter. Juveniles start hatching from late autumn and hatching continues through winter into spring. As weather warms up in spring the snails start to look for shelter in which to aestivate.

Cultural control

Snails are highly dependent on presence of humid sheltering refuges to which they retreat 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

Weeds are plants growing where we do not want them. In the context of snail control in orchards, weeds are plants that provide dense shelter and ladders into the fruit trees for the snails. Not all plants on the orchard floor will be weeds even though some of them are considered weeds in pastures or gardens. Predatory and parasitic insects that control moth caterpillars, aphids, mealybugs, and mites usually rely on pollen and nectar from flowering plants on the orchard floor for energy and protein to mature their eggs. Small predatory animals like lizards that prey on snails rely on cover from plants on the orchard floor to protect them from predation by larger animals including birds. Maintaining a weed free tree line is good practice for snail control and, provided the inter-row sward contains some appropriate flowering plants, you will still be able to provide habitat for the beneficial predatory species that keep your other pests under control.

Snail eggs can survive in moist soil under fallen leaves. Ground sprays of urea used for scab control can cause those leaves to break down quicker and eliminate those refuges. Leaf raking used for scab control would also expose the sites where snail eggs had been laid.

Barriers

Snails do not like crawling over dry or abrasive surfaces. Orchardists using organic techniques often place rings of ash, sawdust or stone dust around trees to deter snails. Superphosphate is also suitable. Rain and irrigation tend to disperse these barriers and they require frequent reapplication. Copper is an effective snail repellent and copper bands or copper wire round the butts of trees have been reported to be effective, but they need to be checked regularly as the tree butt circumference expands as the tree grows. Copper sheet and wire is expensive, and theft is rife.

Poultry in the orchard

Ducks, geese, chickens, turkeys and guinea fowl have been used in orchards to help control pests. Ducks and geese are effective snail controllers. Khaki Campbell and Indian Runner ducks are very good. Access to dams and waterways should be restricted to encourage the birds to forage in the orchard. A flock of 20 birds reportedly can control snails in an area as large as 20 hectares. Chickens control insects in addition to snails. Guinea fowl feed on snails but are not as effective as ducks or chickens and should be considered if earwigs are a problem. Earwigs are good predators of woolly apple aphid so that needs to be considered before letting guinea fowl loose. Unmanaged birds may create more problems than they solve. Birds must be protected from predators such as foxes, feral cats, and raptors. Some pesticides are highly toxic to birds. A lockable pen or shelter must be available well away from the orchard when pesticides are being applied. If the birds are also to be used for meat or egg production, then pesticide residues need to be considered. Free ranging poultry are prone to Avian Influenza transmitted by wild birds, so precautions need to be taken to avoid contact with wild birds.

Baits

Methiocarb is an active ingredient registered for use in baits in orchards. This chemical is very toxic and can result in poisoning of livestock, companion animals, and children if not used properly. Baiting should only be used as a last resort and appropriate precautions must be used. If baiting is warranted it should be used in autumn to target snails before they start laying eggs. Copper sprays should not be applied while baits are in use because copper will repel snails from the baits. Do not heap baits. A uniform distribution maximises effectiveness.

A better option is to investigate the use of registered snail repellents based on buffered copper complex that can be used on fruit trees prior to flowering as an early season snail control. As with all copper spray products care is required to prevent overspray onto foliage.

Apple and Pear IPDM

Spring beetle

IPDM Quick Facts

- Spring beetle is a native scarab beetle that breeds in pasture and native bush.
- The only stage that attacks pome fruit is the adult beetle
- Adults are active in spring and early summer
- They attack leaves near flowers and the petals.
- Monitoring techniques for apple dimpling bug over flowering, and budworms and loopers after petal fall will detect spring beetles.
- No thresholds have been detected but control measures are generally not warranted unless beetles are present in large numbers or young trees less than 2 years old are being attacked.

The Pest and its Significance

Spring beetle *Colymbomorpha vittata* is a native scarab beetle that is a pest of plantation trees, horticultural crops and ornamental plants especially roses. They occur primarily in the southwest coastal region of Western Australia and are not reported from the eastern states or the Northern Territory. Adults are the only stage reported in orchards. They disperse from areas of native vegetation in warmer weather during spring only, primarily feeding on leaves and flower petals.

Description

Adult spring beetle are shiny metallic green/brown/yellow with stripes along their wing covers, flat/rounded beetles with prominent branched antennae and long legs bearing prominent spines. They are about 12mm long.

Lifecycle

Little is known of the details of the life cycle. Eggs are laid in pasture paddocks and native bush. Larvae initially feed on decaying organic matter and then continue feeding underground on roots and tubers until late winter when they pupate in earthen cells. Adults emerge in spring and may form large swarms that are often seen on calm sunny mornings after rain before they disperse. This period in spring and early summer is the only time that Spring beetle invades orchards, where they prefer feeding on young leaf tissue near the near growing tip and on petals. When disturbed, adults feign death and fall to the ground. They are more likely to be present on warmer days.

Monitoring

Check trees in spring for signs of leaf feeding and confirm whether spring beetles are the cause. Blossom tapping used for monitoring activity of apple dimpling bugs and thrips should detect spring beetle adults on flowers. After flowering, the monitoring techniques for budworms and loopers should detect spring beetles.

Management

Because spring beetles breed outside of orchards in nearby native vegetation or pastures, and the adults invade by aerial dispersal, biological and cultural control options applied to orchards do not provide effective management. Control of spring beetles is not considered necessary except for newly planted trees up to about two years old or when adult beetles attack flowering pome fruit in years when the beetles are very abundant. It is likely that treatments applied to control thrips and dimple bugs in flowers and budworms and loopers after petal fall will also control the spring beetles.

Apple and Pear IPDM

Thrips

IPDM Quick Facts

- Apple and pear flowers are susceptible to attack by thrips from pink bud stage through to petal fall. Two main species are responsible for the damage, but several other minor species may be present.
- The Australian plague thrip *Thrips imaginis* is often the main cause of damage over flowering and can appear suddenly in the orchard, having blown in from long distances in plague proportions. Western flower thrips (WFT) *Frankliniella occidentalis* overwinters on broad-leaved weeds in or near the orchard and moves into the trees when the herbage starts to dry out (naturally or because of herbicide applications) or mowing has removed weed flowers.
- Onion thrips *Thrips tabaci*, tomato thrips *Frankliniella schultzei*, are other species that may be present and could be confused with WFT or plague thrips. The two species of *Thrips* have 7-segmented antennae and the two species of *Frankliniella* have 8-segmented antennae but these characteristics and other diagnostic features are difficult to see without the aid of a microscope.
- Thrips feeding on developing flowers can cause the flowers to desiccate and abort if large numbers of thrips are present. Immature and mature thrips feed on the developing flowers.
- Historically, a threshold of 6-8 thrips/flower has been used to determine the need for spraying but this has not been revised as new pesticides became available. WFT is resistant to many pesticides and resistant strains develop so quickly that written publications become out of date before they are printed.
- WFT tends to remain in the orchard throughout the season and can attack apple fruit in the lead up to harvest, causing pansy spots that cause the fruit to be downgraded.
- Yellow or blue sticky traps can be used throughout the season to monitor activity of plague thrips and WFT. They have the added benefits of detecting dimple bug and allowing monitoring activity of beneficial species.

- **Pesticides used to control WFT and plague thrips over flowering have the potential to disrupt IPDM for most other pests so check their known impact on beneficials and choose carefully**.

The Pests and their Significance

Two species of thrips can cause damage to Australian pome fruit. The biology of these species is very similar but the damage they cause, and their management, differs. Effective control of thrips can only be undertaken if you have identified which species of thrips is responsible for the problem. Accurate identification of thrips is a specialised skill and where thrips damage is suspected, samples should be submitted to state government agricultural departments or trained pest management consultants for identification.

Plague thrips (left) and Western flower thrips (right)

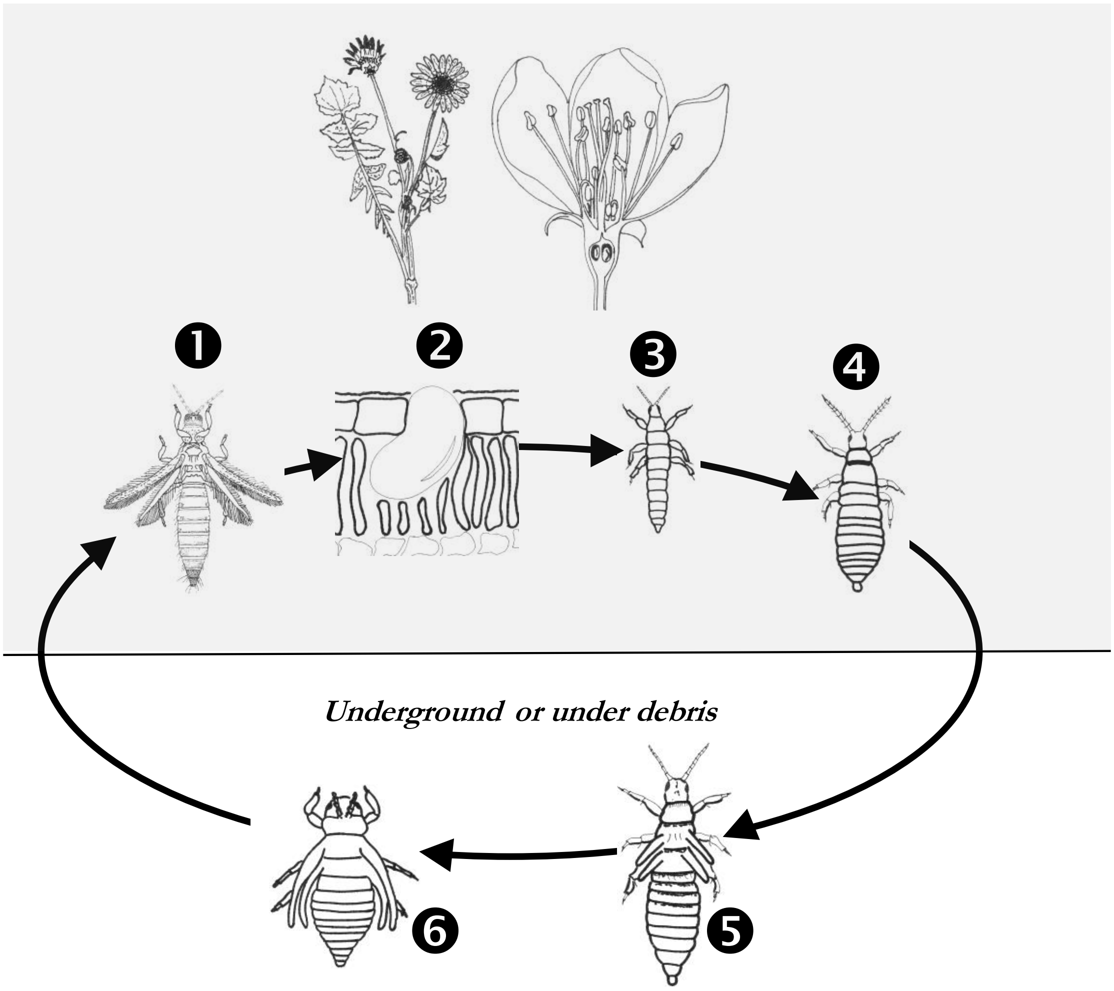
Plague thrips

Plague thrips (*Thrips imaginis*) is a very common native species which damages a range of crops (including stone fruit). Females of this species are 1.1 to 1.3 mm in length while 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 in colour. However, identification can be confused because yellow forms exist in some regions. Plague thrips have 7-segmented antennae.

Western flower thrips (WFT)

Western flower thrips (*Frankliniella occidentalis*) is slightly larger than plague thrips. Females are 1.4 to 1.8 mm in length while 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. Female WFT have 8-segmented banded antennae and a pattern of darker spots on the top of their abdomen.

Life cycle



The various species of plant-feeding thrips have similar life cycles. This is true of plague thrips and WFT, but important differences do exist and are noted below. Adult thrips are found mostly in flowers ❶. They infest a wide range of plants including clover, acacia, and broad-leaved weeds including 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 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 larvae (juvenile stages) by late bloom. There are two larval stages (❸ and ❹) which look like small wingless adults. Both adults and larvae feed on floral parts. 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.

Damage

Both species of pest thrips can cause commercially significant damage to fruit. Larvae of plague thrips feed on flower stamens and styles and can cause severe flower abortion. Often, where populations are low, this damage has a similar effect to flower thinning. In plague years however, significant crop losses can occur.

WFT damage occurs later in the season as fruit develops. Pansy spotting (also called ghost spotting) occurs around the site of egg laying. While all varieties are susceptible to WFT, damage is more obvious on light skinned varieties and on lighter portions of the fruit.

Pansy spotting caused by WFT

Similar damage

Poor fruit set can be caused by many things.
Where plague thrips is suspected to be responsible check in flowers at very early petal fall for tiny white thrips larvae on stamen filaments

Prevention and good orchard management

Weed management

Both WFT and plague thrips can be found on a wide range of broad-leaf 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. Managing your ground cover and weeds is critical to reducing WFT populations and preventing population carryover. As WFT dos not feed on grasses, replacing broad-leaved ground cover with grasses is an option that also reduces LBAM problems.

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. Mowing ground covers / weeds throughout the development of the fruit, especially close to harvest, may reduce WFT populations but it may also reduce the populations of beneficial predatory species that control other pests, and WFT. If WFT is not a problem and you have good populations of beneficial species in your orchard you are probably better off doing what you normally do, because it must be working.

If thrips have been a problem in previous seasons and a decision is made to control weeds using a herbicide, it is advisable to treat for thrips at the same time. If thrips are not treated, they will move to trees as the weeds die.

Movement

Plague thrips ca 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 broadleaved 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 that were 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 these are 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 while you are doing your dimple bug monitoring. White containers are better for dimple bug but make it hard to see juvenile thrips. Once you have checked the contents for dimple bugs you can dislodge the contents into the palm of your hand or onto a yellow or blue card to check for thrips. Alternatively, empty the contents into a ziplok plastic bag. As you progress through your dimple bug sampling keep topping up the ziplok bag. Once finished with monitoring take the bag back to the office and add some rubbing alcohol (isopropanol) which is safer than methylated spirits and shake the bag. Collect the washings and if you see thrips and want them identified you can then send them off for identification. Postal services do not like alcohol being transported in containers that might leak so make sure they are secure.

For plague thrips, all varieties are affected, but Granny Smith and Delicious are most readily damaged, and should be kept under close observation.

If you have not sent thrips away for identification but have sprayed and still have plenty of thrips present it is possible that you have WFT, because they are resistant to many of the registered pesticides.

Yellow or blue sticky traps

Monitoring with yellow or blue sticky traps is useful for determining the presence or absence of thrips within an orchard. The traps are continuously collecting thrips, rather than just relying on instantaneous sampling, so you get better and earlier indication of a potential problem. Yellow traps may attract some beneficial species but since you do not need many traps you will not decimate the beneficial population and you can use the results to assess the abundance of beneficials. You can use the traps all through the season, so you get early warning of WFT presence in the lead up to harvest.

- As a rough guide, use two traps in a block or 5 traps / hectare. Hang them in the lower third of the tree.
- If you place traps in the ground cover from bud burst to fruit set, they should not be located where they will be run over by machinery or present a trip hazard to staff. Putting them on a stake at a height of 0.25 to 0.5 m in vegetation at the end of the row or near irrigation risers is safer than putting them in the inter-row and the thrips are attracted to the colour so will move towards them from the vegetation 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 prior to harvest. Keep the used traps so you can refer to them if problems occur. The used trap can be wrapped in a single layer of clear plastic food wrap to make them easier to handle. 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. Many agronomists and most pest management scouts have been trained in WFT identification and may also offer an identification service.

Management

Responsible use of pesticides

Since thrips can infest opening buds at about the same time as the buds need a protectant spray for dimple bug then a spray at early pink bud stage will usually protect the developing flower. As with dimple bug, the pests may come into the orchard later than pink bud. The period between pink bud and full bloom is the most critical for control of both pests. After full bloom most flowers that may still be susceptible to damage will likely be poorer quality flowers that may not set fruit anyway. Choice of sprays to use at this stage is critical to your entire season's pest management. Some of the sprays registered for thrips and dimple will wipe out predatory mites for the entire season and have long term repercussions that could cost you more than the loss of a few flowers. Refer to Chapter 6 for information on the impact of pesticides on beneficials, before deciding which chemical, if any, you will apply over the blossom period.

Follow product label directions for the minimum interval between successive applications and the maximum number of applications allowed per season for resistance management.

It is also **essential** that the type of thrips observed or collected during monitoring is correctly identified as the pesticides which are effective vary between species.

For plague thrips, the spray threshold has been 6-8 thrips 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.

WFT activity can occur during flowering. This pest is continually developing resistance to pesticides so we cannot advise here on what actives to use. Check with your local agronomist or Department of Primary Industries for the latest resistance status before deciding what to use.

If monitoring indicates the spray was ineffective, 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 preventative strategies mentioned earlier will minimise the impact of thrips but are unlikely to provide complete control during seasons in which thrips infestations are severe. While predatory mites are used to control WFT in glasshouses, they do not persist in the orchard.

Natural enemies include the parasitic wasp *Ceranisus menes*, entomopathogenic fungi, predatory bugs *Orius* spp and apple dimpling bug *Campylomma liebknechti*, predatory thrips, and ants.

Apple and Pear IPDM

Weevils

IPDM Quick Facts

- Five species of weevils attack apple and pear trees
- Each species has different timing and feeding requirements
- Fullers rose weevil (FRW) feeds on leaves and the stem of the apple but its main contribution to damage is by laying eggs that block irrigation drippers and microsprinklers.
- Garden weevil (GW)feeds on fruit.
- Apple weevil (AW) feeds on the apple stems.
- Eucalyptus weevil (EW) is more of a nuisance than a pest causing damage. It flies in from nearby gum trees and contaminates fruit bins by its presence.
- Fruit tree root weevil (FTRW) adults feed on the leaves and the larvae eat channels or grooves along the roots, affecting water uptake, killing branches, and reducing tree vigour.
- Weevils are difficult to control once they establish in an orchard. Effort needs to be put in to preventing infestations. Orchard hygiene can reduce the chance of a serious weevil infestation.
- Weed control is important because the larval stage of FRW, GW and AW feed on weed roots,
- No single monitoring technique suits all five weevils.
- Limb jarring is suitable for monitoring FRW and FTRW adults.
- Corrugated cardboard trunk bands are suitable for monitoring GW and AW but need to be changed regularly in areas with codling moth because they will provide pupation shelters for codling moth larvae.
- Birds and parasitic nematodes are promising biocontrol agents.

The Pests and their Significance

Weevils are pests in all Australian pome fruit 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 and pears. Some species also lay their egg masses in sprinkler heads, blocking them, disrupting irrigation and affecting productivity. Most adult weevils are nocturnal and flightless (except Eucalyptus weevil) and hide in cracks in the soil, under clods or between fruit during the day. The larvae of some weevils feed on tree roots and others feed on weed roots.

There are five major pest species and orchardists should learn to recognise those which are present in their regions.

Fuller's rose weevil (*Asynonychus cervinus*) adults are approximately 8mm long. They are grey-brown and darker on the sides, with a distinguishing, short white crescent-shaped line halfway down the side of the body. They are flightless. Adults can be present as early as October but usually emerge between December and March. Fullers rose weevil adults feed on leaves, flowers and buds, hide in the stem cavity of apples during the day and often chew into the fruit stem, pre-disposing it to early fruit fall. They lay their eggs in tight places including the orifices of irrigation components such as drippers and micro-sprinklers that then become blocked. Products with large orifices are less likely to be blocked than others. The egg masses are resistant to drought and hatch when conditions become suitably moist. The larvae feed amongst the fine roots of some fruit trees and weeds.

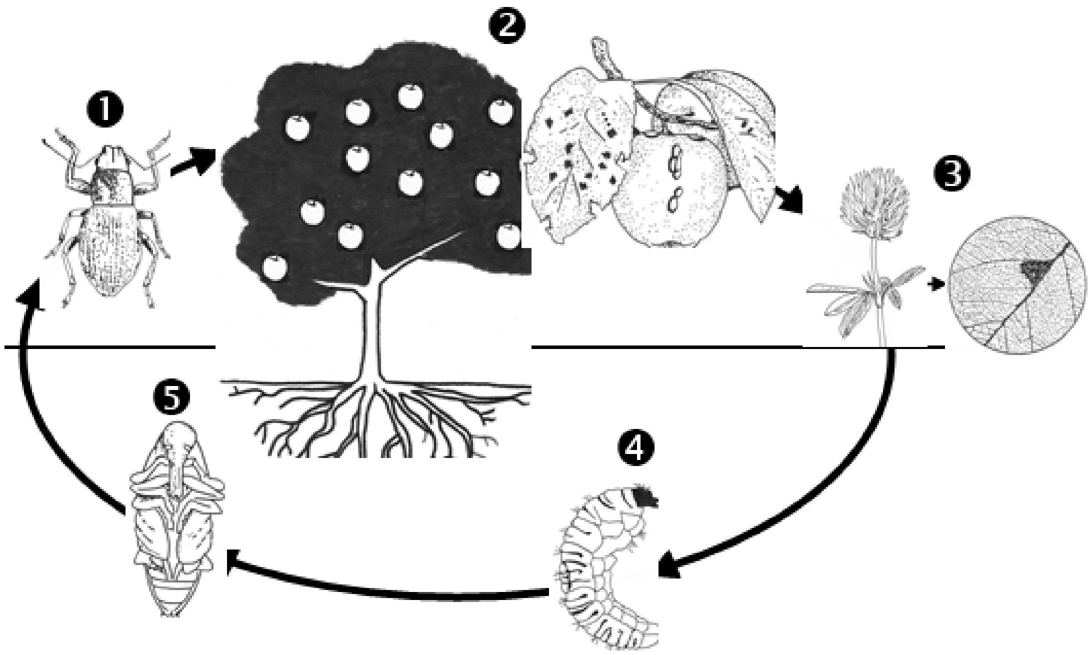
Garden weevil (*Phlyctinus callosus*) adults are approximately seven millimetres long. They are grey–brown with a prominent, pale V stripe at the base of their abdomen. They have a bulbous abdomen and are flightless. They chew the surface of the fruit and leave large shallow feeding holes. They shelter in the stem cavity during the day. Their larvae feed on roots and tubers of weeds like dandelions, flat weed, and fat hen.

Apple weevil (*Otiorynchus cribricollis*) adults are dark brown to almost black and approximately 8mm long with a slightly bulbous abdomen. It has short spines over the body and legs. The adult weevil is flightless, nocturnal and all are females. Larvae appear to feed more on roots in the tree zone than in the inter-row,

Eucalyptus weevil (*Gonipterus scutellatus*) seldom cause any damage to apples but can contaminate export shipments. They can be distinguished by their square shoulders. The adult weevils are approximately 10mm long and vary considerably in colour from grey to red-brown with darker markings on the back. They are covered by small pale brown hairs which give a rough appearance to the body. Eucalyptus weevils lay their eggs in pods or capsules on the surface of newly expanded, mature eucalyptus leaves. The pods contain 3-16 pale yellow eggs arranged in vertical layers. They particularly like *Eucalyptus globulus* (Blue gum) and *E. viminalis* (Manna gum)

Fruit tree root weevil (*Leptopius robustus*) adults are large (about 20mm long) buff-grey hard-backed beetles with prominent snouts, feeding on buds and leaves or sheltering around the base of the tree. Larvae feeding on roots give rise to channels in the root surface and affect water flow to the tree. Typical symptoms above ground are sudden wilting of leaves beginning at the tip of the branch, sparse growth on one or more limbs of an otherwise vigorous tree, or a red colouration to the bark of some less vigorous limbs. Attack is common where acacia trees are nearby or in blocks that were previously bush. Adults emerge between August and December but are most numerous between September and November.

Lifecycle



The life cycle diagram above is simplified and generalised but will help orchardists to target IPM strategies at more susceptible phases of the pest's life.

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 occur. Fullers rose weevil and garden weevil do not commence egg laying until about 3 weeks after emergence. Apple weevil takes about 6 weeks to start laying eggs. Eggs are laid in loose clusters or groups ❸.in sheltered positions. Fuller's rose weevils have a habit of laying egg masses in fine irrigation tubing and spray heads. The minimum length of time between laying and hatching varies between species but tend to be between 10 and 20 days.

Upon hatching, young larvae burrow immediately into the soil where they feed on plant roots ❹. Initially larvae are yellow but become white as they mature. Fully mature larvae of most species are around 9mm long. The larvae develop into pupae ❺ that are essentially adult insects in a soft, fragile state, neatly folded and enclosed in a protective skin. This length of the pupal period varies between species. For Fuller's rose weevils, it is typically 10 days before the adult emerges while for Garden weevils the length of the pupal stage is commonly 3-4 weeks.

Damage

Fruit damaged by garden weevil adults feeding on the skin and flesh have obvious scars that result in downgrading of the fruit. Weevils feeding on leaves and hiding in the stem cavity excrete around the stem end of fruit, resulting in downgrading. Feeding by Fullers rose weevil and apple weevil on fruit stalks (pedicels) causes partial or complete ringbarking, reducing fruit size and pre-disposing it to early fruit fall. Losses of up to 50% of fruit have been attributed to garden weevil and 15-20% by apple weevil.

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 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.

Tree roots are not specifically targeted by weevil larvae except for larvae of fruit tree root weevil whose feeding activity produces distinct channels or grooves on medium to large roots that can lead to branch death and declining tree vigour. Although larvae of other weevils feed on plant roots they do not specifically target apple trees. Although some damage is likely reports of significant losses are rare.

Similar Damage

Weevil damage to apple leaves can look like feeding by loopers and feeding by garden weevil on fruit also looks like looper damage but looper damage on fruit tends to run together rather than being large discrete shallow holes. A number of other pests cause similar damage to apple leaves. Light brown apple moth feeds on the leaf surface skeletonising it but usually the leaf is rolled. Where weevil infestation is responsible 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 and care is needed to make the correct identification of the responsible pest.

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. Where infestations are migrating from adjoining bush or plantation properties, orchardists should contact the relevant managers and persuade them to control the pest.

Orchard hygiene

Weevils are difficult to control once established in an orchard. The larvae of some species can survive in soil for up to five years allowing re-infestation when conditions become suitable in apparently clean blocks. Prevention of establishment and spread is crucial to weevil control.

Adult weevils can be present in orchards from October through to late April and can be on fruit transported in bins to the coolstore and packing shed. Once they are out of direct sunlight they become active and can contaminate packing lines. They also have an ability to cling tightly to rough surfaces. Carefully inspect any equipment including ladders and bins which are being moved from infested areas to clean blocks. Preferably work in infested areas last. Where 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. Removal of cape weed, sorrel, dandelion and dock will help to reduce weevil survival and abundance. However, where large numbers of weevils are seen on 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 are 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 life and prefer lighter soils. They also benefit from cracks in the soil profile caused by drought. It is likely that the addition of well rotted compost or other organic material when blocks are established will reduce weevil numbers by encouraging greater numbers of generalist predators and entomopathogenic fungi.

Choice of drippers

Fuller's rose weevil blocks irrigation components with its egg masses. Some products are less likely to be blocked than others. Drippers with orifices greater than 3mm, and sprinklers with no pivot points and larger gaps between spinning parts and spindles are least susceptible to blockage by egg laying.

Sticky bands

In some areas and for some species sticky bands can be used to limit the number of weevils which climb the tree. Sticky bands such as Tacgel® are less likely to work on dusty blocks as they will 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.

Monitoring

Larvae

When conditions are appropriate larvae move toward the soil surface prior to emerging. The numbers of larvae actively feeding on the roots of trees or weeds provides a prediction of the abundance of adult weevils which can be expected on trees later. The Western Australia guidelines for assessing garden weevil larvae are to dig up shovelfuls of soil and if half of the shovelfuls have no weevil larva, while 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.

Pupae

While larvae are long-lived in the soil, the insect passes through its pupal stage relatively quickly. Nonetheless, monitoring for pupae should be carried out in a similar way to that for larvae. As pupae grow older they darken and become easier to spot.

Adults

No single monitoring treatment suits all the weevils that inhabit apple and pear trees. The use of cardboard trunk bands is the most efficient way of monitoring garden weevil and apple weevil activity provided they cannot access the tree via weeds, trellis poles or trellis wires. Limb jarring similar to the technique for apple dimpling bug is the best method for collecting adult Fullers rose weevil and Fruit tree root weevil adults.

Adult weevils start emerging in spring from about the star of October and can be present through to May. 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 the 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 wooden plank traps on the ground. Tree bands consisting of single faced cardboard attached to the butt or leader of a tree should be 150 mm wide and wax coated to increase their field life. Attach Velcro at each end of the band to save time placing them onto the tree on each sampling occasion. A light coloured cotton cloth placed on the ground under the band before it is removed from the tree will facilitate both catching weevils that fell to the ground as the band was removed and to also count weevils. Check the traps fortnightly from November onwards. Note: They also attract codling moth larvae seeking pupation sites.

Limb jarring involves counts of adult weevils *in situ* in the tree canopy, based on using a "scratch" tray to define the length of limb that is inspected per sampling unit. By holding the tray under the limb during sampling, weevils that both remain on the limb and those dislodged during examination are recorded. The "scratch" tray is a Nally product part no. H 009 - 456 mm x 312 mm x 55 mm deep

Leaf damage. Look for the distinctive saw-tooth edge of leaves damaged in the early stage of weevil infestations. This can be done as part of the one-minute tree inspection technique described in Chapter 3. Where damaged leaves are seen verify the presence of weevils by inspecting the trees at night.

Management

Responsible use of Pesticides

Where preventative 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 is registered for use against Fuller's rose weevil, garden weevil and apple weevil. It is less likely 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 are relatively broad spectrum and not desirable in the context of an IPM program. Check Chapter 6 for information on effects of pesticides on beneficials. 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. Poultry need to be properly managed to ensure safety from predators such as foxes, feral cats, and raptors, and so that they are not exposed to chemicals that will produce residues in meat or eggs. An Australian strain of parasitic nematode *Heterorhabditis zealandica* X1 has given promising results against garden weevil. A range of natural biological control agents also attack weevils. Other natural enemies include wasps, assassin bugs, and praying mantises.

Acknowledgements

The adult weevil images were provided for the 1st edition of the manual, courtesy of Simon Hinkley and Ken Walker (Museum Victoria).

Apple and Pear IPDM

White root rot

IPDM Quick Facts

- Above ground symptoms are indistinguishable from other root infecting diseases
- Below ground there is almost complete destruction of primary and secondary roots and there is profuse growth of white fungal mycelium.
- The fungus survives in the soil on old rotted roots and root debris left in the ground and on the roots of various native trees and weeds such as fleabane (*Conyza* spp.) and stinking roger (*Tagetes minuta*).
- The interconnected root zones of medium and high-density orchard plantings will greatly increase the distribution and rapidity of spread of this disease within orchards
- Remove affected trees from the orchard as soon as possible, preferably while the tree is still alive, to make it easier to remove roots. Remove several trees either side of the affected trees.
- It is probably counterproductive to plant back into spaces where infected trees were removed.
- Clean machinery after use in a block affected by white root rot and consider establishing a footbath so that staff and scouts walking in the area can disinfect their footwear before going on to another block.
- Consider using a long-term (several years) crop rotation for severely affected blocks, after a short-term (one 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 two-year-old trees into remediated blocks. Then crop these trees within one year of planting instead of two

The Pest and its Impact

The fungus *Rosellinia necatrix* (previously *Dematophora necatrix*) causes the disease white root rot. White root rot is only recorded from 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 replant orchards, where the previous apple trees were affected. In the past, serious losses occurred in new orchards established in land cleared of native vegetation susceptible to the fungus. This disease will become more important as the numbers of medium to high density orchards increase.

Symptoms

Above-ground symptoms of white root rot (left) are indistinguishable from other root-infecting diseases. Below ground (right) the disease is characterised by almost complete destruction of primary and secondary roots and profuse growth of white fungal material.

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. 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 suffer 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 healthy internal wood. Affected roots can be covered with white strands of fungal growth, which can also grow into 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.

Source of infection and spread

The fungus survives in the soil on old rotted roots and root debris left in the ground and on the roots of various native trees and 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 of medium and high-density orchard plantings will greatly increase the distribution and rapidity of spread of this disease within orchards.

Fleabane in flower. © 2010 DAFWA

Management

- Thoroughly remove infected roots from affected trees.
- Remove affected trees from the orchard as soon as possible, preferably while the tree is still alive, to make it easier to remove roots.
- Remove at least two, and preferably three, healthy appearing 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 amid 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 (one 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 two-year-old trees into remediated blocks. Then crop these trees within one year of planting instead of two.

Further information

Horlock C. M., Haselgrove,L. and Cameron, D. 2007 Final Report HAL project AP03026 Sustainable management of white root rot of apple in Queensland. 61pp.

Pérez-Jiménez 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. †

Acknowledgement

This section is an edited version of the original written by Christine Horlock (Senior Plant Pathologist, Queensland Department of Primary Industries and Fisheries) for the first edition of this manual.

Apple and Pear IPDM

Woolly apple aphid

IPDM Quick Facts

- Woolly apple aphids (WAA) can be a serious pest in all Australian apple growing areas
- It causes damage to aerial parts of the tree and to the roots.
- Use resistant rootstocks, if possible, to reduce the impact of root feeding.
- It is more of a pest where naturally occurring predators and parasitoids have been affected by poor choice of insecticides for early season pests such dimple bug, thrips, budworm and loopers, and codling moth.
- Parasitised WAA colonies can be collected in autumn and winter and maintained at low temperatures until spring to supplement populations that may have been impacted by spring spraying programs
- Root drenches are effective on young trees but less effective on trees over 7 years old.
- Monitoring WAA and parasitoid activity is important for making good decisions about the need to spray.
- Earwigs are very effective predators of WAA

The Pest and its Significance

The woolly apple aphid *Eriosoma lanigerum* is a serious pest of apple production in all Australian fruit growing regions. This pest infests apple trees and very occasionally pears. It can affect all parts of the tree resulting in direct damage to fruit, limbs, roots and gradual decline in tree health. Because of its characteristic sticky waxy 'wool' covering that contaminates human skin and clothing it also affects orchard operations, particularly summer pruning, thinning and harvesting.

Damage

Limbs and shoots. The most obvious sign of woolly apple 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 fruit and shoots beneath and fosters the development of sooty mould resulting in subsequent fruit down grading. In addition, brushing and crushing aphids during summer-thinning, pruning or harvesting releases their body fluids which causes a purple stain 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 apple aphid has been implicated in the transmission of diseases such as perennial canker.

Roots. Feeding by woolly apple 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. Where 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 which causes sooty mould.

Occasionally, where numbers of the pest are particularly high, the aphid will infest the calyx end of the fruit. This is particularly the case for open-calyx varieties.

Similar damage

Other pests such as mealybugs waxy coverings and can look like small colonies of woolly aphid, especially since both produce a lot of honeydew. Woolly apple aphid tends to infest axils and colonies form along shoots whereas mealybugs prefer sheltered sites.

Root galling is a little more difficult to distinguish from galling caused by nematodes or crown gall. 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 apple aphid is responsible.

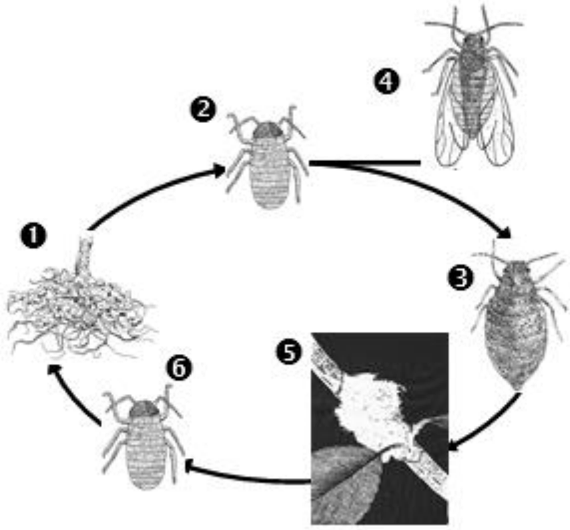
Monitoring

In Australia aerial colonies are often kept under control as a result of insecticides applied 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', below).

During late summer or autumn, apple trees with woolly apple 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 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, trees can still be found and treated. It also provides a useful historical record which can be used to determine how successful pest management has been.

Colonies can be assessed using a 1-5 rating score presented in Chapter 3.

Life cycle



There is confusion in the literature regarding the overwintering biology of WAA. In areas with cold winters, such as the UK and NE USA the lifecycle is portrayed as in the diagram above where overwintering is by cold hardy 1st instar nymphs (crawlers). In areas with warmer winters, such as Australia, California and South Africa WAA it is considered to overwinter as adults on roots and aerial parts of apple trees as adults. Part of the confusion arises from the difficulty of observing root colonies and the observations worldwide that crawlers move between the aerial and root populations. For simplicity we assume here that WAA populations on the roots include both crawlers and adults, and that aerial populations over winter are largely late instar nymphs or adults since 'wool' is evident. WAA feeding on the roots cause large galls to form ❶. As temperatures increase towards spring females in the root colonies produce crawlers that begin to disperse in October.❷. Crawlers grow and moult four times before becoming adult. Later nymphal stages grow larger with each moult and produce the characteristic white waxy 'wool'. There are two types of adults. The most common form has no wings and is asexual ❸. The wingless adult aphid is about 2 mm long. It does not lay eggs but produces an average of 120 live young during its life (all female). Woolly apple aphid can have 10 to 20 generations per season. Toward the end of summer, particularly in warm regions, winged adult female aphids appear ❹. They are commonly found sitting on top of colonies of wingless individuals. They are 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. But these males and females do not produce viable offspring and make no further contribution to the lifecycle. Woolly clusters or colonies occur because, although dispersive, crawlers often settle close to their parent ❺. Woolly apple aphids are spread through the orchard in the wind and by planting infested nursery stock. Crawlers migrate between roots and shoots throughout the season, but as winter approaches most movement is towards the roots ❻.

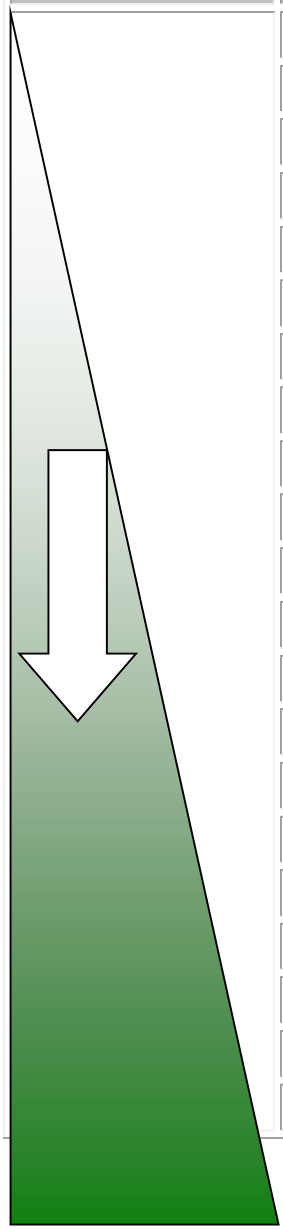
Prevention and good orchard management

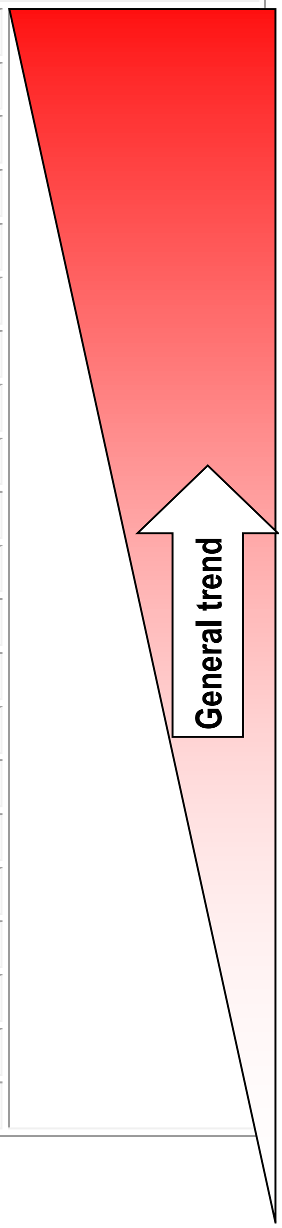
Varieties

High density plantings on dwarfing rootstocks return better yields, result in better quality fruit and are becoming the industry norm. However modern dwarfing rootstocks are generally not as resistant to woolly apple infestation as older rootstocks. This problem is exacerbated in high density plantings because Woolly apple aphid moves easily from tree to tree because canopies overlap.

The susceptibility of a range of rootstocks to infestation by woolly apple aphid. Information derived from Campbell 2005.

Rootstock vigour	Rootstock	Susceptibility to Woolly apple 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





The Merton-Malling series are resistant to woolly apple 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 apple 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 and there is limited information on its performance under Australian conditions.

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 apple aphid occurs below ground therefore pruning can only assist in the management of infestations. Nonetheless summer pruning to remove large colonies will help. Painting large pruning wounds also discourages woolly apple aphid from establishing colonies.

Because of their woolly, waxy coating it is difficult to sufficiently wet colonies for insecticides to be effective. Pruning will allow better penetration of canopies with insecticide applications.

Management

In Australia the key to good management of woolly apple aphid is to support biocontrol of the aerial infestations combined with chemical control of the root infesting phase of woolly apple aphid's life cycle. Applications of insecticides specifically to control aerial colonies of this pest are often unnecessary following effective application of a soil drench.

Responsible use of pesticides

Soil drench. Imidacloprid and Clothianidin are registered for use as soil drenches for the control of woolly apple aphid and the technique for application of these insecticides is similar. The product need only be applied 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 seven years old. Timing is critical and the application needs to be made between green tip and petal fall. Remove any weeds or mulch from around the base of the tree, leaving bare soil. Apply the drench to the soil for a distance of about 15cm from the trunk. Penetration into the soil will be better if it 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 using a lance sprayer from the back of a four-wheel bike is sufficient. Where a substantial percentage of trees are infested – particularly where they are in the same row – special rigs are available for automated application of products to the base of trees.

Some orchardists have expressed concern at the cost of this technique. Dependent on soil type and moisture and the age of the tree it is likely that soil drenches need only be carried out every three years. Careful monitoring of trees should be carried out in the seasons following a soil drench 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 apple 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 below) will soon control woolly apple aphid without a pesticide application?

Biological control, biorational pesticides and organics

The parasitoid wasp *Aphelinus mali* is established in all Australian apple-growing regions. It is particularly effective in warmer areas and seasons. The wasp has a higher developmental threshold temperature than WAA as an adaptation that ensures it becomes active after WAA has progressed beyond the crawler stage. The wasp lays its eggs into the aphid and 1st instar crawlers do not provide adequate food to produce female wasps and only male wasps emerge. By synchronising with development of later WAA instars the wasp ensures it can produce female offspring that can go on to parasitise more WAA. In cooler areas such as the New South Wales Tablelands, Tasmania and parts of Victoria, parasitoid activity may appear to lag behind that of its host and growers think they need to apply a pesticide to control the WAA. The real reason that the WAA infestation is building up is more likely to be that poor choice of sprays against codling moth and LBAM have impacted the parasitoid and the other important predator European earwig. Neither the wasp nor earwig can easily reach the root colonies unless the ground dries up and cracks, so trees with a history of heavy WAA infestations should be treated with a soil drench before the wasps become active.

***Aphelinus mali* is an effective parasitoid of woolly apple aphid. The parasitoid is a tiny wasp (left). Parasitised colonies have sparse wool and black aphid mummies(centre). Close inspection of the mummies shows the exit hole from which *Aphelinus* emerged (right)**

Aphelinus mali is a parasitoid which lays more than one egg in each of its woolly apple aphid hosts. Eggs can be laid in all stages of aphid growth but the parasitoid only emerges from its host 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 abdomen.

Before deciding 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.

European earwigs are excellent predators of aphids and other pest insects. They can be 'farmed' by placing rolled op newspaper of rolled corrugated cardboard bands out in areas where earwigs are likely to congregate, like alongside wooden fences or in amongst stacks of timber (but beware of snakes) and when the rolls have been colonised by the earwigs they can be moved to where WAA infestations need attention.

Parasitised WAA can also be collected during winter pruning and stored in the coolroom until spring and released as a supplement to the wasps that survived in the orchard after your first sprays were applied. **Make sure that the parasitised colonies you are storing have plenty of black mummies that do not have holes in them. The holes indicate the wasp has emerged.**

Other predators worth conserving include syrphid (hover fly) larvae and aphid-eating ladybird beetles such as the common spotted ladybird *Harmonia conformis* and the transverse ladybird *Coccinella transversalis*.