2024-25 COTTON PEST MANAGEMENT GUIDE

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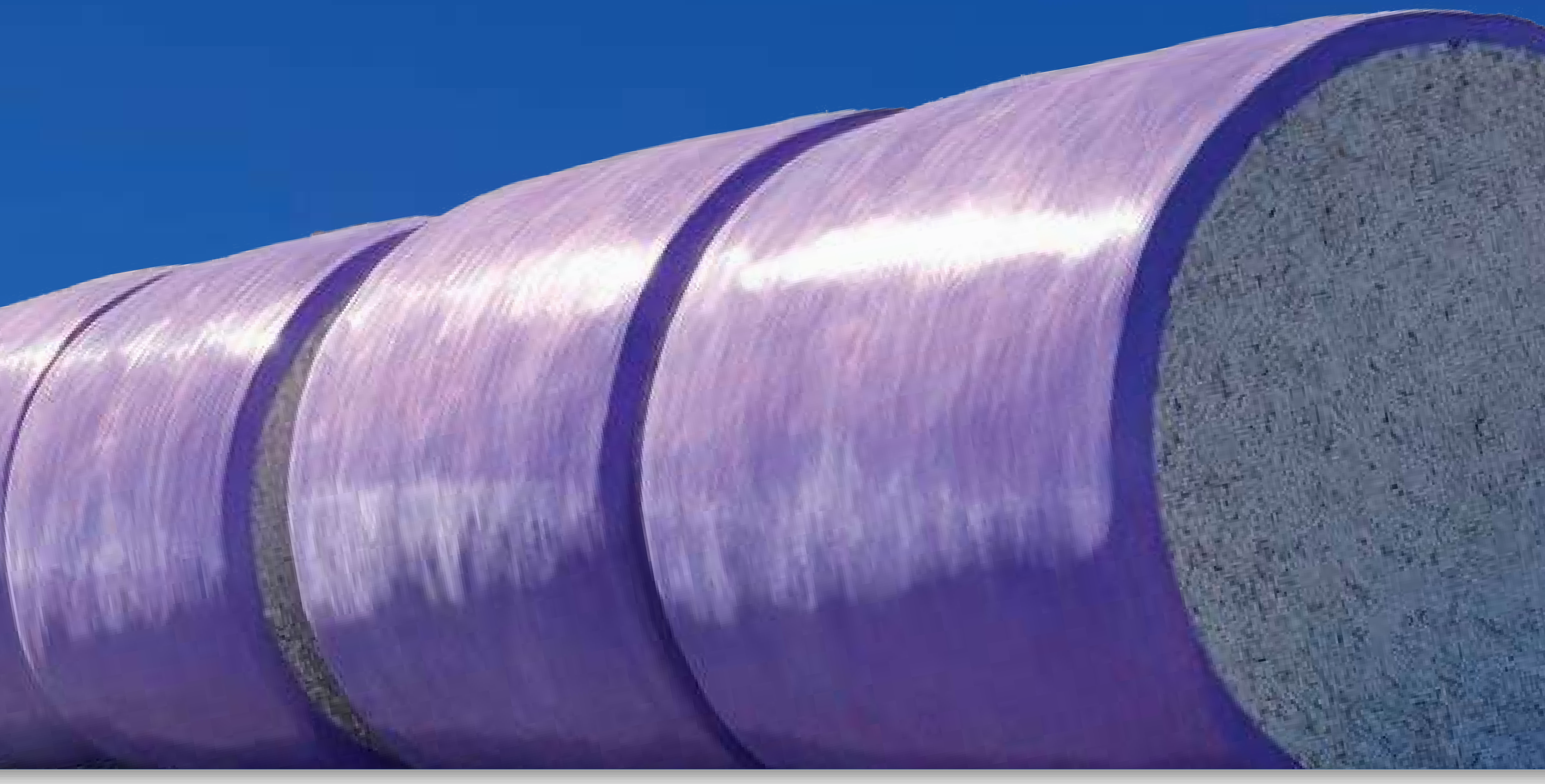

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Contents...

Cover photo courtesy Janelle Montgomery.

Foreword

Megan Woodward (CottonInfo and CRDC)

Welcome to the 2024-25 Cotton Pest Management Guide (CPMG). This Guide provides you with a comprehensive summary of the key cotton crop protection issues, and is brought to you by the organisations responsible for cotton industry research, development and extension (RD&E): the Cotton Research and Development Corporation (CRDC) and CottonInfo.

CRDC invests in RD&E for the Australian cotton industry. A partnership between cotton growers and the Australian Government, CRDC exists to deliver impact. CRDC's new Strategic RD&E Plan for 2023-28, Clever Cotton, is now in place, built on the three investment pillars: Paddock, People, and Planet (which you may recognise from the Australian Cotton Sustainability Framework: PLANET. PEOPLE. PADDOCK). In 2024-25, CRDC will invest $32.13 million into RD&E projects via Clever Cotton, on behalf of growers and the Government and in collaboration with research partners.

CottonInfo is an initiative of the joint venture partners: CRDC, Cotton Australia and Cotton Seed Distributors. It is designed to connect you – our cotton growers and consultants – with research and provide you with information, when and where you need it. The CottonInfo team takes the research and development invested in by CRDC and turns it into practical information and knowledge, applicable to you and your farm, with the intent to Help You Grow: grow cotton, grow knowledge and grow industry connections. CottonInfo integrates closely with the industry's best management practices program, *my*BMP, supported by Cotton Australia and CRDC, which sets the industry's best practice performance criteria and provides a framework by which growers can participate in, and be accredited in, best practice.

This Guide, along with its sister publication, the *Australian Cotton Production Manual*, are two of the key ways that CRDC and CottonInfo provide the latest in cotton industry RD&E out to you each year. The manual contains additional information on spray application and integrated management and is available to download from the CottonInfo and CRDC websites
cottoninfo.com.au/publications-and-media or
crdc.com.au/publications.

This year's edition features a new introduction, revised insect and herbicide tolerance sections, additional information on two diseases, two new tables, and a revised IRMS matched to plant growth stages with increased focus on mites.

Remember, the CottonInfo team of regional extension officers (REOs), technical leads and *my*BMP experts are available to assist you with all your cotton information needs (you can find our contact details on the inside back cover). You can also find information from the CottonInfo team online at our website cottoninfo.com.au, while best practice information for your farm is available at the *my*BMP website mybmp.com.au. And you can find information about all of CRDC's investments online at crdc.com.au.

On behalf of CRDC and CottonInfo, thank you to coordinating editor Tonia Grundy, and the team of authors, reviewers and contributors from across the cotton research community and the wider industry for their invaluable assistance with this publication. We hope you find this year's *Cotton Pest Management Guide* a valuable and informative reference.

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DISCLAIMER

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Pests and crop protection

Mention the word 'pest' and the first thing that comes to mind for many people are insects. However in agriculture, pests can be any living organism (animal, weed or pathogen) that adversely impacts production.

Managing pest impact on cotton yield and quality is an essential part of enabling a crop to reach its full potential. Pest impacts on cotton include the direct damage symptoms listed in Table 1, but pests can also influence production indirectly. For example, weeds can compete with the crop for nutrients, water or light, and may also act as alternate hosts for insects or pathogens.

Some of these other impacts of pests include:

- reduced crop vigour and/or developmental delays
- damage to growing terminals
- reduced photosynthetic capacity
- reduced vascular tissue function (may lead to wilting)
- module contamination
- reduction in lint or seed quality.

There can also be unintended impact from pest management actions (e.g. herbicide damage).

What is causing damage?

Not all crop symptoms are caused by pests. A range of abiotic influences, including soil constraints, environmental/weather factors, herbicide drift, pesticide phytotoxicities and nutrient deficiencies or toxicities can also cause crop damage, and at times exacerbate pest impacts. For example, stressed plants can attract some insect pests and may take longer to recover.

It is important before enacting any pest management action to both identify the correct cause of the damage and ensure it is:

1. still present,
2. still causing damage and
3. able to be controlled.

Ideally, management actions should be effective, economically viable, and have minimal off-target impacts (such as increased pesticide resistance or pest flaring/resurgence).

Look beyond the plant (including soil, weather and recent use of inputs) to determine if abiotic factors could be influencing crop symptoms. Keep records of environmental conditions, nutritional analyses and all field operations to assist with symptom diagnosis.

Integrating your pest management approach

Integrated management information is often focused on a specific pest type (insects/mites, weeds or diseases), but a range of key principles apply to all biotic pests:

- **Farm hygiene.** Manage pests year-round across the entire farm area and integrate appropriate biosecurity protocols into everyday activities.
- **Forward planning.** Consider paddock history and how pathogen or weed seed dormancy might interact with planned crop rotations. Use seasonal forecasts, select appropriate varieties and focus on producing a healthy crop. Choose agronomic tactics that disadvantage pests both immediately and in the longer term.
- **Effective monitoring.** Tailor crop monitoring to the likely pest risks at each crop development stage, and learn when pests are most vulnerable to available control methods. Focus on accurate identification and keep good records to compare pest levels within and between seasons. Utilise industry expertise to identify unusual species or symptoms.
- **Consider damage potential.** Ensure that the pest(s) are still present and causing damage before enacting a control. Use economic thresholds where possible and monitor the impact of any action taken (ideally, leave a small untreated area for comparison).
- **Preserve pesticide usefulness.** Target the appropriate pest stage, follow label directions and calibrate equipment to optimise efficacy. Avoid unnecessary prophylactic sprays and adhere to stewardship programs such as resistance management strategies.
- **Work with your neighbours.** Highly mobile insects or weeds with wind-borne seeds can quickly spread between farms. Improved coordination of agronomic and pest management practices within your local area can provide pest management benefits. Check for nearby beehives or sensitive areas/crops before applying pesticides.

When out in the crop, note general plant health and keep an eye out for all pest types.

Consider utilising the services of an experienced consultant for advice on management options applicable to your situation.

Note that some product registrations are restricted to specific areas (e.g. NSW and QLD only). ALWAYS check the label for allowable usages relevant to your region.

Learning as you go is the key to success. When things change, be prepared to adapt what you are doing to overcome new challenges. Considering how, what, where and why something is happening can highlight the best approaches for your management program. If you have unanswered questions, seek information and advice via your consultant, industry resources or your peers.

Cotton production in the tropics...

The majority of the information in this guide has been developed for production in temperate central and southern growing regions. Northern Australia has some very different abiotic challenges affecting the crop and resident pests that need to be factored into management plans. Higher temperatures, rainfall and humidity not only lead to a higher risk of climatic-induced shedding, but can promote disease and accelerate arthropod or weed development. Species that are not usually considered a problem in traditional growing areas may achieve pest status under these conditions. For more information on growing cotton in the north, visit the CottonInfo website cottoninfo.com.au/tropical-cotton-production

TABLE 1: Crop symptoms and potential cause(s)		
Crop damage	**Biotic factors**	**Abiotic factors**
Seedlings not emerging	Seedling diseases Soil/establishment pests	Residual herbicides (Groups 5/C, 3/D, 15/K) Planting issues Salinity/sodicity Soil compaction Fertiliser burn
Seedlings emerged but stunted, dying or deformed	Seedling diseases Black root rot Fusarium wilt Soil/establishment pests Thrips Aphids Mealybugs Nematodes Exotic root rots*	Herbicide damage (2/B, 5/C, 4/I, 15/K, 3/D) Planting issues Soil compaction Fertiliser burn Nutritional issues (S, Zn, P) Salinity/sodicity Wind damage Allelopathy
Spots/lesions or dead areas on leaves	Fungal leaf spots Mites Leafhoppers Bacterial blight Tobacco streak virus Tropical rust	Herbicide damage (2/B, 5/C, 27/H, 4/I, 10/N) Frost Fertiliser burn Wind damage Nutritional issues (B, Mg, K,P, Zn) Sunspot or sunscald
Leaf discolouration (mottled, spots or interveinal)	Cotton bunchy top Fungal wilts (fusarium or verticillium) Ramularia/grey mildew Sucking insects (aphids, mites or leafhoppers) Tobacco streak virus Blue disease*	Nutritional issues (Fe, Mg, P, K, Zn) Herbicide damage (2/B, 5/C, 27/H, 4/I, 10/N) Chimera (genetic fault)
Leaf discolouration (whole leaf) or premature senescence	Nematodes Exotic root rots*	Salinity/sodicity Waterlogging Herbicide damage (2/B, 5/C, 9/M) Nutritional issues (B, N, S, K)
Abnormal growth (including leaf wrinkling)	Cotton bunchy top Verticillium wilt Sucking insects (aphids, thrips, mites or leafhoppers) Black root rot Bacterial stunt Blue disease* Cotton leaf curl disease*	Herbicide damage (2/B, 4/I) Soil compaction Nutritional issues (B, Mg)
Chewing damage to leaves/terminals	Caterpillars (cluster, helicoverpa, loopers, bollworms) Redshouldered leaf beetle Locusts	
Fruit shedding	Sucking bugs (mirids, stink bugs or cotton stainers) Excessive fruit set	Cloudiness Heat and/or moisture stress Waterlogging Herbicide damage (2/B, 5/C, 27/H, 4/I, 22/L, 9/M, 10/N) Nutritional issues (B, N)
Wilting or sudden death	Fungal wilts (reoccurring, fusarium, verticillium or sudden) Nematodes Exotic root rots*	Herbicide damage (5/C) Lightning Insufficient soil moisture
Defoliation	Alternaria leaf spot Ramularia/grey mildew Fungal wilts (fusarium, verticillium or sudden) Mites Bacterial blight (exotic variant*)	Herbicide damage (5/C, 4/I, 22/L, 10/N) Lightning Sunscald Nutritional issues (P, K)
Stem lesions or internal stem discolouration	Black root rot Fungal wilts (reoccurring, fusarium, verticillium or sudden) Exotic root rots* Bacterial blight (exotic variant*)	Lightning
Boll spots	Alternaria leaf spot Boll rot/tight lock Seed rot Sucking bugs Bacterial blight (exotic variant*)	Herbicide damage (22/L)
Damage to boll/lint/ seed	In-field or post-harvest boll rots Sucking bugs (stink bugs, cotton stainers or mirids) Caterpillars (bollworms or helicoverpa) Boll and seed rot pathogens Mice Boll weevil*	High temperatures Rainfall
Sticky cotton	Whitefly Aphids Mealybugs	
* exotic pests		

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Integrated Pest Management (IPM)

The integrated management of insects and mites could also be called Intelligent Pest Management as it aims to use our knowledge and understanding of the arthropod(s), the crop, and the environment to minimise the likelihood of outbreaks and reduce reliance on insecticides. Some arthropod pests (such as mites, mealybug and whitefly) have limited chemical options for control and effective integration of mangement options is needed to prevent populations from rapidly increasing.

IPM is not a recipe, but instead requires a mix of pre-emptive and responsive pest management actions to reduce the risk of crop loss and improve the health of both the environment and ourselves.

An effective IPM system promotes longer term stability of pest and beneficial populations, reducing the risk of resistance, minimising economic losses of crop yield and quality and threats to human health and the environment.

IPM – the basics

Practices that form a solid basis for implementing IPM on your farm include:

- **Farm hygiene.** Minimise cotton volunteers, ratoons and other weeds in fallow fields, field edges, roadways and drainage lines to limit the survival and spread of overwintering pests such as mealybugs or resistant aphids that might also carry bunchy top disease. Put simply, **CLEAN FARMS TEND TO HAVE LESS PEST AND DISEASE PROBLEMS THAN DIRTY ONES.**
- **Preventing problems.** Sowing date, crop sequences and field selection are just some of the tactics available to disadvantage pests. Avoiding back-to-back cotton in fields that had mealybugs to limit season carryover, or not planting as late so that your crop is not exposed to displaced populations of silverleaf whitefly (SLW) are just two examples of how to strategically avoid giving pests the upper hand.
- **Grow a healthy crop.** Cotton plants have a significant ability to recover from damage (especially early season damage) with no reduction in yield or delay in maturity. Plant monitoring in conjunction with regular insect monitoring allows an assessment of pest effects that might be difficult to detect in regular sampling. Plant monitoring can assist in decision making where pest levels are just below threshold or where there are combinations of pests present. Acceptable damage levels will vary depending on crop physiology stage, yield expectations and climatic conditions.

Dryland cotton...

- Dryland cotton has the same pests and beneficials as irrigated crops. Effective IPM and resistance management are critical regardless of where or how cotton is grown.
- A key IPM challenge for dryland crops in minimum tillage systems is to ensure 100% crop destruction. Ratoon cotton or volunteers that emerge in a subsequent grain crop can provide a green bridge for pests and diseases. Crop mulching or slashing in isolation at the end of the season is not sufficient to prevent pest carryover unless it is followed with tactics that prevent regrowth.

Best practice...

- Knowledge is the key that unlocks effective IPM.
- Seek to PREVENT pest outbreaks through good farm hygiene, complementary crop rotation and conserving beneficial populations.
- Regularly MONITOR pest species, beneficials, crop stage, crop growth and the weather.
- Bring it all together with effective management ACTION that is mindful of pest thresholds, resistance risks and potential impacts on natural enemies, bees and the environment.

- **Sample your crop effectively.** Detecting and being able to quantify both pests and beneficials is a fundamental requirement for good decision making. Recommended sampling techniques may vary, depending on the crop stage and pest or beneficial type. While some thresholds only require monitoring of one lifecycle stage, awareness of all life stages can help identify if a population has built up within the crop or has migrated in recently.
- **Take note of where your crop is at.** The development stage of your crop has a big bearing on (i) whether it is susceptible to yield loss and (ii) if it can recover from pest damage without intervention.
  - Minimal squares on a normal crop at 10-12 nodes might indicate poor retention due to pest or weather damage, but if the plant has been developmentally delayed, the retention levels may be appropriate.
  - Cotton can compensate for early season damage, particularly vegetative plant parts, if growing conditions remain favourable.
  - Ensure you can distinguish between vegetative and fruiting branches when measuring retention during early crop development. View a CottonInfo video that explains the difference between branch types in young crops: youtu.be/7PXIAuinmeY
  - Pests that can contaminate open cotton with honeydew (such as SLW or aphids) become more important as bolls open.
- **Know your enemy.** This guide outlines common pests that you would expect to deal with on a regular basis when growing cotton. Key to managing these pests is to understand what they are, what damage they cause, preventative steps you can take to minimise their numbers or impact, how best to sample for them, when control is likely to be required (action thresholds), and what types of control techniques (chemical, biological or physical etc) are likely to be suitable and effective. Knowledge of the pest's interaction with the environment can help determine whether a spray is warranted. For example, two-spotted mite populations can be suppressed by cool conditions, but will increase rapidly when it is hot and dry.
- **Know your friends.** Cotton crops host a diverse array of beneficials that can suppress pests, particularly mites, SLW, aphids and mealybugs. Noting which beneficials are present when sampling can help inform your control decisions. Conserving beneficials can have a significant impact on whether you develop a mite or mealybug problem later in the season. Table 6 (pages 20-21) allows you to compare the potential impact of different products so that you can make a balanced control decision. Naturally-occurring pathogens of arthropods may also be present. Look for insects that are weeping or have developed fungal growth.

- **Do you even need to spray?** Many pest insects have scientifically-based action thresholds that can help you decide whether your pest populations or crop damage might require control action. Resist the urge to use insecticides prophylactically with herbicide application operations. Economic thresholds are defined as the pest density or damage level at which control must be implemented to prevent economic loss, and should be considered in the context of other factors that may influence the need to spray. For pest abundance just over threshold but with low damage and high beneficial populations, consider delaying control for several days. This is a low risk strategy to allow time for beneficials to reduce pest levels to below threshold, thereby avoiding a potentially disruptive spray and reducing insecticide costs and selection for resistance. Conversely, for high pest damage with low beneficial populations, immediate control with an insecticide may be the best option. Thresholds for cotton aphid, two-spotted mite and SLW are based on cumulative population changes and require comparison of multiple samplings to determine if action thresholds have been reached.
- **Choose insecticides wisely.** When insecticide control is warranted make sure the product you have selected appropriately balances effectiveness against the target pest with any potential harm to natural enemies. Actively avoiding the use of broad-spectrum disruptive insecticides (e.g. organophosphates, pyrethroids and some neonicotinoids) wherever possible, especially early to mid-season, will go a long way to reducing mite, SLW and mealybug numbers later in the season. Be aware of the product's mode of action (MoA) group, and of restrictions on the use of certain products as part of the Industry's Insecticide Resistance Management Strategy (IRMS pages 58-65). If several pesticide options are available, examine their selectivity profiles (see Table 6). For example, clothianidin will reduce populations of ladybird beetles (aphid predators) and *Eretmocerus* wasps (whitefly parasitoids) but conserve predatory bugs and thrips (mite predators). In contrast, the low rate of fipronil will reduce predatory bug populations, and conserve ladybird beetles, but its impact on the key wasp parasitoids of whitefly is unknown. Increases in populations of non-target pests such as aphid, mite and whitefly may follow insecticide applications if the beneficial populations keeping them in check are disrupted. Lower registered rates of a product may provide sufficient efficacy against the target pest, while minimising impact on beneficials.
- **Preserve the usefulness of insecticides and Bollgard.** The ability of insecticides or *Bacillis thuringiensis* (Bt) protein-expressing Bollgard crops to provide control depends on pest populations being susceptible to the active compounds. Follow label directions and consider both your application technique and environmental conditions to optimise chemical efficacy. Adhere to resistance management programs to ensure that the industry continues to have access to pest control tactics that give good control.
- **Look after bees.** Bees are particularly susceptible to many of the insecticides used on cotton farms (see Table 6). The productivity of hives can be damaged by direct or indirect contact with the applied product by foraging bees, or when insecticide drifts over hives or neighbouring vegetation. Always look for and follow label directions regarding impact on bees and refer to the *Protecting pollinators* section for more information.
- **Working with your neighbours.** Pests and beneficials do not recognise farm boundaries. Working with your neighbours to better coordinate planting, farm hygiene and crop spraying can provide benefits for the management of pests such as SLW on an area-wide basis. In some regions growers hold area wide management (AWM) meetings to discuss pest issues and work towards shared solutions. Talk with your nearest CottonInfo Regional Extension Officer (REO) about any AWM groups in your valley.

How do I implement IPM?

The great thing about IPM is that it does not have to be complicated – it's an evolving process that builds on taking practical steps to reduce the survival of pests. For example, a simple first step could be improved on-farm hygiene. This might be followed by a decision to avoid the use of a particular type of disruptive insecticide. See Table 2 for examples of activities to consider when planning your IPM program.

For first time growers, the easiest way to start your IPM journey is to employ the services of an experienced consultant to help guide you through the process of pest management decision making. A consultant will be able to provide information on what is going on in your crop and advise you on various management options that might be applicable to your situation.

For the more experienced manager who is familiar with pest management principles, consider challenging your boundaries by asking yourself some simple 'WHY' questions such as "Why were silverleaf whitefly higher or lower than last season?" or "Why am I using this particular insecticide?". The answers might provide insight into the most appropriate next steps for your management program. These types of questions are also good starting points in discussions with your advisor.

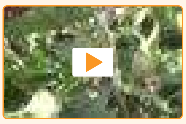
The important thing about IPM is to appreciate that biological systems are continually evolving along with our knowledge about pest species and control options. Keeping up to date with the latest information is essential for effective IPM. The latest research findings are made available to growers and advisors via industry meetings and a range of CottonInfo information products, including this guide.

As your IPM program evolves, new practices will bring prospective benefits as well as potential trade-offs (e.g. the use of a more selective insecticide may cost more to apply than a broad-spectrum option but reduce the likelihood of secondary pest outbreak which may require further spraying). The key is to learn as you go, build on the successes that you have, and when things change, be prepared to adapt what you are doing to suit new challenges.

USEFUL RESOURCES:

Pest and Beneficial Insects in Australian Cotton Landscapes.
cottoninfo.com.au

What is IPM?
youtu.be/BdQRLx4hN5o



IPM in action
youtu.be/k5-0XrzBEeg

TABLE 2: Seasonal activity plan for IPM

	Overwinter & planning	Planting – first flower	Flower – first open boll	Open cotton – harvest
Develop an IPM strategy	Review last season's IPM approach. Communicate IPM goals and pesticide application management plan (PAMP) for the coming season.	Good record keeping supports both your PAMP and regulatory requirements, and allows end of season assessment of IPM strategy.		
Know your enemy	Get the latest guides and IPM related information.	Participate in IPM training, field days, or workshops: Contact your nearest CottonInfo Regional Extension Officer (REO) (see inside back cover) to join CottonInfo's e-news mailing list or go to cottoninfo.com.au/subscribe		
Take a year-round approach	Manage winter crops carefully to avoid disrupting beneficial populations. Plan ahead to ensure insecticides are available.	Consider the summer cropping plan and pest risk.	Reduce pest risk for next season by considering rotation crop type and location.	
Think beyond the crop	Participate in area wide management (AWM) all year round. Apply IPM principles to all crops. Consider rotation crops (type, location, and potential to host pests and disease). Establish and maintain communication with beekeepers in your region. Avoid spray drift. Native vegetation can harbour a range of beneficial species (including insects, birds and bats). Maximise its value by maintaining health and diversity and controlling weeds.			
Have good on-farm hygiene	Zero tolerance to volunteer cotton in entire landscape all year. Ensure a host free period for pests and diseases. Keep farm weed free all year. Where practical remove weeds from native vegetation areas.	Consider pre-irrigation, to allow control of cotton volunteers and other weeds with non-glyphosate control prior to planting. Consider in-crop cultivation where necessary.	Continue to manage volunteer cotton in entire landscape (e.g. fence lines, channels, perennial vegetation and pastures). Consider chipping.	Conduct effective crop removal to prevent ratoons.
	Practice Come Clean. Go Clean. all year round			
Consider options to avoid or reduce pests	When planning cotton, consider paddock history, proximity to sensitive areas, pest hosts and beneficial habitats. Manage areas of vegetation to encourage beneficials. Consider a summer trap crop. Assess risk of soil pests.	Use a suitable variety for your region. Provide optimum planting conditions to promote healthy seedlings. Consider insecticide choice or releasing natural enemies to build beneficial numbers.	Monitor crop development to maintain a healthy crop. Maintain high beneficial numbers.	Slash and pupae bust last generation summer trap crop (follow guidelines). Follow pupae busting guidelines for Bt cotton. Practice Come Clean. Go Clean. to prevent spread of pests on, off and around farm.
Sample crops effectively and regularly	Remain up-to-date with key pests, beneficials, sampling techniques and thresholds. Monitor for soil pests pre-planting.	Sample for pests, beneficials, parasitism, fruit load and plant damage at least twice weekly. Consider both current numbers and population trends. Use pest and damage thresholds and the beneficial to pest ratio.		
Grow a healthy crop	Consider the best rotation crop for your situation. Soil test to determine fertiliser requirements for cotton crop. Consider potential disease risks.	Optimum planting conditions will promote healthy seedlings that can outgrow damage. Monitor leaf and tip damage and first squaring node development.	Monitor crop development, fruit retention, nodes above white flower and vegetative growth. Manage nutrition and irrigation to maintain a healthy crop.	Monitor crop development, nodes above cracked boll and percentage of open bolls for defoliation decisions. Manage nutrition and irrigation to avoid or reduce regrowth that may harbour pests.
Use established thresholds	Use thresholds and careful spray selection for all crops.	Use pest and damage thresholds relevant to region, time of season and sampling method. Consider the beneficial to pest ratio taking parasitism into account.		
Choose insecticides wisely	Use thresholds and careful spray selection for all crops. Use field history and pre-season sampling to determine if seed treatments or at planting insecticides are appropriate.	Consider insecticide selectivity and impact on beneficials, including bees. Do not apply prophylactic sprays. Avoid broad-spectrum products where possible (particularly early in the season). Consider edge or patch spraying for clumping pests (aphids, mites, mealybug etc).		Defoliation may be a late season alternative to an insecticide.
Apply good resistance management principles	Complete pupae busting (follow guidelines). Zero tolerance of volunteer and ratoon cotton across the entire landscape.	Adhere to refuge requirements. Consider choice of at-planting insecticides/ seed dressings and implications for later sprays.	Ensure refuges are attractive/effective.	Pupae bust as soon as possible after harvest. For Bt cotton, follow pupae busting guidelines in the RMP.
	Use pest thresholds and follow the Insecticide Resistance Management Strategy (IRMS) for every spray			

A closer look at retention

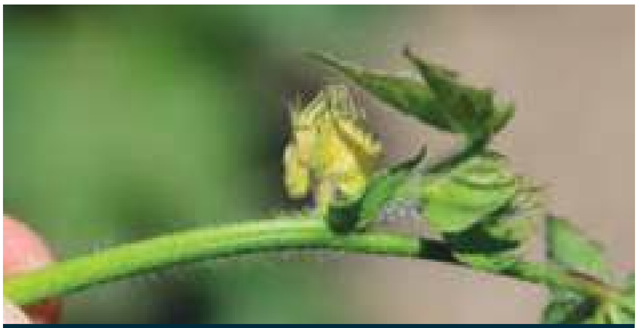
One of the simplest ways to improve IPM on your farm is to avoid unnecessary insecticide use. A common 'shortcut' in glyphosate-tolerant cotton has been adding an insecticide to over the top (OTT) glyphosate applications to improve retention. However, this not only disrupts the establishment of natural enemies that are important for sucking pest (aphids, SLW & mites) control, but is of little use if the crop is at either pre- or early squaring or has very few retention-influencing pests (mirids or thrips) present.

Recent industry-wide research on the impact of early square loss on yield potential found that square loss during early squaring (9-13 nodes) prior to first flower did not impact crop maturity, yield or lint quality. Cotton's ability to rapidly compensate under good growing conditions declines during flowering as developing bolls compete for resources, so mid-season fruit loss is more likely to impact a crop's yield and maturity. Aim to manage square retention from the initiation of the fifth fruiting branch onwards.

Fruiting vs vegetative branches

The node at which fruiting branch initiation commences will vary across varieties, regions and seasons, so it is critical to ensure that vegetative branches (which lack squares during early development) are not counted when assessing retention on pre-flowering crops. For example, a crop at 10-11 nodes may only have 1-3 fruiting branches present and thus appear to have a low total number of squares even if all fruiting places are retained.

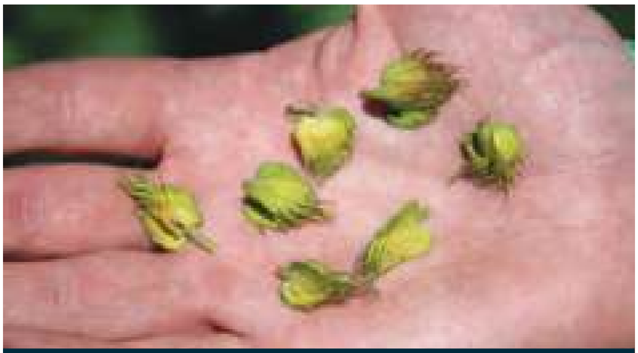
Fruiting branches during squaring will always have either a square or a scar (from where a square has been lost) directly opposite a subtending leaf. The pictures below and video on the next page show what to look for when examining crops during squaring. Checking 5-10 plants in several locations will provide a reasonable idea of the crop's development status.



Cotton plants can rapidly compensate for early fruit loss if growing conditions are good. Paul Grundy, Qld DAF

Environmental stress

No amount of insecticide will stick fruit if the shedding is due to environmental causes. Temperature extremes (below 12°C and above 35°C) or cloudy weather for only a few days can cause significant square loss on young plants. Often environmentally-induced shedding is patterned (loss of squares of a certain size or at a particular branch node). If crop development or environmental conditions do not explain the low retention, check carefully for pest insects, as mirids or thrips can impact retention at squaring.



Knowledge is the key to effective pest management. The shedding of these squares was caused by environmental factors, not pest damage. Paul Grundy, Qld DAF

A vegetative branch has no fruiting sites (left). Fruiting branches have a square opposite the subtending leaf (centre) or a scar indicating a lost fruiting site (right). Paul Grundy, Qld DAF

TABLE 3: Guidelines for monitoring and managing retention		
Crop stage	**Square retention**	**Pest control action**
Up to 5 fruiting branches. Commence square retention assessment at 3-4 fruiting branches (9-12 nodes). Count all positions.	Less than 40%	ONLY take control action if pest insects are still present, at threshold AND the crop has reached 4-5 fruiting branches.
	40-80%	No action required. Monitor for insects.
	More than 80%	No action required. Monitor for insects. Some insect damage to reduce retention may be desirable, particularly in warm areas.
5 fruiting branches to first flower. Count all P1 and advanced* P2 squares.	Less than 40%	Actively manage retention. Control insects if at threshold to allow compensatory fruit production.
	40-60%	Retention levels are adequate. If closer to 40% ensure retention is trending upwards. Continue monitoring for insects.
	More than 60%	No action. Monitor for insects. If retention is very high (greater than 80%), some square loss may be desirable.
First flower to cut-out (4 to 5 NAWF). Count P1 and advanced* P2 squares between NAWF and terminal.	Less than 40%	Manage for greater than 60% retention during first 2-3 weeks of flowering. Compensation will occur via replacement bolls held at sites immediately above or beside lost positions.
	40-60%	No action required if lower canopy fruit retention below the main stem white flower is adequate (40-60%). If retention of earlier bolls is below 40% (either due to prior square loss, subsequent insect damage or physiological shedding), manage for increased retention of remaining squares leading into peak flower.
	More than 60%	No action required. Note that as boll load increases, physiological shedding of squares and recently pollinated bolls will begin to occur as NAWF decreases below 5.

* 'advanced' squares are garden pea sized or bigger.

Guidelines for monitoring and managing retention

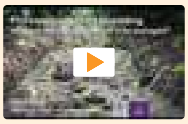
These guidelines are based on early season square damage in high-yielding irrigated fields, where crops averaged a total of 15-16 fruiting branches and compensation was largely achieved within the first 10-12 fruiting branches. In crops likely to produce less than 10 fruiting branches (i.e. cut-out prior to 18-19 total nodes) a more stringent approach to early management may be warranted. Note that:

- Very high retention (>80%) on the first 5 fruiting branches can reduce mid-season canopy expansion.
- Premature cut-out is likely to limit the crop's yield potential.
- The fruit setting period (late squaring – peak flower) is dynamic. Retention management should consider crop stage, existing boll set and factors that might reduce boll set (insects, weather, etc).

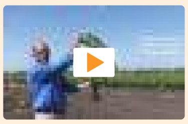
USEFUL RESOURCES:

Qld DAF, Toowoomba
Paul Grundy 0427 929 172.

Distinguishing between vegetative and fruiting branches in young crops
youtu.be/7PXIAuinmeY



Physiological Fruit Shedding: What are the causes and can it be managed?
youtu.be/FFPOAhmLhFw



Fruiting positions and retention levels in cotton
youtu.be/kcN8P9Nf6zo

When managing for early season retention

1. Only count fruiting branches. Vegetative branches are not sufficiently advanced during early crop development to have squares.
2. Early fruit loss does not automatically mean yield loss. Square loss from crops that have only produced 4-5 fruiting branches will have no discernible impact on crop maturity, lint yield and quality.
3. Focus on total retention prior to flowering. First position boll retention is not the only driver for yield potential in current varieties. A combined retention of 40% or more of all fruiting sites by first flower is adequate to maintain high yield, earliness and lint quality.
4. Avoid applying insecticides before 4 fruiting branches are produced, where possible. While early season thrip management in southern regions may be warranted, early insecticide applications can negatively impact the build-up of natural enemy populations.
5. Actively manage for retention from 4-5 fruiting branches. Check for pest activity prior to spraying and consider the possibility that environmental factors may have caused square loss. Remember that the plant can compensate for sites lost during early squaring.
6. Be aware of physiological shedding. Sub-optimal temperatures, cloudiness or moisture stress can induce shedding. This natural response allows continued growth and rapid recovery once conditions improve. Maintaining a large early season fruit load during periods of short-term environmental stress can limit future canopy expansion, fruiting site production, and even lead to premature cut-out, and be counter-productive for yield potential.

Protecting beneficials

Not all arthropods found in cotton are pests. Some are just passing through, and some are actively providing benefits, either to the crop directly (e.g. predators or parasitoids of crop pests; often referred to as 'natural enemies') or to the local ecosystem (e.g. pollinators).

Building and/or conserving beneficial populations is at the heart of integrated pest management (IPM). Pest management decisions need to be well informed and supported by effective sampling and valid control thresholds. Knowledge of the beneficials present, their activity on pests (see Table 4 for common examples), and the potential impacts of other pest control measures helps ensure the best management decisions are made for your crop.

Choose insecticides wisely to conserve beneficials

Balance the contribution of beneficials against the need to protect the crop from significant loss. Where insecticide control is warranted (based on industry recommended monitoring and thresholds), select products based on:

- Efficacy on the pest.
- Impact on beneficials, including bees (see Tables 5 & 6).
- Allowable usage in the cotton industry's Insecticide Resistance Management Strategy (IRMS).

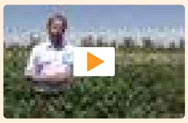
Always aim to maximise effectiveness against the pest while minimising impact on beneficials. Consider other factors such as rate, application technique and other products used in tank mixes that could either improve or hinder efficacy. Also consider the potential for unintended consequences such as flaring of non-target pests or increased resistance (including cross-resistance) in the target or secondary pests.

Some insecticides are very selective and have little impact on beneficial insects (often referred to as 'soft'), while others are highly disruptive to beneficial populations ('broad-spectrum or 'hard'). Knowing the selectivity of an insecticide helps to assess the risk that following its use, populations of other pests may 'flare' (increase rapidly). The relative selectivity of insecticides available for use in cotton can be found in Tables 5 and 6 (which have been largely based on industry-funded research).

In addition to general impact, Table 6 lists the product's selectivity to specific types of beneficials. For example, if mealybugs are present, look for insecticides that have less effect on parasitic wasps and key mealybug predators such as lacewings and ladybird beetles. When products are registered for a range of rates, using lower rates may provide sufficient efficacy against some target pests, while minimising impact on beneficials. Note that these ratings are based on results after a single application, and multiple applications of a product with a low rank can still have a cumulative disruptive impact.

When selecting an insecticide, refer to the IRMS (pages 64-65) to reduce the risk of resistance, and follow the product's label directions.

USEFUL RESOURCES:



Conserving beneficials in cotton
youtu.be/g3GYrt6QoN8

TABLE 4: Key beneficials and their activity on pest groups

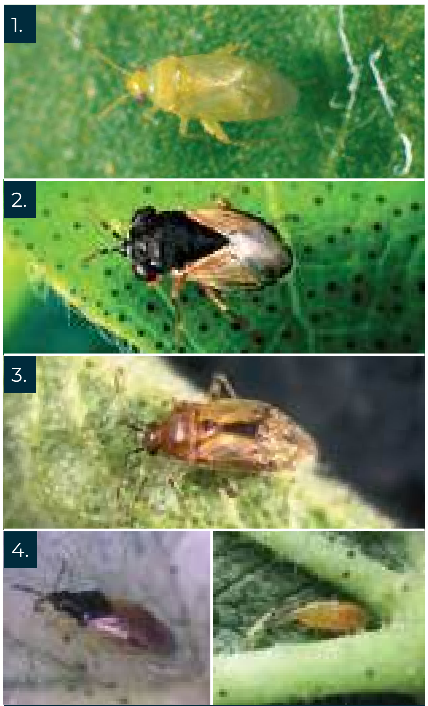
	Helicoverpa	Aphids	Mealybugs	Spider mites	SLW	Mirids	Jassids	Thrips	Notes
Ladybird beetles		✔	✔	✔	✔		✔	✔	Also feed on scale insects.
Red and blue beetle	✔	✔	✔		✔				Partly predacious. Feed on eggs, small larvae, other slow-moving insects, and pollen.
Damsel bug	✔	✔		✔		✔			Will feed on helicoverpa eggs and small caterpillars.
Big-eyed bug	✔	✔		✔	✔	✔			Important predator of eggs and small soft-bodied insects.
Brown smudge bug	✔		✔	✔	✔				Important predator of eggs and small soft-bodied insects.
Apple dimpling bug				✔	✔				Can also reduce fruit retention, but only 1/4 as damaging as green mirids.
Glossy shield bug	✔								Also predators of other caterpillars.
Spined predatory bug	✔					✔			Also predators of other caterpillars.
Minute pirate bug				✔	✔			✔	Effective predators of eggs.
Assassin bug	✔					✔			Also predators of other caterpillars.
Lacewings	✔	✔	✔	✔	✔			✔	Both adults and larvae of brown lacewings are predatory. In green lacewings, only the larval stage is predatory.
Spiders	✔			✔	✔	✔	✔		Generalist predators.
Parasitoids	✔	✔	✔		✔				Target specific pests. Monitor pests for signs of parasitism.
Hoverfly and silverfly larvae		✔							Larval stage is predatory.
Thrips				✔	✔				Can be a pest of seedlings.

Examples of beneficial species

PREDATORY BUGS

Glossy shield bug. 12 mm. J. Wessels
Nymph on right. J. Wessels

Assassin bug. 25 mm. L. Wilson

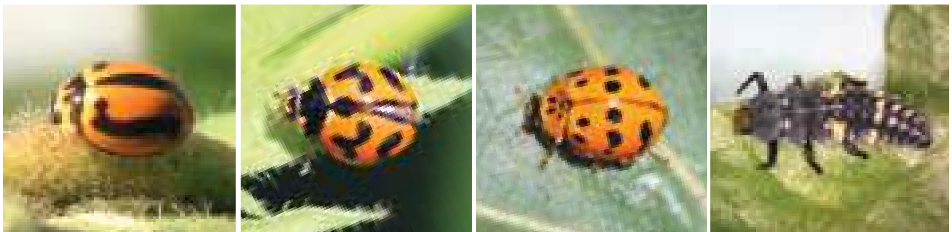


Small (2-4 mm) predatory bugs:
1. Apple dimpling. J. Wessels
2. Big-eyed. M Dillon
3. Brown smudge. C Mares
4. Minute pirate. T. Grundy & L. Wilson (nymph)

Spined predatory bug. 12 mm. L. Wilson
Nymph on right. J. Wessels

Damsel bug. 8 mm. D. McClenaghan
Nymph on right. J. Wessels

PREDATORY BEETLES



Ladybird species (4–8 mm): Striped L. Wilson, Transverse and 3 banded P. Grundy and 3 banded larva. T. Grundy

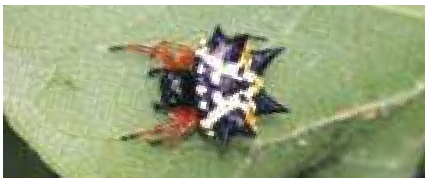
Red and blue beetle adult. 5 mm. D. McClenaghan

LACEWINGS

Lacewing brown adult (8 mm) and larva (5 mm). Both stages are predatory. J. Wessels

Green lacewing adult (12 mm) and larva (6 mm). Larval stage is predatory. T. Grundy and M. Miles

SPIDERS



Christmas spider. 15 mm. P. Grundy

Tangle web spider. 5 mm. P. Grundy

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Transform controls a range of cotton pests while proving soft on beneficials. Because of its unique Mode of Action, Transform can control insects that are resistant to other insecticides.

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Examples of beneficial species (continued)

OTHER PREDATORS


Brown earwig. 20 mm. J. Wessels


Hoverfly adult 9 mm (left) and larva (larval stage is predatory) 7 mm. P. Grundy

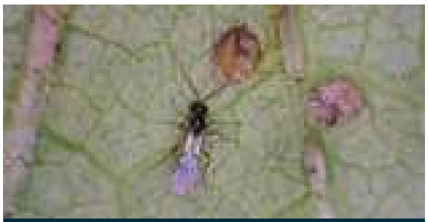

Thrips feeding on a spider mite. L. Wilson

PARASITOIDS


Two-toned parasite. 20 mm. P. Reid


The banded caterpillar wasp can locate underground pupae. 14 mm. P. Reid


Microplitis wasp pupae (3 mm) attached to medium Helicoverpa larvae. M. Dillon


Lysiphlebus wasp recently emerged from aphid 'mummy'. 2–3 mm. M. Miles

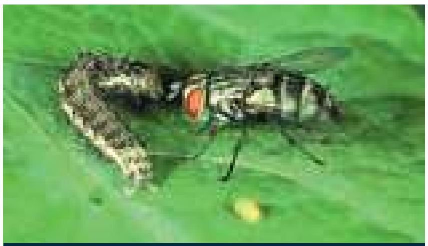

Tachinid fly attacking Helicoverpa larvae. 5–6 mm. J. Wessels

TABLE 5: Impact of insecticides at planting or as seed treatments on natural enemies in cotton

Active	MoA group	Rate	Target pest(s)					Persistence[1]	Impact on beneficials[2]	
			Wireworm	Mites	Mirids	Aphids	Thrips		Thrips	Others[3]
At planting (rate = g ai/ha)										
Phorate	1B	600	Y	Y	Y	Y	Y	Medium-long	Very high	Very low
Chlorpyrifos	1B	250-750	Y					Medium	—	Very low
Bifenthrin	3A	37.5	Y					Medium	—	Very low
Chlorpyrifos + Bifenthrin	1B + 3A	250-750 + 12.5-37.5	Y					Medium	—	Very low
Seed treatments (rate = g ai/100 kg seed) used by professional seed treatment companies										
Imidacloprid + Thiodicarb + Fipronil	4A + 1A + 2B	350 + 250 + 50	Y				Y	Medium long	—	Very low
Imidacloprid	4A	525 or 702	Y			Y	Y	Medium	Very high	Very low
Thiamethoxam	4A	276 or 522	Y			Y	Y	Medium	Very high	Very low

Note: Some regsistrations may be restricted to specific areas (e.g. NSW and QLD only). ALWAYS check the product label.
1. Persistence: short, 2-3 weeks; medium, 3-4 weeks; long, 4-6 weeks.
2. Impact rating (% reduction in beneficials following application):
very low, <10%; low, 10-20%; moderate, 20-40%; high, 40-60%; very high, >60%; —, no data.
3. Other beneficials include predatory beetles, predatory bugs, spiders, wasps and ants.

TABLE 6: Impact of foliar insecticides and miticides on predators, parasitoids and bees in cotton

Insecticides (in increasing rank order of impact on beneficials)	MoA group	Rate (g ai/ha)	Target pest(s)							Beneficials[1]																	Pest resurgence[2]			Toxicity to bees[8]
											Predatory beetles				Predatory bugs							Hymenoptera								
			Helicoverpa	Mites	Mirids	Aphids	Thrips	Silverleaf whitefly	Persistence[3]	Overall ranking	Total[4]	Red & blue beetle	Minute 2-spotted ladybird beetle	Other ladybird beetles	Total[5]	Damsel bug	Big-eyed bug	Other predatory bugs	Apple dimpling	Lacewing adults	Spiders	Total (wasps)[22]	*Eretmocerus*[6]	*Trichogramma*	Ants	Thrips[7]	Mites	Aphids	*Helicoverpa*	
Bt[9]	11A		✔						Very short	Very low	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL				VL
NPV[10]	31		✔						Very short	Very low	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL				VL
Pirimicarb	1A	250				✔			Short	Very low	VL	VL	VL	VL	L	L	M	VL	VL	VL	VL	VL	M	M	VL	L				VL
BioPest®[11]		2-4%				✔			Short	Very low	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	L	—	L	M	VL				VL
Pyriproxyfen	7C	50						✔	Long	Very low	M	—	M	M	VL	—	—	—	—	L	VL	L	L	VL	VL	VL				L
Parachute®[11]		2%	✔		✔	✔		✔	Short	Low	VL	L	VL	VL	VL	VL	VL	VL	VL	VH	VL	M	VH	M	M	L				VL
Sero-X®	UNE	800	✔		✔			✔	Short	Low	VL	VL	M	L	VL	VL	VL	—	L	VL	VL	L	—	L	VH	VL				VL
Etoxazole	10B	38.5		✔					Short	Low	VL	VL	—	L	VL	VL	VL	VL	VL	VL	M	L	—	VL	VL	L				VL
Buprofezin	16	440						✔	Long	Low	L	H	VL	VL	VL	L	L	VL	VL	H	VL	L	VL	L	VL	VL				VL
Indoxacarb (low+/- salt, oil)	22A	60			✔				Medium	Low	L	L	H	M	VL	L	—	L	H	M	VL	VL	VL	VL	H	VL		+ve		H
Chlorantraniliprole	28	52.5	✔						Long	Low	L	M	M	L	VL	VL	VL	L	VL	VH	VL	M	M	L	L	VL		+ve		VL
Afidopyropen	9D	10				✔			Medium	Low	L	L	H	M	VL	VL	VL	—	H	VL	L	M	VH	H	VH	VL	+ve			VL
Spinetoram	5	48	✔				✔		Long	Low	M	M	H	H	VL	VL	VL	VL	VL	VL	VL	H	VH	H	VH	VH	+ve			H[18]
Diafenthiuron	12A	350		✔		✔		✔	Medium	Low	M	H	VL	M	L	M	VL	L	H	VL	L	M	H	VL	H	L			+ve	VH
Pymetrozine	9B	150				✔			Short	Low	M	M	M	M	L	L	L	VL	H	M	L	L	M	L	M	VL				M
Indoxacarb	22A	127.5	✔		✔				Medium	Low	H[18]	L	VH	VH	L	M	L	L	VH	M	VL	M	M	VL	VH	VL		+ve		H
Dimpropyridaz	36	120				✔		✔	Long	Moderate	L	L	L	L	M	L	VH	VL	M	VH	VL	M	M	H	VH	L				L
Cyantraniliprole	28	60	✔			✔[16]		✔	Long	Moderate	M	M	VL	L	M	M	M	H	L	VH	M	M	VH	VL	VL	H	+ve			VH
Sulfoxaflor (low)	4C	48			✔	✔			Medium	Moderate	L	L	L	M	L	VL	L	M	VH	H	VL	H	VH	M	H	H	+ve		+ve	VH
Spirotetramat	23	96				✔		✔	Medium	Moderate	M	L	H	H	VL	VL	VL	VL	M	VH	M	M	VL	M	M	M				H[17]
Flonicamid	29	70			✔	✔			Medium	Moderate	VL	VL	VL	VL	H	H	VH	H	H	VL	M	M	M	H	VL	H				H[17]
Sulfoxaflor (mid)	4C	72			✔	✔			Medium	Moderate	M	L	M	H	L	VL	L	M	VH	H	VL	H	VH	H	H	H	+ve		+ve	VH
Dinotefuran (low)	4A	18			✔			✔	Medium	Moderate	M	M	M	VL	M	VL	VH	M	H	VL	L	M	VH	VH	H	M	+ve			VL
Abamectin	6	5.4	✔[19]	✔					Medium	Moderate	L	M	H	VL	M	L	M	M	H	VL	M	M	H	M	H	M				VH
Emamectin benzoate	6	8.4	✔						Medium	Moderate	L	VL	M	VL	H	H	H	H	H	L	M	H	VH	M	VL	M				VH
Propargite	12C	1500		✔					Medium	Moderate	M	H	H	M	M	H	VL	VL	L	VL	M	M	L	H	H	M		+ve	+ve	VH

Acetamiprid	4A	22.5			✔	✔			Medium	Moderate	M	M	VH	H	M	M	H	M	VH	L	VL	H	VH	H	VH	VH				H
Clothianidin (low)	4A	25			✔				Medium	Moderate	M	VL	—	H	L	M	VL	VL	H	H	M	H	VH	M	VH	VL			+ve	H
Skope® (low)[13]	4A+6				✔			✔	Medium	Moderate	H	H	VH	VH	M	—	—	—	VH	M	VL	VH	VH	VH	VH	H				L
Fipronil (low)	2B	12.5			✔		✔		Medium	Moderate	L	L	H	L	L	H	L	L	VH	L	M	H	VH	M	VH	VH	+ve	+ve	+ve	M
Thiamethoxam	4A	100				✔			Medium	Moderate	H	H	H	H	M	M	M	H	H	M	VL	H	VH	H	VH	H	+ve		+ve	H
Sulfoxaflor (full)	4C	96			✔	✔		20	Medium	Moderate	H	L	M	H	L	VL	L	M	VH	H	L	H	VH	H	VH	H	+ve		+ve	L
Fipronil (high)	2B	25			✔		✔		Medium	Moderate	L	L	H	L	M	H	H	L	VH	L	M	H	VH	M	VH	VH	+ve		+ve	VH
Imidacloprid	4A	49			✔	✔			Medium	Moderate	H	L	VH	H	H	M	H	L	VH	L	L	L	VH	M	H	H	+ve		+ve	H
Clothianidin (high)	4A	50			✔				Medium	Moderate	H	VL	—	VH	M	M	L	VL	H	H	M	H	VH	H	VH	VL	+ve		+ve	H
Dinotefuran (high)	4A	75			✔			✔	Medium	Moderate	H	H	H	VL	H	M	VH	M	H	VL	L	M	VH	VH	VH	H	+ve		+ve	VH
Methomyl	1A	169	✔						Very short	High	H	L	VH	VH	M	L	VH	L	VH	M	M	M	VH	H	H	H	+ve			VH
Thiodicarb	1A	750	✔						Long	High	VH	M	VH	VH	M	M	L	L	VH	VL	M	M	—	M	M	H	+ve	+ve		M
Dimethoate	1B	200		✔[21]	✔	✔[21]	✔		Short	High	M	M	H	H	M	H	—	H	H	VH	M	H	H	H	VH	M	+ve		+ve	VH
Skope® (high)[13]	4A+6		✔	✔	✔			✔	Medium	High	VH	H	VH	VH	H	—	—	—	VH	H	L	VH	VH	VH	VH	VH				H[17]
OPs[14]	1B		✔	✔	✔	✔	✔		Short-medium	High	H	M	H	H	H	M	H	H	VH	L	M	H	VH	H	VH	H	+ve			M[17]
Carbaryl[12]	1A		✔						Short	High	H	—	—	—	H	—	—	—	—	—	—	—	—	—	—	H				H
Pyrethroids[15]	3A		✔	✔	✔			✔	Long	Very high	VH	—	—	—	VH	—	—	—	VH	VH	VH	VH	VH	VH	VH	VH	+ve	+ve	+ve	H

1. Impact rating (% reduction in beneficials following application): VL (very low), less than 10%; L (low), 10-20%; M (moderate), 20-40%; H (high), 40-60%; VH (very high), >60%. A '—' indicates no data available.
2. Pest resurgence is +ve if repeated applications of a particular product are likely to increase the risk of pest outbreaks or resurgence. Avoid sequential applications of products with a +ve pest resurgence rating for the same pest species.
3. Persistence of pest control: Very short, about 24 hours; short, less than 3 days; medium, 3-7 days; long, greater than 10 days.
4. Total predatory beetles: Includes ladybird beetles, red and blue beetle, other predatory beetles.
5. Total predatory bugs: Includes big-eyed bug, minute pirate bug, brown smudge bug, glossy shield bug, predatory shield bug, damsel bug, assassin bug, apple dimpling bug.
6. Rankings for *Eretmocerus* sp. primarily based on data from Jamie Hopkinson and Jacob Balzer (Qld DAF) in replicated laboratory leaf assay experiments, based on % mortality of adult wasps up to 96 hrs after application (highest impact occurred within the first 48 hours). Also considered are rankings for *E. mundus* (P. De Barro, CSIRO, unpublished) and *E. eremicus* (Koppert B.V., The Netherlands).
7. Effects on thrips populations present on leaves (thrips in flowers are more likely to avoid exposure). Applicable to seedlings (when thrips cause leaf damage) and in mid-late season crops (when thrips adults and larvae help control mites as well as feeding on leaf tissue).
8. Bee impact sources: APVMA Public Release Summaries and British Crop Protection Council. 2003. The Pesticide Manual: A World Compendium (Thirteenth Edition). Where LD50 data is not available, impacts are based on comments and descriptions. Where LD50 data is available, impacts are based on the following LD50s at 48 hours: very low >100 ug/bee; low <100 ug/bee; moderate <10 ug/bee; high <1 ug/bee; very high <0.1 ug/bee. See also the Protecting pollinators section in this guide.
9. Toxin derived from *Bacillus thuringiensis*.
10. Nucleopolyhedrovirus.
11. Paraffinic oil.
12. Sources: Citrus pests and their natural enemies, edited by Dan Smith; University of California Statewide IPM project, Cotton, Selectivity and persistence of key cotton insecticides and miticides.
13. Skope® is a mixture of acetamiprid and emamectin benzoate. Low rate (175 ml/ha) is equivalent to 38.2 g ai/ha acetamiprid and 5.7 g ai/ha emamectin benzoate. High rate (350 ml/ha) is 76.3 g ai/ha and 11.4 g ai/ha. Skope may flare mite populations where abamectin resistant two-spotted mites are present.
14. Organophosphates: Includes omethoate, profenofos, chlorpyrifos, chlorpyrifos-methyl.
15. Pyrethroids: Includes alpha-cypermethrin, cypermethrin, cyfluthrin, bifenthrin, fenvalerate, esfenvalerate, deltamethrin, lambda-cyhalothrin. Bifenthrin is registered for mite and silverleaf whitefly control; alpha-cypermethrin, beta-cyfluthrin, bifenthrin, deltamethrin and lambda-cyhalothrin are registered for control of mirids.
16. Suppression only.
17. Wet residue of these products is toxic to bees. Applying the products in the early evening when bees are not foraging will allow spray to dry, reducing risk to bees the following day.
18. high impact on minute two-spotted ladybeetle and other ladybeetles for wet spray, moderate impact for dried spray.
19. *Helicoverpa punctigera* only
20. Transform is registered for control of greenhouse whitefly at the 96 g ai/ha rate.
21. Will not control organophosphate resistant pests (e.g. mites, some cotton aphid (*Aphis gossypii*) populations.
22. Ratings for total wasps have been revised to consider results from laboratory assays (see Footnote 6). New ratings represent the highest potential impact on wasps, which may differ with crop stage and pest status in the field.

DISCLAIMER: Information provided is based on the current best information available from research data. Users of these products should check the label for further details of rate, pest spectrum, safe handling and application. Further information on the products can be obtained from the manufacturer.

CONTRIBUTORS: Simone Heimoana (CSIRO); (Jamie Hopkinson (DAF Qld); Lewis Wilson, Martin Dillon and Mark Wade (formerly CSIRO); Moazzem Khan, Brad Scholz, David Murray and Richard Lloyd (formerly DAF Qld); Robert Mensah, Viliami Heimoana and Jonathan Holloway (formerly NSW DPI); Richard Sequeira (DAF Qld); Paul De Barro (CSIRO).

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Managing key insect and mite pests

This section provides specific management information for the key insect and mite pests of Australian cotton to assist growers and advisors in planning their integrated pest management (IPM) programs. Cotton production now covers a diverse range of environmental conditions, planting dates and agronomic strategies. Be aware of any regional differences in pest activity or damage potential that may impact your insect management decisions.

Crop damage

Visible damage indicates that a pest could be influencing crop development and possibly yield potential. In some instances, damage symptoms will be observed without the pest, meaning either the pest is hidden or has since left the crop. In other cases, a pest (or incidental non-pest insect) may be observed with little or no associated crop damage. Use knowledge of the pests/beneficials present in combination with crop damage to make appropriate pest management decisions. Be aware that some pest damage symptoms (such as square shedding/abscission) can easily be confused with damage from physiological/ environmental or related causes.

Sampling and thresholds

Sampling is the process of collecting regular information on pest and beneficial abundance and crop damage used to make pest management decisions, and thresholds provide a rational basis for making those decisions and keeping them consistent. Correctly identifying pest species and knowing the key beneficial predators and parasitoids for each pest is important for developing confidence in IPM approaches to pest management.

Thresholds aim to ensure a positive economic return from a pest management action (the benefit is greater than the cost), and can be based on insect numbers, crop damage, predicted population levels, or a combination of factors.

Product selection

Selecting an insecticide (or miticide) can be a complex decision based on trade-offs between preventing pest damage and conserving beneficials, or reducing levels of one pest but risking the outbreak of another.

Understanding how pests in cotton farming systems can survive, including knowing their resistance status and risks, overwintering habit and alternative hosts can help with good decision making for the longer term.

Other animals can also damage cotton. These gnawing marks are caused by mice. Permits PER93458 and PER94870 to use zinc phosphide baits on mice and long-haired rats respectively expire in April/May 2025. Roger Lindeman

Highly hazardous pesticides (HHP) are pesticides that present particularly high levels of acute or chronic hazards to health or environment, according to internationally accepted classification systems or relevant international agreements or conventions, such as those listed in the Stockholm convention, Montreal protocol and Rotterdam convention. The Better Cotton Initiative (BCI) has banned the use of certain pesticides, and is also looking to phase out others. Phorate and abamectin have been categorised by BCI as HHPs and BCI growers are encouraged to find alternatives where possible. Where an alternative is not available or appropriate (e.g. for resistance management), use a closed transfer system as well as recommended sampling and thresholds as part of a broader IPM strategy.

Registration of a pesticide is not a recommendation for the use of a specific pesticide in a particular situation. The pesticide chosen should be the best one for the crop, pest and current circumstances. Individual insect control tables in this publication focus on in-crop applications. See Table 5 for at planting and seed treatment products. Carefully study the container label before using any pesticide, and note any specific instructions or restrictions relating to the rate, timing, application and safety. Confirm that the registration or permit is current prior to use.

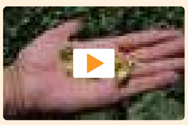
Ensure your insecticide program fits in with the **Insecticide Resistance Management Strategy** (IRMS: see pages 58-65 for more information). Insecticides can be costly, so follow industry thresholds (when available) to prevent unnecessary spraying.

If using Bollgard varieties, refer to your region's Resistance Management Plan for specific insect management instructions and limitations (see also the RMP section in this publication).

Important – avoid spray drift

For legal requirements and best practice information on reducing spray drift, refer to the *Spray application* chapter. Insecticides can be highly toxic to humans and the environment. Carefully follow all label directions.

USEFUL RESOURCES:



What is causing my squares to shed?
youtu.be/XMQr2mC25zc

What's on my beat sheet?
youtu.be/3r4uqD5hp-w

Aphids

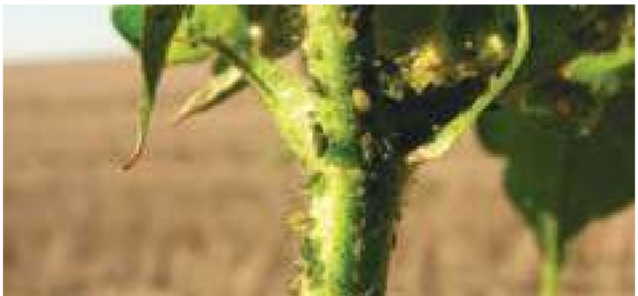
Cotton aphid – *Aphis gossypii*
Cowpea aphid – *Aphis craccivora*
Green peach aphid – *Myzus persicae*

Cotton aphid is the most common species in Australian cotton. Green peach aphid and cowpea aphid can migrate from winter hosts to be pests of young cotton, but tend to disappear as temperatures increase. IPM practices have reduced the incidence of aphids in most fields, however occasional outbreaks can still occur, particularly late season. Nymphs and adults can feed in the terminals, on young stems, on the undersides of leaves, and on developing fruit.

Damage symptoms

Early aphid infestations can increase quickly, inhibiting photosynthesis and reducing yield. Aphids in the terminal can stunt plant growth, and populations on leaves can cause stunting and downward cupping of leaves, with portions of the leaf's upper surface turning red in severe cases. The sugary 'honeydew' excreted by aphids can promote sooty mould on leaves and fruit and contaminate the lint, so sampling for aphids is still critical as bolls open.

Cotton aphids also transmit cotton bunchy top disease (CBT). See page 110 for disease symptoms.



Aphids indirectly damage crops by transmitting cotton diseases. Lewis Wilson

Sampling

Monitor visually, at least weekly from seedling emergence to defoliation, focusing on non-winged adults and nymphs. If you are mostly finding winged aphids, recheck within a few days to see if nymphs are present. Winged adults can be transitory, but the presence of nymphs indicates that a population has settled in the crop. Wingless females surround themselves with their offspring, so clumps of differently sized aphids in a small area indicates a growing population. Aphids are most abundant on the edges of fields so ensure some perimeter sampling occurs.

Use a hand lens to verify the species (particularly early in the season) before implementing any management strategies. If you are not sure, contact your nearest cotton REO (see inside back cover) for assistance. If cotton aphid hotspots occur early season, also check these areas for CBT symptoms.

Green peach aphids are pale green and oval, and have 'W'-shaped tubercles (bumps on the head between the antennae) and long siphunculi (tubes between the back legs). Cotton aphid and cowpea aphid are rounder, don't have tubercles and the siphunculi are shorter. Adults and nymphs of cotton aphid are matt and body colours vary widely (yellow, green, olive, brown, dull black), but adult siphunculi are always black. Cowpea aphid adults are shiny black and nymphs are dusky matt grey.

Cotton aphid. Tonia Grundy, Qld DAF

Cowpea aphid. Tonia Grundy, Qld DAF

Green peach aphid. Andrew Weeks, Cesar Australia

Sampling protocols are for non-winged adults and nymphs on the underside of at least 20 mainstem leaves (from different plants) 3-5 nodes below the plant terminal. If a plant has less than 3 leaves, sample the oldest. Mites can be monitored using the same leaves.

- **Seedling to first open boll:** Use a 0-5 scoring system based on the number of aphids/leaf and the Cumulative Aphid Score (see page 28).
- **First open boll to harvest:** Use a presence/absence scoring system on at least 20 plants: a leaf with 4 or more wingless aphids in a 2 cm^2 area is considered 'infested'. Also assess plants for the presence of honeydew.

Thresholds

Cotton aphid

From seedling until first open boll, thresholds are based on the potential for feeding damage to reduce yield, taking into consideration both crop value and control costs. After first open boll, the thresholds aim to protect the quality of the lint by avoiding contamination with honeydew and subsequent possible discolouration from sooty moulds, as penalties for honeydew contamination are severe.

SEEDLING TO FIRST OPEN BOLL	FIRST OPEN BOLL TO HARVEST
Calculate the Cumulative Season Aphid Score (see page 26) to determine an estimate of yield loss	50% plants infested OR 10% if trace amounts of honeydew present

Yield loss due to aphid-vectored CBT is not considered by this threshold as the risk of CBT being spread through crops and affecting yield is low, except where significant populations of ratoon cotton or alternative weed hosts are nearby. Removing cotton ratoons/volunteers and weeds in and around fields well before planting will reduce both aphid survival and CBT carryover. If alternative hosts are in the vicinity, monitor for the presence or spread of aphids twice weekly, and if aphids become established control may be required to minimise a subsequent CBT outbreak. Choose a selective option to conserve beneficials.

Other aphids

Green peach aphid can severely stunt young cotton plants, so the threshold for control is lower (25% of plants infested) than for cotton aphid. However, it is unusual for control to be necessary as populations usually decline naturally when temperatures increase.

Cowpea aphid populations also usually decline quickly as temperatures increase. Control would only be needed if populations persisted (e.g. in cooler seasons) and plants were showing signs of damage and stunting.

Key beneficials

Predators include ladybird beetle adults and larvae, red and blue beetles, damsel bugs, big-eyed bugs, lacewing larvae, hoverfly and silverfly larvae. Parasitoids (cause mummification) include *Aphidius colemani* and *Lysiphlebus testaceipes*.

Selecting an insecticide

When choosing a pesticide for aphid control, consider aphid resistance status, previous insecticide applications, and rotate chemical groups (see Table 7). If control is required early season, use a selective option (see Table 5) in accordance with the IRMS (pages 64-65) to help conserve beneficial populations that can assist in controlling any survivors from the insecticide.

Spot the parasitoid (mummy) amongst the aphids.
Paul Grundy, Qld DAF

Resistance profile

Aphids are parthenogenic (reproduce asexually, meaning the offspring are clones), meaning all progeny of a resistant individual will also be resistant. Once resistance is selected for in a population, it can quickly give rise to new, entirely resistant populations which cannot be genetically diluted.

Of particular concern are neonicotinoid (4A) products, where the development of resistance to one neonicotinoid will cause cross-resistance between other insecticides in the same group. This resistance can be inadvertently selected in two ways: widespread use of neonicotinoid seed treatments and the use of foliar insecticides targeting pests such as mirids, stink bugs or Rutherglen bugs. Even when aphids are present at very low levels, resistance is being selected.

Within Group 1, phorate (1B) has cross-resistance with dimethoate (1B) and pirimicarb (1A). In the early 2000s, cross-resistance in cotton aphid between pirimicarb and dimethoate rendered these compounds ineffective. Although this resistance had declined, it re-emerged in 2023 in all growing regions with populations in some regions being fully resistant to these insecticides. The IRMS stipulates not to use dimethoate in rotation with pirimicarb. Avoid early season dimethoate use to prevent selection of below-threshold populations that may be present in crops.

It is critical to follow the recommendations of the IRMS and rotate insecticide chemistries, taking into account the insecticide group of any seed treatment or at-planting insecticide (see Table 5).

Alternative hosts

In cotton growing areas, aphids persist through winter on whatever suitable host plants are available, however cool temperatures slow their growth rate dramatically.

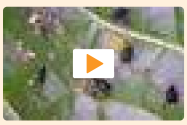
Cotton aphid has a broad host range. Winter hosts include marshmallow, capeweed, thistles, and some legume crops such as faba bean. Spring and summer hosts include thornapples, nightshades, paddymelon, bladder ketmia, Bathurst burr and sunflower crops/volunteers. Ratoon or volunteer cotton is a preferred host and can act as a green bridge for CBT.

Cowpea aphid also has a broad host range, including burr medic, marshmallow, dwarf amaranth, caustic weed and volunteer cotton in winter, and hogweed, cathead, volunteer cotton, cobbler's peg, thornapples, tarvine, small crumbleweed, paddy melon and sowthistle in summer.

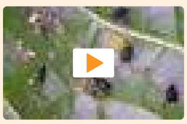
Winter and spring hosts of green peach aphids include turnip weed, marshmallow, peach vine, thornapples and canola.

USEFUL RESOURCES:

NSW DPI, Tamworth
Lisa Bird (02) 6763 1128 0427 992 466.



Aphids in cotton
youtu.be/Vi07GhSoQtg



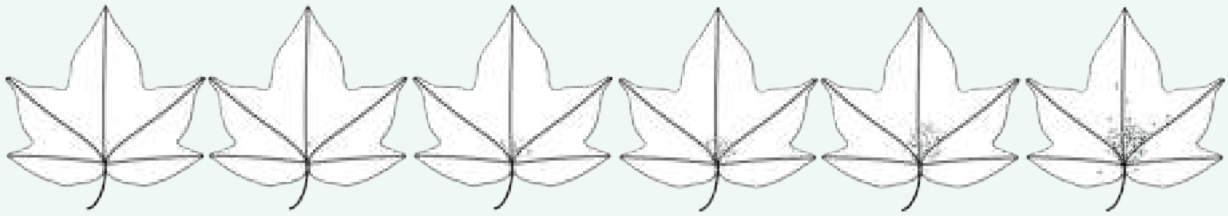
Aphid sampling and management in cotton
youtu.be/L9N64u1yi8E

To submit surviving aphids for resistance testing, see the 'Sending samples for resistance testing' protocol on page 43.

SAMPLING PROTOCOLS FOR COTTON APHID – FOR USE UNTIL FIRST OPEN BOLL

STEP 1: Collect and score leaves.

Collect 20 leaves from each of several locations, taking only one mainstem leaf per plant from 3, 4 or 5 nodes below the terminal (these leaves can also be used for mite scoring). Sample regularly, as yield loss estimates will be most accurate when using the time aphids first arrive in the crop.
Estimate the number of aphids on the leaf and allocate each leaf a score of 0 to 5 (ignore pale brown bloated aphids as these are parasitised). Sum the scores and divide by the number of leaves to calculate the **Average Aphid Score**.



Score = **0** No aphids | Score =**1** 1-10 aphids | Score = **2** 11-20 aphids | Score = **3** 21-50 aphids | Score = **4** 51-100 aphids | Score = **5** >100 aphids

STEP 2: Calculate the cumulative season aphid score.

Convert the Average Aphid Score calculated in Step 1 to a **Sample Aphid Score** using the look-up table below to account for the length of time the aphids have been present in the crop. Find the value where the Average Aphid Scores from 'this check' and the 'last check' intersect, and multiply by the number of days that have lapsed between checks to calculate the Sample Aphid Score. If aphids are found in the first assessment of the season, assume the 'Score last check' was '0' and that it occurred 5 days ago.
As the season progresses, add each check's Sample Aphid Score to the previous value to give the **Cumulative Season Aphid Score**. Note that aphids can disappear due to predation by beneficials, changes in the weather or insecticide application. When aphids are sprayed, or if the Average Aphid Scores return to '0' in 2 consecutive checks during the season, reset the Cumulative Season Aphid Score to '0'.

Average score last check	Average score this check										
	0	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**
0	0.0	0.3	0.5	0.8	1.0	1.3	1.5	1.8	2.0	2.3	2.5
0.5	0.3	0.5	0.8	1.0	1.3	1.5	1.8	2.0	2.3	2.5	2.8
1.0	0.5	0.8	1.0	1.3	1.5	1.8	2.0	2.3	2.5	2.8	3.0
1.5	0.8	1.0	1.3	1.5	1.8	2.0	2.3	2.5	2.8	3.0	3.3
2.0	1.0	1.3	1.5	1.8	2.0	2.3	2.5	2.8	3.0	3.3	3.5
2.5	1.3	1.5	1.8	2.0	2.3	2.5	2.8	3.0	3.3	3.5	3.8
3.0	1.5	1.8	2.0	2.3	2.5	2.8	3.0	3.3	3.5	3.8	4.0
3.5	1.8	2.0	2.3	2.5	2.8	3.0	3.3	3.5	3.8	4.0	4.3
4.0	2.0	2.3	2.5	2.8	3.0	3.3	3.5	3.8	4.0	4.3	4.5
4.5	2.3	2.5	2.8	3.0	3.3	3.5	3.8	4.0	4.3	4.5	4.8
5.0	2.5	2.8	3.0	3.3	3.5	3.8	4.0	4.3	4.5	4.8	5.0

STEP 3: Estimate the yield loss.

Use the Cumulative Season Aphid Score to estimate the **percentage yield loss** that aphids have already caused (excluding risks of yield loss from CBT) in the table below. The 'Days remaining' in the season is determined using the first time aphids are found in the crop, based on 165 days from planting to 60% open bolls.
For example, if aphids are first found 9 weeks (63 days) after planting, the days remaining would be ~100. When aphids are sprayed, or if they disappear from the crop then reappear later in the season, reassess the days remaining based on the number of days left in the season from the time of their reappearance.

Cumulative Season Aphid Score	Days remaining (until 60% open bolls from the time when aphids are first observed)*									
	100	**90**	**80**	**70**	**60**	**50**	**40**	**30**	**20**	**10**
0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
10	2	2	1	1	1	0	0	0	0	0
15	5	4	3	3	2	1	1	0	0	0
20	7	6	5	4	3	2	1	1	0	0
25	9	8	7	6	5	3	2	1	0	0
30	11	10	8	7	6	5	3	2	1	0
40	15	13	12	10	8	7	5	3	1	0
50	19	17	15	13	11	9	7	5	2	0
60	23	21	18	16	13	11	8	6	3	1
80	31	28	25	22	18	15	12	8	5	1
100	38	34	31	27	23	19	15	11	7	2
120	45	41	37	32	28	23	18	13	9	3

*Crop sensitivity to yield loss declines as the crop gets older. These estimates take into account factors affecting aphid population development, such as beneficials, weather and variety. Yield reductions >4% are highlighted, however use individual crop value and cost of control to determine how much yield loss can be tolerated before intervention is required.

TABLE 7: Control of aphids (refer to label for target species)				
Active ingredient	**MoA group**	**Cotton aphid resistance**	**Overall impact on beneficials***	**Comments#**
Pirimicarb	1A	Widespread resistance in all cotton growing regions. Cross-resistance to dimethoate/phorate	**Very low**	Ensure good coverage. Maximum 2 non-consecutive applications per season.
Paraffinic oil	UNM	Unknown	**Very low**	Apply by ground rig using a minimum of 80 L/ha of water. If populations exceed 20 aphids per terminal shoot, apply as a mixture with another aphicide.
Afidopyropen	9D	Unknown	**Low**	Disrupts insect behaviour and feeding. Provides a slow knockdown. Maximum 4 applications per season.
Diafenthiuron	12A	Occasional – low	**Low**	Ensure good coverage. Lower rate for ground rig application only. Maximum 2 applications per season.
Pymetrozine	9B	Unknown	**Low**	Apply to developing populations prior to row closure on an actively growing crop. Maximum 2 applications per season.
Dimpropyridaz	36	Unknown	**Moderate**	Do not apply by aircraft. Offers residual control for up to 21 days. Maximum 2 consecutive applications and no more than 4 applications per season.
Cyantraniliprole	28	Unknown	**Moderate**	Suppression only. Maximum 2 applications per season.
Spirotetramat	23	Unknown	**Moderate**	Use high rate for high pest pressure, increased residual protection or when crops are well advanced. Do not re-apply within 14 days. Maximum 2 applications per season.
Thiamethoxam	4A	Cross-resistance between all the neonicotinoids	**Moderate**	Use with organosilicone surfactant as per label. Maximum of 2 non-consecutive applications per season.
Sulfoxaflor	4C	No resistance	**Moderate**	Use higher rate under heavy aphid infestations and/or when water volume is reduced such as aerial application. Maximum 4 applications per season.
Flonicamid	9C	Unknown	**Moderate**	Apply to to developing populations before honeydew is evident or aphid damage occurs. Ensure good coverage. Maximum 2 applications per season.
Emamectin benzoate/ acetamiprid	6/4A	Cross-resistance between all the neonicotinoids	**Moderate**	Use the high rate under sustained heavy aphid pressure. Maximum 2 applications per season (note maximum of 3 applications in total of Group 6 insecticides). Use organosilicone adjuvant as per label.
Acetamiprid	4A	Cross-resistance between all the neonicotinoids	**Moderate**	Ensure good coverage. Apply with 0.2% Incide® penetrant. Use high rate for sustained heavy pressure. Do not use as first foliar if neonicotinoid seed treatment used. Maximum 2 non-consecutive applications per season.
Clothianidin	4A	Occasional – low. Cross-resistance between all the neonicotinoids	**Moderate**	Apply when aphid numbers are low and beginning to build. Do not use as first foliar if neonicotinoid seed treatment used. Maximum 2 applications per season.
Imidacloprid	4A	Cross-resistance between all the neonicotinoids	**Moderate**	Add Pulse® penetrant or equivalent organosilicone surfactant as per label. Do not use as first foliar if neonicotinoid seed treatment was used. Apply early in the establishment of an aphid infestation. Maximum 2 applications per season.
Dimethoate	1B	Widespread resistance in all cotton growing regions. Cross-resistance to pirimicarb/phorate	**High**	Do not use where resistant strains are present. Maximum 2 applications per season.
Chlorpyrifos	1B	Occasional – low	**High**	Use higher rates on heavy infestations. Maximum 3 applications per season.

Phorate (1B) is also registered for application at planting (Qld, NSW and WA only).
#For all control options always refer to the label for instructions.
*For more details about impact on beneficial insects (including bees), refer to Table 6 in this guide.

Armyworm

Cluster caterpillar – *Spodoptera litura*
Lesser armyworm – *S. exigua*
Fall armyworm – *S. frugiperda*

Armyworm species found in cotton have a wide host range. Moths are a mottled grey-brown and lay clusters of eggs that they cover with scales, giving a 'furry' appearance. Individual larvae (particularly up to medium size) are often mistaken for *Helicoverpa*.

Cluster caterpillar has been a pest of cotton in Northern Australia since pre-commercial crop testing at Kununurra in the 1950s. During commercial cropping in the 1960s and 1970s, cotton growers were challenged with a complex of caterpillar species including *S. litura*, with the combined spraying of these pests leading to resistance in *Helicoverpa armigera*.

Larger larvae have three lengthwise yellow/orange stripes, two bands of distinctive dark half-moon shapes along their back and a row of dark spots along their sides. Primarily leaf feeders, they can attack fruiting structures, particularly open flowers. However, larvae rarely penetrate the bolls like *Helicoverpa* spp. do in conventional cotton.

Spodoptera species have a naturally higher tolerance to Bt endotoxins than *Helicoverpa* and although there is low and ongoing larval survival, the advent of Bollgard 3 (which is currently only registered in Australia for control of *Helicoverpa*) appears to have reduced the frequency of *S. litura*. However, when crops are subjected to environmental stress (e.g. several weeks of extreme heat with cloudy weather, or plant self-shading in the canopy), significant populations of *S. litura* are able to survive.

Research is underway to understand the feeding behaviour of *S. litura* larvae in Bollgard 3 crops and assess potential damage.

Lesser armyworm (also known as beet armyworm) can be present in low numbers in young cotton, occasionally defoliating seedlings, but it generally prefers weed hosts. Larvae are green to brown, with a white stripe along each side. Feeding by groups of larvae is often associated with webbing and frass.

Fall armyworm (FAW) is a migratory tropical species that was first detected in Australia in early 2020, and has since spread to many crop production districts. Although FAW has the capacity to feed on cotton, it appears to prefer grass species with whorls (such as maize and sorghum), and to date no impact on cotton crops has been reported in Australia. Large larvae have plump, smooth skin, a white inverted Y on the head, and four dark raised dots arranged in a square on the second last segment.

For chemical control options for armyworm species, search the PubCRIS and Permits databases at the APVMA website portal.apvma.gov.au/pubcris.


Lesser armyworm. Melina Miles, Qld DAF


Cluster caterpillar feeding on cotton flower.
Sharna Holman, Qld DAF


Fall armyworm. Melina Miles, Qld DAF


Cluster caterpillar eggs. Paul Grundy, Qld DAF

Helicoverpa

Helicoverpa armigera (cotton bollworm)
H. punctigera (native budworm)

In conventional cotton, helicoverpa larvae are major pests and can dramatically reduce yield. Widespread industry adoption of Bt cotton has significantly reduced the need for insecticidal control, however larvae can be present even in Bollgard 3 crops, and the risk of resistance requires careful management.

Damage symptoms

Larvae attack all stages of plant growth. In conventional (non-Bt) cotton, feeding can result in tipped-out seedlings, shedding of squares and small bolls, abnormal development and boll rot in maturing bolls. In Bt cotton, 15% of the field area may carry helicoverpa larvae at or above the recommended threshold levels at some point during peak to late flower, with chewing damage mostly confined to fruit, potentially leading to yield loss.

Sampling

Sample at least 30 plants or 3 separate metres of row for every 50 ha of crop. More samples may be needed in variable fields (e.g. lush areas in head ditches are more attractive to insects). Visually check the whole plant at least twice a week from seedling emergence until 30-40% open bolls in both conventional and Bt cotton crops. Note the life stage for use in management decisions:

STAGE		DESCRIPTION
White egg	WE	pearly white
Brown egg	BE	off-white to brown
Very small larvae	VS	0-3 mm
Small larvae	S	3-7 mm
Medium larvae	M	7-20 mm
Large larvae	L	>20 mm

Eggs are laid on plant terminals, leaves, stems and fruit bracts and larvae can be present on leaves or stems, or inside terminals, squares, flowers and bolls. Note the species where possible, and also assess beneficial insect numbers while sampling. Once squaring begins, also note fruit retention or fruiting factors, to gauge the level of crop damage.

Thresholds

Larval thresholds are preferred as not all eggs hatch (and peak egg lays in Bt cotton do not correspond to yield imapct). Early season eggs are particularly prone to desiccation and being washed/blown from small plants, and parasitism and predation can also dramatically reduce survival of eggs and early larval instars.

In Bt crops, exclude the VS (<3 mm) from your counts. Where small (3-7 mm) larvae are observed on Bt cotton, consecutive checks are essential for decision making. Helicoverpa must feed in order to ingest the Bt toxin. If the number of small larvae are above threshold, chances are that a large proportion of these will ingest a sufficient dose of the toxin and die before the next check.

Key beneficials

STAGE	PREDATORS	PARASITOIDS
Eggs	red and blue beetle*, damsel bug*, lacewings*, ants, yellow night stalker spiders, ladybird beetles, apple dimpling bugs	*Trichogramma* spp., *Telenomus* spp.
Larvae	glossy, brown* and predatory shield bugs, big-eyed bug*, damsel bug*, assassin bug*, red and blue beetle*, lacewings*, common brown earwig, lynx, tangleweb and jumping spiders; wolf spiders and carabids can attack late instar larvae	*Microplitis demolitor*, orange caterpillar parasite, two-toned caterpillar parasite
Pupae	common brown earwig	banded caterpillar parasite
Moths	orb-weaver spiders and bats	

*Species for use in the beneficial to pest ratio formula.

Using the beneficial to pest ratio

The beneficial to pest ratio can be applied in conventional and Bt cotton, and is calculated as:

$$\frac{\text{Total beneficials*}}{\text{Helicoverpa (eggs – (\% parasitised) + VS + S larvae)}}$$

At least 30 plants or 3 to 4 separate metres of row by visual sampling or 20 metres of row by suction sampling is needed in order to use the ratio. Only include the key beneficial insects (marked with an asterisk) and at least three of the six key beneficial species need to be present.

The level of egg parasitism should be estimated and deducted from the total number of helicoverpa eggs, as parasitism rates can vary greatly from farm to farm, region to region and from season to season, although generally levels decline as the season progresses. To assess parasitism, keep collected brown eggs at 25°C until they hatch (healthy) or turn black (parasitised).

When the beneficial to pest ratio is 0.5 or higher, the helicoverpa population should remain below 2 larvae/m.

Insecticide selection

Insecticides registered for the control of helicoverpa in cotton are presented in Table 8. The use of more selective insecticide options will help to conserve beneficial insects (see Table 6). Be aware of resistance status in *H. armigera* and follow the insecticide resistance management strategy (IRMS).

	SEEDLING TO FLOWERING	FLOWERING TO CUT-OUT	CUT-OUT TO 15% OPEN BOLLS	15% TO 40% OPEN BOLLS
Conventional	2 VS-S larvae/m OR 1 M-L larvae/m	2 VS-S larvae/m OR 1 M-L larvae/m OR 5 brown eggs/m	3 VS-S larvae/m OR 1 M-L larvae/m OR 5 brown eggs/m	5 VS-S larvae/m OR 2 M-L larvae/m OR 5 brown eggs/m
	SEEDLING TO 40% OPEN BOLLS			
Bt cotton	2 S larvae/m (in 2 consecutive checks) OR 1 M-L larvae/m			

Note: these thresholds assume that mixed populations of H. armigera and H. punctigera are present.

Normal eggs (left) and parasitised eggs (right). B. Scholtz

Resistance in *H. armigera*

Bt cultivars may have lowered the priority of this pest in the minds of many people, however maintaining effective control is critical for conventional cotton and other crops such as pulses. Large plantings of Bt cotton do NOT change the overall frequencies of insecticide resistance genes in the helicoverpa population and are unlikely to influence the rate at which *H. armigera* will develop resistance to conventional insecticides if significant selection pressure is imposed.

An industry-wide resistance surveillance program, implemented by NSW DPI and supported by CRDC and GRDC, indicates resistance to indoxacarb is generally about 6%, although it has reached much higher in some regions, particularly those with minimal overwintering as indoxacarb resistant *H. armigera* are less likely to survive diapause. Chlorantraniliprole and spinetoram resistance has been detected in some regions but is currently low and there has been no recent detection of emamectin benzoate resistance. The industry has ceased monitoring broad-spectrum chemistry for resistance. However, field failures are likely for synthetic pyrethroids and carbamates.

Insecticide use for control of *H. armigera* in both conventional and Bt cotton crops should be based on relevant thresholds and the IRMS (see pages 64-65). It is also important to adhere to the resistance management strategy (RMS) for the grains industry.

ipmguidelinesforgrains.com.au/ipm-information/resistance-management-strategies/#heli

Pupae busting should be a priority post-harvest operation on all cotton farms. For Bt cotton crops, follow the pupae busting guidelines in the Bollgard Resistance Management Plan (RMP).

Several genes are currently present in field populations of *H. armigera* that confer high-level resistance to the discrete proteins in Bollgard cotton, however none confer cross-resistance to the other proteins. Individuals must carry two copies of these resistance genes to survive consumption of the proteins within Bollgard 3, and the vast majority only carry one copy. However, the continued efficacy of Bt cotton relies on how the industry manages its refuges and implements the other elements of the RMP. For further details, including information about recent changes in the frequency of Bt resistance genes in *H. armigera*, refer to the Bollgard 3 RMP for cotton.

H. armigera larvae (left) have pale hairs compared to darker hairs on ***H. punctigera*** larvae (right). Hugh Brier, Qld DAF
More detailed information on identifying helicoverpa is available at https://thebeatsheet.com.au/key-pests/helicoverpa-identification-and-behaviour

Resistance in *H. punctigera*

Resistance to insecticides has only rarely been detected. In conventional cotton, the tendency for *H. punctigera* to occur in mixed populations with H. armigera often limits insecticide control options to those that also control *H. armigera*.

Several genes are currently present in field populations of *H. punctigera* that confer resistance to the discrete proteins in Bollgard cotton, however none confer cross-resistance to the other proteins. Individuals must carry two copies of these resistance genes to survive consumption of the proteins within Bollgard 3, and the vast majority only carry one copy. However, the continued efficacy of Bt cotton relies on how the industry manages its refuges and implements the other elements of the RMP. For further details refer to the Bollgard 3 RMP for cotton.

Overwintering habit

In colder regions, *H. armigera* over-winters in cotton fields as diapausing pupae (triggered by falling temperatures and shortening day length) that can contribute to carry-forward of resistance from one season to the next. The proportion of pupae entering diapause can reach over 90% in late April – early May, depending on the region. Emergence from diapause (based on rising soil temperature) usually occurs over a 6 to 8 week period, beginning in mid to late September in most regions.

Historically, *H. punctigera* was rarely found late season and spring migrations from inland Australia were thought to be the main source of moths in eastern production areas. However, more recently this species has been persisting throughout the whole cotton-growing season, with significant overwintering now taking place. Migration flights also appear to have lessened, reducing the natural genetic dilution factor. Research continues to investigate whether *H. punctigera* is more likely to develop resistance in the future.

Alternative hosts

H. armigera can be found in both broadleaf and cereal hosts. Spring host crops include faba bean, chickpea, safflower, linseed, canola, pastures and weeds. Summer host crops include soybean, mungbean, pigeon pea, sunflower, sorghum and maize, with a preference for flowering sorghum and maize crops.

H. punctigera moths are able to utilise a vast selection of host plants (mostly broad-leaved). While favourable weather and non-crop hosts such as daisies appear to be critical for the early successful survival, spring crops such as chickpea, canola, faba bean and linseed can be heavily infested by this species. Summer crop hosts include pigeon pea, sunflower and various grain legumes.

USEFUL RESOURCES:

CSIRO Agriculture and Food, Armidale
Sharon Downes 0427 480 967.

Qld DAF, Toowoomba
Paul Grundy 0427 929 172.

NSW DPI, Tamworth
Lisa Bird (02) 6763 1128.

TABLE 8: Control of *Helicoverpa* spp. (refer to label for target species)

MoA	MoA group	Resistance (*H. armigera*)	Overall impact on beneficials*	Comments#
Bacillus thuringiensis	11A	None detected	Very low	Restrictions apply (see Bt cotton Resistance Management Plan).
Helicoverpa NPV	31	None detected	Very low	Use alone or with compatible larvicide. Target egg hatching.
Paraffinic oil	UNM	None detected	Very low	Use a minimum of 80 L/ha of water. Apply only by ground rig before crop closure.
Magnet®	Attractant	None detected	Very low	Use with insecticides as per label instructions.
Indoxacarb	22A	Widespread – moderate	Low	Maximum 3 applications per season.
Clitoria ternatea extract	UNE	Unknown	Low	Ensure good coverage. Treatment effects may not be seen for 3 or more days. Target egg hatch and small larvae. Maximum 5 applications per season.
Amorphous silica	—	Unknown	Low	Target egg hatch. Best results are obtained from two sequential applications 6-7 days apart.
Chlorantraniliprole	28	Occasional – low	Low	Target brown eggs to 2nd instar larvae (before they become entrenched in squares, flowers and bolls). Use high rate for high pest pressure (>2 larvae/m) or increased residual protection. Maximum 3 applications per season.
Spinetoram	5	Occasional – low	Low	Use high rate for heavy infestations. Larvae >8 mm or feeding within bolls & squares may not be controlled. Maximum 2 applications per season.
Cyantraniliprole	28	Occasional – low	Moderate	Target eggs to 2nd instar larvae (before they become entrenched in squares, flowers and bolls). Maximum 2 applications per season.
Abamectin	6	Occasional – low	Moderate	Use the higher rate alone or the lower rate with a suitable mixing partner. Some labels indicate control of *H. punctigera* only. Maximum 2 applications per season.
Emamectin benzoate	6	Occasional – low	Moderate	Apply at or just prior to hatching. Use non-ionic surfactant as per label. Maximum 4 applications per season.
Emamectin benzoate/ acetamiprid	6/4A	Occasional – low Cross-resistance between all neonicotinoids	Moderate	Apply at or just prior to hatching. Use non-ionic surfactant as per label. Maximum 2 applications per season.
Methomyl	1A	Widespread – moderate	High	Do not reapply within 14 days. Higher rate may cause reddening of foliage. Do not apply during periods of plant stress. Maximum 2 applications per season.
Thiodicarb	1A	Widespread – moderate	High	Has both ovicidal and larvicidal activity. See label for details. Maximum 2 applications per season.
Alpha-cypermethrin	3A	Widespread – high	Very high	Use low rate for eggs or newly hatched larvae. Use higher rates for higher egg pressure or larger larvae. Maximum 1 application per season.
Bifenthrin	3A	Cross-resistance to all pyrethroids	Very high	Target egg hatch. DO NOT apply to larvae >5 mm. Use high rate for high pest pressure or increased residual protection. Field failures due to resistance are likely for *H. armigera*. Maximum 1 application per season.
Cypermethrin	3A	Widespread – high	Very high	See label for specific concentrations and higher rate situations. Maximum 1 application per season.
Deltamethrin	3A	Widespread – high	Very high	Use low rate as ovicide and high rates for small to medium larvae. Maximum 1 application per season.
Esfenvalerate	3A	Widespread – high	Very high	Use low rate when larvae are small and pressure is low. Maximum 1 application per season.
Gamma-cyhalothrin	3A	Widespread – high	Very high	Use low rate as ovicide and high rate when egg lay is heavy and/ or *H. punctigera* >10 mm and/or *H. armigera* <5 mm. Maximum 1 application per season.
Lambda-cyhalothrin	3A	Widespread – high	Very high	Use low rate as ovicide and/or for newly hatched larvae. Maximum 1 application per season.

#For all control options always refer to the label for instructions.
*For more details about impact on beneficial insects (including bees), refer to Table 6 in this guide.

Mealybugs

Phenacoccus solenopsis

Ratoon cotton stubs are a major source of solenopsis mealybug infestation in subsequent cotton crops. Mealybug populations surviving between seasons on volunteer cotton and weeds growing in and around the field are also significant sources of infestations.

Damage symptoms

Early infestation leads to distorted terminal growth, crinkled and bunchy leaves, and in severe cases, plant death. Later infestations can cause shedding of leaves, squares and small bolls, boll deformity and premature crop senescence.

Mealybug infestations up to the early boll setting stage have the potential to be highly damaging. Population densities of around 25, 110 and 150 mealybugs per plant in the seedling, squaring and early boll stages, respectively, appear to be sufficient to cause significant economic damage. Heavy infestations (>500 mealybug in the top 8 nodes at cut-out) will result in around 80% reduction in harvestable bolls.

Excreted honeydew is high in melezitose sugar, which is very sticky. It can render seed cotton un-ginnable and promotes the development of black sooty mould.

Sampling

Mealybugs can be present anywhere on the plant, but are most likely to aggregate on the underside of leaves and inside bracts of squares or bolls within the top 10 leaf nodes on the main stem. Mealybugs often appear to be more prevalent in plants that are stressed from lack of moisture, waterlogging and/or nitrogen deficiency, so include potentially stressed areas (e.g. tail drains) in your monitoring schedule. Investigate patches of stunted or dead plants for evidence of mealybugs. Drones may be useful in identifying hotspots.

Upon first detection, mark infested plants/spots. Continue to monitor regularly for mealybugs and key beneficials (lacewings, ladybird beetles and parasitoids) to provide information for ongoing management.

Solenopsis mealybug is best controlled through good crop destruction, farm hygiene and the conservation of naturally-occurring beneficial insects. Minimising impacts of pesticides on beneficial insects is critical for the cost effective control of this pest.

Strictly adhere to good farm hygiene principles and ensure everyone entering the farm practices Come Clean. Go Clean. Brush down clothing between fields and ensure farm equipment is cleaned down after entering fields with mealybugs.

What to do if you find them...

- Correct identification is important. Other mealybug species occasionally occur in cotton, but they are rarely damaging.
- Clearly mark infested plants/spots, as small infestations can be difficult to relocate.
- Look for the presence of natural enemies. Re-check infested plants over time to see if natural enemies are impacting mealybug colonies.
- Come Clean. Go Clean. Avoid spreading mealybugs via people and machinery.

Solenopsis mealybug adults and crawlers. Tonia Grundy, Qld DAF

Mealybug predators: Cryptolaemus ladybird beetle larva (left) and lacewing larvae (right), can look very similar to mealybugs. Zara Hall and Paul Grundy, Qld DAF

Beneficial insects are highly effective in keeping mealybug populations in check. Chemical insecticides should be used for mealybug control only in very specific circumstances. Note that no insecticide option provides 100% control, and mealybug management over the life of the crop is dependent on beneficials. Good coverage is critical for effective control of mealybugs with insecticides. Higher water volumes may increase efficacy, depending on plant size. Sequential applications 10-14 days apart may be required to achieve a satisfactory level of mealybug control with some insecticides. Refer to the product label for directions. For management advice in specific situations or circumstances, contact the CottonInfo team.

Management options until early flowering

Mealybug infestation carries a significant risk of plant death during early development as the cotton plant is highly susceptible and seasonal build-up of beneficial insects has not yet occurred. If there is a growing risk of mealybug infestation/damage, and insufficient beneficials are present, chemical intervention may be required.

Insecticidal options for specifically targeting mealybugs include sulfoxaflor, spirotetramat and buprofezin (Table 9). Consider the presence of other pests:

- If mirids are at or nearing threshold in a crop with mealybugs, use sulfoxaflor for mirid control as it is unlikely to flare mealybugs.
- If whitefly are present and at risk of being flared:
  - Spirotetramat (+ 3-5% oil v/v) is effective on mealybugs and has efficacy on SLW.
  - Buprofezin has suppressive effects on mealybugs and will reduce SLW.

Management options from late flowering to defoliation

Mealybug hotspots mid to late season cotton may be indicative of failure to detect and manage infestations early, and/or a consequence of beneficial disruption. In the absence of other pests, insecticidal control of mealybugs is generally not recommended. Allow beneficials to build and control mealybugs.

If mirids and/or SLW are present, aim to control them without flaring mealybugs by following the product choices recommended above.

AVOID USE OF BROAD-SPECTRUM PRODUCTS.

End-of-season recommendations for a mealybug infested crop

- Prior to crop harvest, destroy all non-crop vegetation that may harbour mealybugs (head, tail drains, sides) to minimise pest survival and carry-over to next crop.
- At harvest, pick infested fields last. If possible lift picker heads above mealybug hotspots or infested sections to reduce spread and avoid contaminated lint.
- After harvest, destroy crop residue thoroughly and root cut to a depth of at least 10 cm to minimise the survival of plant material that could harbour mealybugs.

Key beneficials

Predators – Lacewings, three banded ladybird beetles, white collared ladybird beetles, transverse ladybird beetles, red and blue beetles, cryptolaemus, smudge bugs and earwigs. Lacewings and three banded ladybird beetles are the most common and effective predators.

Parasitoids – The wasp *Aenasius bambawalei* parasitises adult females and is effective in suppressing populations.

Key features that influence survival and pest status

Mealybugs have a high reproductive rate and all hatched stages can cause damage. One female can produce hundreds of offspring; eggs hatch within an hour and take about two weeks to develop into adults. Mealybugs shelter in protected positions – in squares, bracts and under surfaces of leaves and their waxy coating is water repellent, making insecticide contact difficult. They can be spread in the field by wind, surface water runoff, people and farm equipment. Mealybugs disperse most readily as first instar 'crawlers', but all nymph and adult stages can move between plants by crawling.

Adults and large nymphs can survive for long periods without a host. The crawler stage can live for up to 6 days, and the third instar stage for up to 50 days without food or water.

Overwintering mealybugs can be found in the root zone of weed hosts. In spring, breeding and dispersal begins.

Three banded ladybirds are very effective mealybug predators. Paul Grundy, Qld DAF

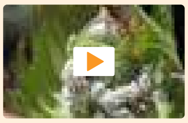
The pupal (top) and adult wasp (bottom) lifestages of ***Aenasius bambawalei***. Zara Hall, Qld DAF

Alternative hosts

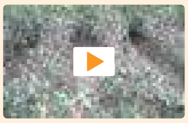
The solenopsis mealybug has a wide host range and has been recorded on pigweed, sowthistle, bladder ketmia, native rosella, vines (cow, bell and potato), crownbeard, stagger weed, marshmallow, verbena, raspweed, and volunteer cotton.

USEFUL RESOURCES:

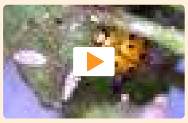
Qld DAF, Toowoomba
Paul Grundy 0427 929 172.



Solenopsis mealybug in cotton
youtu.be/vOTJ2XkAsug



Mealybug hotspots in cotton
youtu.be/r4aeGPcVHk0



What to do if you find a mealybug hotspot
youtu.be/pR7U_1ng71E

TABLE 9: Control of solenopsis mealybug

Active ingredient	MoA group	Overall impact on beneficials*	Comments#
Buprofezin	16	**Low**	Target early nymph stages. Ensure good coverage. Maximum 2 applications per season.
Spirotetramat	23	**Moderate**	Do not re-apply within 14 days. Maximum of 2 applications per season, however note that re-application presents a risk for SLW resistance management.
Sulfoxaflor	4C	**Moderate**	Ensure good coverage. Addition of an adjuvant may improve control.

#For all control options ALWAYS refer to the label for instructions.
*For more details about impact on beneficial insects (including bees), refer to Table 6 in this guide.

Mirids

Green mirid – *Creontiades dilutus*
Brown mirid – *Creontiades pacificus*
Apple dimpling bug (yellow mirid) – *Campylomma liebknechti*

Green and brown mirids are about 12 mm long and look similar, but brown mirids have darker pigmentation. Green mirids are usually more abundant in cotton and they move into crops earlier, so they do more damage during squaring. Both species cause similar damage at the boll stage.

Apple dimpling bug are around 3 mm long and can damage small squares (at about ¼ of the rate of adult green mirids), however they are also a predator of mites, silverleaf whitefly (all life stages) and helicoverpa eggs.

Damage symptoms

Mirid adults and nymphs cause blackening and death of plant terminals and mid-season damage to squares and small bolls including blackening of pinhead squares and square shedding. Older (4th and 5th) instars can cause as much damage as adults.

Square loss depends upon mirid feeding patterns (which can change in response to factors such as temperature and the presence of natural enemies) and size of the squares. Therefore, consider both square retention and mirid numbers when making a control decision. Feeding on small or medium sized squares is very likely to directly damage the developing ovules and anthers, resulting in shedding. Feeding on large squares may not result in shedding but still damage the developing ovules, resulting in poor fertilisation and seed development in several locks. The resulting misshapen bolls are commonly referred to as being 'parrot beaked', a deformity that can also be caused by high temperatures, hence good pest monitoring is important to avoid unnecessary sprays.

Cut bolls open to determine if black spots correspond to internal lock damage. Paul Grundy, Qld DAF

Green mirid adult (top) and nymph (bottom).
C. Mares & M. Khan

Bolls that are damaged during the first 7-10 days of development may be shed. Bolls damaged between 10-20 days old will be retained but may not develop normally resulting in one or more stunted, brown locks. Apart from reduced weight, damaged bolls may not open sufficiently to enable efficient spindle picking. Black, shiny spots on the outside of bolls can indicate feeding sites for a number of species (mirids, green vegetable bugs and pale cotton stainers), however environmental conditions can also give rise to similar looking marks. Cut bolls open with a sharp knife and inspect the underlying tissue to confirm whether the boll marks are the result of feeding damage. Warty growths can often be found beneath the spots or there might be light brown discolouration of developing lint.

Once bolls exceed 20 days of development, susceptibility of the developing seed and lint to feeding damage reduces as fibre elongation ceases and seed is located deeper within the boll relative to the boll wall.

Sampling

Mirids are mobile and are easily disturbed so be careful when sampling to ensure numbers are not underestimated (discussed later in this section). It is also important to distinguish between nymphs and adults. The presence of nymphs can indicate that a mirid population has become entrenched.

Once squaring commences, regularly assess fruit retention. Monitor for all types of plant damage potentially caused by feeding such as tip damage (early-season) and boll damage (mid-season).

Sample at least twice a week to identify sudden changes in abundance that may indicate rapid influxes of adults. The greatest risk from mirids is through the period of peak fruit production, from first flower until first open boll.

Methods and sample size

Sample throughout the field to gain a reliable estimate of overall mirid density. Visual inspection of whole plants, using a beat sheet or sweep netting, all give comparable estimates of mirid abundance when plants are small. Once the crop reaches 9-10 nodes the efficiency of visual whole plant sampling declines because the plants are too big to sample quickly and effectively. Therefore from 10 nodes onwards, a beat sheet is the recommended option.

When beat sheeting, place the sheet against the base of a row of plants and drape across the furrow and up over the adjacent row. Vigorously shake a section of row with a 1 m stick onto the area of beat sheet lying across the furrow. Quickly count the number of adult mirids dislodged onto the beat sheet. Look also for mirid nymphs, which can easily be confused with other small green insects. The easiest way to identify them is by their noticeably long antennae and fast movement across the beat sheet.

Accurate estimation of mirid numbers is closely linked to sample size – more is better. A minimum of 12-15 beat sheets per management unit (approximately 50 ha) should provide reasonable estimates of the mirid density.

If using a standard (380 mm diameter) sweep net, collect 20 sweeps along a single row of cotton per sample. At least 6 sweep samples are required per management unit to achieve a good estimation of mirid numbers.

It is essential to also monitor fruit retention and signs of fruit damage to assess if mirid presence is affecting the crop. Note that other stresses (e.g. day or night high temperatures or cloudiness) can also cause square and young boll shedding. If mirid damage is suspected, a sample of bolls from multiple locations should be cut open and checked for internal damage. For more information, see the retention section on pages 13-14.

Thresholds

Economic thresholds are based on when the amount of damage by a given population of pests will exceed the costs (product and application) associated with controlling that pest. More difficult to determine are the other costs that may arise later as a result of the control operation (e.g. the flaring of secondary pests such as silverleaf whitefly). Cheap broad-spectrum products may appear to justify low pest control trigger points, but it may be more cost-effective overall to delay control until mirid numbers are higher and use a more expensive but selective product option. Alternatively, the use of a more selective option at a particular pest threshold could be considered on the basis of potential future savings on consequent controls or secondary pest control.

Mirid thresholds take into account mirid damage in high-yielding Bollgard 3 crops and give the user greater flexibility in determining the relative economics of pest control. They are based on thorough sampling twice weekly, the cost of control (product and application costs/ha), crop stage and commodity value.

Research suggests that a density of 1 mirid per square metre at squaring could result in potential loss of about 0.026 bales/ha, while at flowering this loss could be around 0.021-0.042 bales/ha/mirid. When the estimated cost of mirid control is $45/ha, and cotton prices are at $550/bale, using a threshold of 3 mirids/m up until flowering aims to prevent an economic yield loss (see Table 10).

Deciding when to spray

Sometimes few mirids seem to be causing a lot of damage, while at other times, large populations of mirids cause little damage. When making a mirid management decision, it is also important to consider:

- **The crop's ability to compensate for damage.** This varies with the season length and the plant's development stage. Well-managed crops with optimised agronomic inputs have a very high capacity for compensation to overcome fruit loss during squaring, but this reduces as the crop progresses through early flowering. Ultimately the capacity for compensation depends on the extent of damage and crop stage, and how these two factors relate to available season length and availability of additional resources such as soil water.
- **Regional differences.** Shorter season areas have a smaller window for crop compensation, particularly after flowering commences. Severe early season damage (tipping and/or fruit loss) may also cause a maturity delay. In regions with shorter seasons, additional caution may be required when managing mirids e.g. using lower thresholds or higher levels of retention.
- **Other factors** that may influence the likelihood of mirid damage include the presence and behaviour of beneficials (predation and disruption of mirid feeding behaviour), the abundance of alternative host plants, the presence of other pests (mirids may preferentially feed on insect eggs), and temperature effects. Other factors that might also be relevant for mirid management include nymphal stages, the influence of time of day on sampling accuracy, previous spray history, recent weather events or trends, and the likelihood that secondary pests (e.g. whitefly or mealybug) might be flared by ongoing control practices.

The first step is to confirm that the damage in the crop is actually caused by mirids (or other sucking pests) and not environmental factors. Low temperatures can reduce the production of squares by the plant while lack of water, high temperatures, or cloudiness may cause the plant to shed squares. Exposure of fruit to high temperatures may cause infertility, resulting in beaked bolls. If dried, brown squares are shed in conjunction with low mirid numbers, it is likely they are shed due to other stresses. In the case of heat stress, shed squares tend to also have a wilted petiole. As bolls develop through the season, it is normal to see black spots on the fruit that are unrelated to mirid damage. Cutting the fruit and checking the inner capsule wall for piercing will confirm if the spot was due to mirid feeding or caused by aging.

Table 10 provides a checklist to assist with making the decision to spray based on economic thresholds. The 'Cost of control' should incorporate not only the cost of the insecticide and application, but also likely longer term costs, such as triggering other pests and the need for subsequent sprays. Each farm will vary in this respect so consider your unique system.

Key beneficials

Damsel bugs and larger lynx spiders, yellow night stalkers and jumping spiders attack mirid adults. These predators also attack smaller instars, as do big-eyed bugs and smaller instars of these spiders. Predatory shield bugs may also attack mirids. None of these beneficials are considered to be specialist mirid predators, however their presence can provide an overall reduction of mirid numbers and reduce the survival of developing nymphs.

Selecting an insecticide

Insecticide products registered for the control of mirids in cotton in Australia are presented in Table 11. The use of more selective insecticide options will help to conserve beneficial insects (see Table 6 on pages 20-21). A lower rate of indoxacarb mixed with salt provides similar efficacy against mirids and stink bugs to the full rate alone but with reduced negative effects on beneficials.

If using reduced rates, remember that residual efficacy might be reduced and if an influx of adults has had time to deposit eggs within the crop, hatching nymphs may escape control and require a follow up treatment 5-10 days later, potentially negating any benefits. Be cautious when considering reduced rates where populations have built up over time to reach threshold levels, as a mixed population of adults and eggs is more likely to exist compared with treating sudden influxes.

Resistance profile

Mirids are not known to have developed resistance to insecticides in Australian cotton, however they are difficult to bioassay. It is possible that resistance could develop and the principles underlying the IRMS should be followed in making mirid management decisions.

Many of the products registered for mirid control in cotton are also registered for the control of other pests. It is critical that mirid management decisions also consider sub-threshold populations of other pests that are present in the field, as application against mirids will also select for resistance in these other pests. For example a number of neonicotinoid (Group 4A) insecticides (acetamiprid, clothianidin, dinotefuran) could cause resistance to aphids and silverleaf whitefly. Any decision to use an additional active ingredient (either in a co-formulation or a mix) should be threshold-based. Not only can additional active ingredients be unnecessarily disruptive, but they can lead to resistance. For example use of abamectin (Group 6) when treating mirids has caused high-level resistance in mites.

Overwintering habit

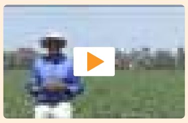
Mirids survive on weeds and native plant hosts surrounding cotton fields. They also breed on native hosts in inland (central) Australia in winter and can migrate to cotton growing areas in spring in a similar way to *Helicoverpa punctigera*. Considering whether there are many local hosts or if there has been inland rain (and therefore an abundance of inland hosts), can help with IPM planning for heavy pressure seasons.

Alternative hosts

Other crop hosts include soybean, mungbean, pigeon pea, lucerne, safflower and sunflower. It is known that mirids migrate between these crops. Weed hosts include turnip weed, Noogoora burr, yellow vine, variegated thistle and volunteer sunflowers.

USEFUL RESOURCES:

NSW DPI, Tamworth
Lisa Bird (02) 6763 1128.



Mirids in cotton:
1. Identification & damage
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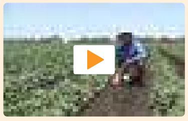

Mirids in cotton:
2. Sampling & management
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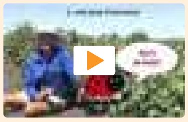

'Soft' options for mirids
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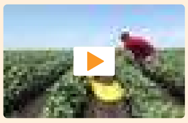

Using a beat sheet in cotton
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TABLE 10: Mirid thresholds

Economic factors		Thresholds (adults or nymphs/m)	
Product value	**Cost of control (1:1 cost benefit)**	**Planting to 1 flower/m**	**Flowering to 1 open boll/m**
$450	$15	1.5	1
$550		1	0.5
$650		1	0.5
Consider reducing the thresholds if:		• No plant compensation time (e.g. short, cool season) • <40% retention up to first flower • >50% light tip damage (black embryo leaves within terminal) • >20% heavy tip damage (terminal and 2-3 nodes dead) • <60% retention first flower to 4 NAWF • >10% boll damage	
Economic factors		**Thresholds (adults or nymphs/m)**	
Product value	**Cost of control (1:1 cost benefit)**	**Planting to 1 flower/m**	**Flowering to 1 open boll/m**
$450	$45	4	2.5
$550		3	2
$650		2.5	1.5
Consider raising the thresholds if:		• Time for plants to compensate (e.g. long, warm season) • Many beneficials • High levels of retention (~80%) • High threat of whitefly damage (raises the cost of control)	
Economic factors		**Thresholds (adults or nymphs/m)**	
Product value	**Cost of control (1:1 cost benefit)**	**Planting to 1 flower/m**	**Flowering to 1 open boll/m**
$450	$60	5	3
$550		4	2.5
$650		3.5	2

The thresholds are based on beat sheet sampling, however they are also applicable to sweep net sampling. Visual sampling is not recommended when mirid densities are low. In high mirid density situations, visual thresholds will be approximately half of the corresponding thresholds for beat sheet sampling.

TABLE 11: Control of mirids

Active ingredient	MoA group	Overall impact on beneficials*	Comments#
Paraffinic oil	UNM	Very low	Use low rate for suppression if <0.5 mirids/m. If population reaches 0.5 mirids/m, use high rate or apply 2 successive low rate sprays not more than 7 days apart.
Clitoria ternatea extract	UNE	Low	Ensure good coverage. Maximum 5 applications per season. Treatment effects may not be seen for 3 or more days. A repeat application may be required at 14-20 days if conditions favour pest development.
Indoxacarb	22A	Low	If populations are high, may only achieve supression. Maximum 3 applications per season. A lower rate with salt can be used for controlling green mirids ONLY. Limited residual activity.
Sulfoxaflor	4C	Moderate	Use lower rate when infestation is predominately nymphs. Maximum 4 applications per season.
Fipronil	2B	Moderate	Ensure thorough coverage. Use higher rate under sustained heavy pressure. May take 3-4 days to reach full effectiveness. Compatible with early season IPM. Avoid repeated use of this insecticide group.
Flonicamid	29	Moderate	Ensure good coverage. Maximum 2 applications per season.
Emamectin benzoate	6	Moderate	Suppression only. Target developing populations (nymphs). Use non-ionic surfactant as per label. Maximum effect may take 5 to 7 days. Maximum 2 applications per season.
Acetamiprid	4A	Moderate	Apply with 0.2% Incide® penetrant. If populations are high, may only achieve supression. Maximum 2 applications per season.
Emamectin benzoate/ acetamiprid	6/4A	Moderate	Use higher rate on heavier populations and for longer residual control. Use non-ionic surfactant as per label. Maximum 2 applications per season.
Clothianidin	4A	Moderate	Maximum 2 applications per season.
Imidacloprid	4A	Moderate	Do not use as first foliar if neonicotinoid seed treatment was used. Maximum 2 applications per season.
Dinotefuran	4A	Moderate	Performance can be reduced in stressed crops, when senescing late season, or when pests are not actively feeding in the upper crop canopy. Maximum 2 applications per season. Do not reapply within 14 days.
Dimethoate	1B	High	Do not use where resistant strains are present. Maximum 2 applications per season.
Gamma-cyhalothrin	3A	Very high	Maximum 1 application per season.
Lambda-cyhalothrin	3A	Very high	
Alpha-cypermethrin	3A	Very high	Use high rate for high pest pressure or increased residual protection. Maximum 1 application per season.
Bifenthrin	3A	Very high	
Deltamethrin	3A	Very high	Suppression only. Maximum 1 application per season.

Phorate (1B) is also registered for mirid suppression when applied at planting (Qld and WA only).
#Target pest is predominantly green mirid (*Creontiades dilutus*). For specific species registrations and all other control options ALWAYS refer to the label for instructions.
*For more details about impact on beneficial insects (including bees), refer to Table 6 in this guide.

Mites

Two-spotted spider mite – *Tetranychus urticae*
Bean spider mite – *T. ludeni*
Strawberry spider mite – *T. lambi*
Broad mite – *Polyphagotarsonemus latus*

Two-spotted spider mite is the main pest species; other spider mite species seldom cause economic damage, even in high numbers. In recent years strawberry spider mite has become more common, and the difference in damage potential means that correct identification of the species present is crucial for informed management decisions.

Broad mites are a sporadic pest of cotton. They are extremely small, translucent and are very difficult to see even with a x 20 hand lens. It is best to focus on perceiving movement rather than spotting individual mites.

Other mite species, including blue oat mite, redlegged earth mite and brown wheat mite occasionally occur on seedling cotton in southern areas.

Damage symptoms

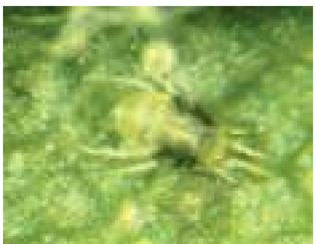
Mites feed on the underside of leaves but the damage symptoms differ markedly between species.

Two-spotted mite damage creates brownish areas on the lower leaf surface, usually starting at the junction of the petiole and leaf blade or in leaf folds, that show up as red patches on the upper surface. At high mite densities, leaves become completely red and fall off.

Bean spider mite damage results in white, intensely stippled areas on the lower leaf surface, but there is generally no reddening of the upper surface. Severe damage may result in some leaf shedding.

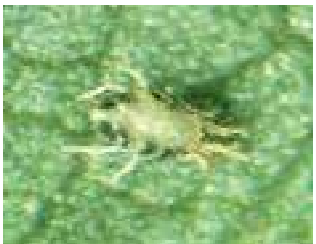
Strawberry spider mite can be very abundant (>90% of plants infested) but rarely, if ever, affects yield. Damage is a light, sparse stippling or white dots on the underside of the leaf. There is generally no reddening of the upper leaf surface.

Broad mite infestations can resemble herbicide damage. Leaves may distort, develop shiny undersides and become hard or brittle.



Two-spotted mite with egg (mite is 0.5 mm long). Lewis Wilson

Bean spider mite. 0.5 mm. M. Hill



Strawberry spider mite. 0.3 mm. C. Mares

Male carrying female broad mite. 0.2 mm. T. Grundy

The top and underside of leaves showing two-spotted spider mite damage (left) and strawberry spider mite damage (right). Carlos Trapero Ramirez, CSIRO

Leaves damaged by broad mites become brittle with shiny 'wet' undersides. Tonia Grundy, Qld DAF)

Sampling spider mites

Presence/absence sampling allows many plants to be sampled quickly, increasing the likelihood of finding mites if they are present. Monitor at least weekly from seedling emergence to 20% open bolls, and more frequently if mite populations begin to increase, conditions are hot and dry, or sprays that impact natural enemy abundance are used.

Sampling protocol

1. Walk into the field about 40 m. Early in the season also sample near the field edges for incursions.
2. Take a leaf from the third, fourth or fifth main-stem node below the terminal. If the plant has less than three leaves, collect the oldest (or pull out whole plants).
3. Walk five steps and take a leaf from a plant on your opposite side. Repeat until you have 50 leaves.
4. Score each leaf by looking at the underside with a hand lens, firstly near the stalk, then scan the rest of the leaf. If mites of any stage (including eggs, which cannot be seen with the naked eye) are present, score the leaf as infested. Also look for fine webbing that protects the developing mite population.
5. Calculate the percentage of plants infested.

Repeat the above steps at several widely separated places in the field to allow for population variability. Depending on the field size, 4-6 sites are usually needed to obtain a good estimate of mite abundance in the field. It is helpful to plot the development of mite populations on a graph to allow changes in mite populations to be seen at a glance.

Determine the mite species present

Two-spotted spider mite is a pale yellowish-green with a dark spot on either side of its body. Diapausing two-spotted mites turn bright orange. Strawberry spider mite is also pale yellowish-green, but has three dark spots on each side (that may merge with age) and the adults are smaller. Bean spider mite is the same size as two-spotted mite but is dark red. Mixed life stages are usually present, making identification challenging, so also consider signs of damage (e.g. leaf reddening usually indicates two-spotted spider mite).

Thresholds for two-spotted mites

The thresholds and yield loss charts (page 42) have been developed for two-spotted mite specifically. Bean spider mite causes half the damage of two spotted mite, and strawberry spider mite does not cause significant damage.

A general threshold of 30% of plants infested is advocated through the bulk of the season (squaring to first open boll). Yield loss due to mites depends on when mite populations begin to increase and how quickly they increase. Use Table 12 to determine whether the rate of increase in two-spotted mite populations warrants control (adjust for bean spider mite if required). In general:

- **Seedling emergence to squaring:** Mites are normally suppressed by predators (particularly thrips) during this period. When more than 5% of plants are infested also count the numbers of mites on plants, and estimate the damage level (as a % of total leaf area per plant). Only consider a miticide if populations do not decline within 6 weeks (indicating that natural enemies are not providing sufficient control) or if damage in young cotton plants exceeds 20% of leaf area.
- **Squaring to first open boll:** Implement control if mite populations increase at greater than 1% of plants infested per day in two consecutive checks, or if more than 30% of plants are infested.
- **First open bolls to 20% open bolls:** Control is only warranted if mites are well established (greater than 60% plants infested) and are increasing rapidly (faster than 3% per day).
- **Crop exceeds 20% open bolls:** Control is no longer warranted.

Using the yield reduction charts

A simple relationship based on the rate of population increase and the time remaining until defoliation allows a quick-reference prediction of yield loss from two-spotted spider mites in various regions (Table 12). Calculate the rate of increase of the mite population by dividing the change in the percentage of plants infested between consecutive checks by the number of days between the checks. For example, if a field had 10% of plants infested a week ago and 24% infested now, this gives a rate of increase of 2% of plants infested per day. To use the table:

1. Find the section or rows that is closest to your crop's rate of development.
2. Look at the section of columns that is closest to the current infestation level of the field (i.e. 10, 30 or 60%).
3. Select the column with the rate of increase closest to that of the mite population in the field.
4. Look down this column to the value that corresponds with the current age of the crop to get the predicted percentage yield loss that the mite population is likely to cause if left uncontrolled.

Note that these charts only provide a guide for potential yield losses caused by mites. You will also need to consider crop vigour, other pests (if the control spray may flare mites) and the environmental conditions (e.g. mite populations develop faster in hot dry conditions). The effect of beneficials is built-in as high predation on mites will result in lower rates of mite population growth and less risk of yield loss.

Key beneficials

Predators of mites include thrips, minute two-spotted ladybird beetle, mite-eating ladybird beetle, damsel bug, big-eyed bug, brown lacewing adults, brown smudge bug, apple dimpling bug, minute pirate bug, predatory mites and tangleweb spiders.

Once cotton is ~8-10 nodes, thrips cease to be a seedling pest and become important predators of mites. Where thrips are preserved, they can provide sustained suppression of mite populations below damaging levels. Insecticide seed or furrow treatments at planting are likely to significantly impact thrip populations.

Selecting a miticide

Miticide products registered for the control of spider mites in cotton in Australia are presented in Table 13. There are currently no registrations for control of broad mites.

Mite infestations may increase after the application of some broad-spectrum insecticides used for *Helicoverpa* or mirid control, such as synthetic pyrethroids, fipronil, and organophosphates because key beneficial species are removed allowing resistant mite populations to flourish (see Table 6 for the impact of pesticides on key beneficials). If mite control is required, use a selective option to help conserve beneficial populations, in accordance with the IRMS (pages 64-65).

Resistance in mites

Two-spotted mite has a long history of developing resistance to miticides and resistance can be selected very quickly. Avoid consecutive sprays of the same miticide. If mite numbers rebuild after a miticide application, rotate to a product from a different chemical group. Abamectin resistance frequencies in cotton have been elevated in recent years. Insensitivity to diafenthiuron has also increased dramatically in some areas and is now at levels that will cause field failures. However, two-spotted mites remain largely susceptible to propargite and etoxazole. It is critical to avoid following up a field failure with a product from the same MoA group.

Overwintering habit and alternative hosts

While their lifecycle slows in cool temperatures, mites produce large numbers of offspring, especially as conditions warm up in spring. Spider mites have a wide host range and can survive through the year on a wide range of broad-leafed weeds. Controlling winter hosts will help reduce carry-over of mites between seasons. Preferred winter hosts include turnip weed, marshmallow, deadnettle, medics, wireweed and sowthistle. Alternative winter and spring host crops include safflower, faba bean and field pea. In summer, two-spotted spider mite can also attack sorghum, maize, pulses, sunflower and many horticultural crops.

Broad mites also have a wide host range, including many horticultural crop and ornamental species.

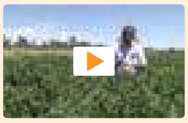
TABLE 12: Yield reduction caused by two-spotted spider mites

The charts below can be used to estimate the percentage of yield reduction, for different cotton growing regions.

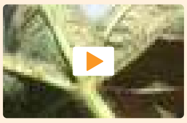
Days from planting	Current % plants infested with mites																				
	10							30							60						
	Observed rate of increase (%/day)							Observed rate of increase (%/day)							Observed rate of increase (%/day)						
	0.5	1	1.5	2	3	5	7	0.5	1	1.5	2	3	5	7	0.5	1	1.5	2	3	5	7
Warmer regions; planting to 60% bolls open in 134-154 days. Biloela, Bourke, Emerald, Macintyre, Mungindi, St. George, Theodore and Walgett																					
10	1.1	4.0	8.6	14.9	32.8	89.3	100.0	1.8	5.2	17.2	10.3	36.1	94.7	100.0	3.1	7.3	13.2	20.8	41.2	100.0	100.0
20	1.0	3.5	7.4	12.9	28.2	76.7	100.0	1.6	4.6	9.0	14.9	31.2	81.6	100.0	2.6	5.8	10.3	16.0	31.2	76.7	100.0
30	0.9	3.0	6.3	10.9	23.9	65.0	100.0	1.5	4.0	7.8	12.9	26.7	69.6	100.0	2.6	5.8	10.3	16.0	31.2	76.7	100.0
40	0.7	2.5	5.3	9.2	20.0	54.3	100.0	1.3	3.5	6.7	10.9	22.6	58.4	100.0	2.4	5.2	9.0	13.9	26.7	65.0	100.0
50	0.6	2.1	4.4	7.6	16.5	44.5	86.2	1.1	3.0	5.6	9.2	18.8	48.3	91.5	2.2	4.6	7.8	11.9	22.6	54.3	99.6
60	0.5	1.7	3.6	6.1	13.3	35.7	69.1	1.0	2.5	4.7	7.6	15.4	39.1	73.8	2.0	4.0	6.7	10.0	18.8	44.5	81.1
70	0.4	1.4	2.8	4.8	10.4	27.9	53.9	0.9	2.1	3.8	6.1	12.3	30.9	58.0	1.8	3.5	5.6	8.4	15.4	35.7	64.5
80	0.3	1.1	2.2	3.7	7.9	21.0	40.5	0.7	1.7	3.1	4.8	9.5	23.7	44.1	1.6	3.0	4.7	6.8	12.3	27.9	49.9
90	0.3	0.8	1.6	2.7	5.7	15.1	29.1	0.6	1.4	2.4	3.7	7.1	17.4	32.2	1.5	2.5	3.8	5.5	9.5	21.0	37.1
100	0.2	0.6	1.1	1.9	3.9	10.2	19.5	0.5	1.1	2.8	2.7	5.1	12.1	22.1	1.3	2.1	3.1	4.2	7.1	15.1	26.2
110	0.1	0.4	0.7	1.2	2.4	6.3	11.9	0.4	0.8	1.3	1.9	3.4	7.7	13.9	1.1	1.7	2.4	3.2	5.1	10.2	17.2
120	0.1	0.2	0.4	0.6	1.3	3.3	6.1	0.3	0.6	0.8	1.2	2.0	4.3	7.6	1.0	1.4	1.8	2.3	3.4	6.3	10.0
130	0.1	0.1	0.2	0.3	0.5	1.2	2.3	0.3	0.4	0.5	0.6	1.0	1.9	3.2	0.9	1.1	1.3	1.5	2.0	3.3	4.8
140	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.5	0.6	0.7	0.8	0.8	0.9	1.0	1.2	1.5
Average regions; planting to 60% bolls open in 161-170 days. Dalby, Gwydir, Lockyer, Lower Namoi																					
10	1.5	5.3	11.5	20.0	44.1	100.0	100.0	2.3	6.7	13.5	22.6	47.9	100.0	100.0	3.7	9.0	16.7	26.7	53.9	100.0	100.0
20	1.3	4.7	10.1	17.6	38.8	100.0	100.0	2.0	6.0	12.0	20.0	42.3	100.0	100.0	3.4	8.2	15.0	23.9	47.9	100.0	100.0
30	1.2	4.1	8.8	15.4	33.8	92.0	100.0	1.9	5.3	10.6	17.6	37.1	97.4	100.0	3.2	7.4	13.5	21.3	42.3	100.0	100.0
40	1.0	3.6	7.7	13.3	29.1	79.1	100.0	1.7	4.7	9.3	15.4	32.2	84.2	100.0	2.9	6.7	12.0	18.8	37.1	92.0	100.0
50	0.9	3.1	6.5	11.3	24.8	67.3	100.0	1.5	4.1	8.0	13.3	27.6	71.9	100.0	2.7	6.0	10.6	16.5	32.2	79.1	100.0
60	0.8	2.6	5.5	9.5	20.8	56.3	100.0	1.3	3.6	6.9	11.3	23.4	60.6	100.0	2.5	5.3	9.3	14.3	27.6	67.3	100.0
70	0.6	2.2	4.6	7.9	17.2	46.4	89.9	1.2	3.1	5.8	9.5	19.5	50.3	95.2	2.3	4.7	8.0	12.3	23.4	56.3	100.0
80	0.5	1.8	3.7	6.4	13.9	37.4	72.4	1.0	2.6	4.9	7.9	16.0	40.9	77.2	2.0	4.1	6.9	10.4	19.5	46.4	84.7
90	0.4	1.4	3.0	5.1	10.9	29.4	56.8	0.9	2.2	4.0	6.4	12.9	32.5	61.0	1.9	3.6	5.8	8.7	16.0	37.4	67.7
100	0.4	1.1	2.3	3.9	8.4	22.3	43.0	0.8	1.8	3.2	5.1	10.0	25.0	46.8	1.7	3.1	4.9	7.1	12.9	29.4	52.6
110	0.3	0.8	1.7	2.9	6.1	16.2	21.2	0.6	1.4	2.5	3.9	7.6	18.6	34.4	1.5	2.6	4.0	5.7	10.0	22.3	39.5
120	0.2	0.6	1.2	2.0	4.2	11.1	21.3	0.5	1.1	1.9	2.9	5.5	13.1	23.9	1.3	2.2	3.2	4.5	7.6	16.2	28.2
130	0.2	0.4	0.8	1.3	2.7	7.0	13.3	0.4	0.8	1.4	2.0	3.7	8.5	15.4	1.2	1.8	2.5	3.4	5.5	11.1	18.8
140	0.1	0.3	0.5	0.7	1.5	3.8	7.1	0.4	0.6	0.9	1.3	2.3	4.9	8.7	1.0	1.4	1.9	2.4	3.7	7.0	11.3
150	0.1	0.1	0.2	0.3	0.6	1.6	2.9	0.3	0.4	0.6	0.7	1.2	2.3	3.9	0.9	1.1	1.4	1.6	2.3	3.8	5.7
160	0.0	0.0	0.1	0.1	0.2	0.3	0.5	0.2	0.3	0.3	0.3	0.4	0.7	1.0	0.8	0.8	0.9	1.0	1.2	1.6	2.0
Cooler regions; planting to 60% boll open in >170 days. Upper Namoi, Boggabri, Breeza, Cecil Plains, Pittsworth, Trangie, Macquarie, Southern NSW																					
10	1.7	6.3	13.6	23.7	52.2	100.0	100.0	2.6	7.7	15.7	26.5	56.3	100.0	100.0	4.1	10.2	19.2	30.9	62.8	100.0	100.0
20	1.6	5.6	12.1	21.0	46.4	100.0	100.0	2.3	7.0	14.1	23.7	50.3	100.0	100.0	3.8	9.4	17.4	27.9	56.3	100.0	100.0
30	1.4	4.9	10.7	18.6	40.9	100.0	100.0	2.1	6.3	12.6	21.0	44.5	100.0	100.0	3.5	8.5	15.7	25.0	50.3	100.0	100.0
40	1.2	4.3	9.4	16.2	35.7	97.4	100.0	1.9	5.6	11.1	18.6	39.1	100.0	100.0	3.3	7.7	14.1	22.3	44.5	100.0	100.0
50	1.1	3.8	8.1	14.1	30.9	84.2	100.0	1.7	4.9	9.8	16.2	34.1	89.3	100.0	3.0	7.0	12.6	19.8	39.1	97.4	100.0
60	0.9	3.3	7.0	12.1	26.5	71.9	100.0	1.6	4.3	8.5	14.1	29.4	76.7	100.0	2.8	6.3	11.1	17.4	34.1	84.2	100.0
70	0.8	2.8	5.9	10.2	22.3	60.6	100.0	1.4	3.8	7.3	12.1	25.0	65.0	100.0	2.6	5.6	9.8	15.1	29.4	71.9	100.0
80	0.7	2.3	4.9	8.5	18.6	50.3	97.4	1.2	3.3	6.3	10.2	21.0	54.3	100.0	2.3	4.9	8.5	13.1	25.0	60.6	100.0
90	0.6	1.9	4.1	7.0	15.1	40.9	79.1	1.1	2.8	5.3	8.5	17.4	44.5	84.2	2.1	4.3	7.3	11.1	21.0	50.3	92.0
100	0.5	1.6	3.3	5.6	12.1	32.5	62.8	0.9	2.3	4.3	7.0	14.1	35.7	67.3	1.9	3.8	6.3	9.4	17.4	40.9	74.3
110	0.4	1.2	2.6	4.3	9.4	25.0	48.3	0.8	1.9	3.5	5.6	11.1	27.9	52.2	1.7	3.3	5.3	7.7	14.1	32.5	58.4
120	0.3	0.9	1.9	3.3	7.0	18.6	35.7	0.7	1.6	2.8	4.3	8.5	21.0	39.1	1.5	2.8	4.3	6.3	11.1	25.0	44.5
130	0.2	0.7	1.4	2.3	4.9	13.1	25.0	0.6	1.2	2.1	3.3	6.3	15.1	27.9	1.4	2.3	3.5	4.9	8.5	18.6	32.5
140	0.2	0.5	0.9	1.6	3.3	8.5	16.2	0.5	0.9	1.6	2.3	4.3	10.2	18.6	1.2	1.9	2.8	3.8	6.3	13.1	22.3
150	0.1	0.3	0.6	0.9	1.9	4.9	9.4	0.4	0.7	1.1	1.6	2.8	6.3	11.1	1.1	1.6	2.1	2.8	4.3	8.5	14.1
160	0.1	0.2	0.3	0.5	0.9	2.3	4.3	0.3	0.5	0.7	0.9	1.6	3.3	5.6	0.9	1.2	1.6	1.9	2.8	4.9	7.7
170	0.0	0.1	0.1	0.2	0.3	0.7	1.2	0.2	0.3	0.4	0.5	0.7	1.2	1.9	0.8	0.9	1.1	1.2	1.6	2.3	3.3

USEFUL RESOURCES:

NSW DPI, Tamworth
Lisa Bird
(02) 6763 1128 0438 623 906.



Sampling spider mites in cotton
youtu.be/2hB84S7p6vY



Spider mites in cotton
youtu.be/oUcatfAOOQM

Broad mites in cotton
youtu.be/PexkYjLQnoU

Sending samples for resistance testing

If mites or aphids are collected after a spray, ensure sufficient time has lapsed for the application to be fully effective. Depending on the product, this may take 7 to 10 days.

Avoid sending collections on Thursdays or Fridays. If collections are made late in the week they can be stored in paper bags in the fridge and sent on the following Monday.

1. Collect between 20 and 50 leaves depending on the level of infestation (i.e. heavy infestations 20 leaves, light infestations 50 leaves).
2. Place infested leaves loosely inside paper bags without compressing the plant material. Fold and secure the top of the bags with tape or staples.
3. Pack the samples in an insulated bag or esky. It's a good idea to include an ice brick with the sample. Important: Do not send samples in plastic bags or courier satchels.
4. Phone, text or email Lisa Bird (see below) to let her know you are sending the sample.
5. Clearly label samples with the following information:

Farm Name	Phone No ....
Field	Fax No ....
Region (e.g. Gwydir)	Email address ....
Collector's Name	Date of collection ..../........../..........

6. Include relevant comments (e.g. details of the problem if a control failure has occurred). This helps us to prioritise products for testing.
7. Attach the sample details and send by overnight courier to:

Lisa Bird
Department of Primary Industries
Tamworth Agricultural Institute
4 Marsden Park Rd. Calala NSW 2340
Ph: 02 6763 1128 or 0438 623 906

TABLE 13: Control of spider mites (refer to the label for target species)

Active ingredient	MoA group	Mite resistance	Overall impact on beneficials*	Comments#
Etoxazole	10B	Occasional – low	**Low**	Ensure good coverage. Refer to label for no-spray zones and record keeping. Best on low to increasing populations. Maximum 1 application per season.
Diafenthiuron	12A	Significant increase in Namoi/Gwydir Valleys in 23/24 season	**Low**	Treatment at higher infestations may lead to unsatisfactory results. Maximum 2 applications per season.
Abamectin	6	Widespread – med/high	**Moderate**	Resistance levels increasing. Best results will be obtained when applied to low mite populations. Maximum 2 applications per season.
Emamectin benzoate	6	Cross-resistance to abamectin	**Moderate**	Suppression only. Reduces rate of mite population development when applied for *Helicoverpa* control. Maximum 2 applications per season.
Propargite	12C	Occasional – low	**Moderate**	Apply before mite infestations reach damaging levels (maximum efficacy occurs 2 weeks post-spray). Maximum of 2 non-consecutive applications per season.
Dimethoate	1B	No data	**High**	Will not control organophosphate-resistant mites. Maximum 2 applications per season.
Bifenthrin	3A	Widespread – med/high	**Very high**	Applications against *Helicoverpa* will give good control of low mite populations. Maximum 1 application per season.
Deltamethrin	3A	Cross-resistance to bifenthrin	**Very high**	Suppression only. Maximum 1 application per season.

Phorate (1B) is also registered for application at planting (Qld, NSW and WA only).
#For all control options ALWAYS refer to the label for instructions.
*For more details about impact on beneficial insects (including bees), refer to Table 6 in this guide.

Soil and establishment pests

True wireworms – *Agrypnus* spp.
False wireworms – *Gonocephalum* spp. *Pteroheleaus* spp.
Black field earwig – *Nala lividipes*
Symphyla – *Hanseniella* spp.

Soil pests can reduce plant establishment, row density and vigour. Symptoms can be confused with other establishment problems, and may be worse if seedling development is slow due to climate or other factors such as allelopathy, disease or soil constraints. Control measures must usually be implemented at planting, so pre-plant sampling for these pests is required, particularly in fields with a history of soil pest activity.

Sampling

Sampling for earwigs and wireworms is best conducted using a baiting technique. Soil surveying can be used for detecting pests such as symphylans and scarab larvae.

Grain or potato baiting can be conducted following planting rain or irrigation:

1. Soak insecticide-free crop seed in water for at least two hours to initiate germination or cut medium sized aged potatoes in half (ideally, potatoes should be beginning to develop eyes and rapidly sprout once buried). The type of seed used makes no noticeable difference in attracting soil-dwelling insects.
2. Bury a dessert spoon full of soaked seed or a potato half (with the cut side facing down) under 1 cm of soil at each corner of a 5x5 m square at five widely-spaced sites per 100 ha.
3. Mark the position of the baits to easily find them again (high populations of soil insects can completely destroy them).
4. One day after seedling emergence or 5-7 days after placing the potato baits, dig up the remaining bait and count the insects. Feeding on the potato bait will be immediately obvious.

Sampling for soil insects youtu.be/i_ODxTAeASw

Soil surveying involves directly digging to sample for pests. Insert a shovel to full depth at the plant line on the hill and carefully lever the soil out for closer inspection. Start with the deepest soil. Holding a soil clod in one hand, use your other hand to careful break the soil apart.

Factors influencing soil pest numbers

Tillage and farm management practices can influence the composition and abundance of pest species. For example weedy fallows encourage the abundance of soil pests whereas clean fallows generally cause a decline in pest insect numbers due to a lack of food.

The influence of field stubble is contentious as high stubble loads within fields will promote soil pests, however stubble can also provide a diversionary food source as well as increase the diversity of other soil fauna such as predatory beetles (carabidae), centipedes and earthworms. The incorporation of grains stubble prior to planting cotton may increase the damage potential of black field earwig populations as it can cause them to switch feeding activity from stubble to seedlings. Wireworms are found under a range of cultivation and stubble retention regimes.

True and false wireworms

Wireworms are thin, cream-coloured beetle larvae about 20 mm long that attack germinating seeds, the hypocotyl and roots of young cotton plants causing seedling death, young plant 'felling' and patchy plant stands. Adult beetles can also chew seedlings at or just above ground level.

Conduct bait sampling prior to planting to determine wireworm abundance. There are no specific thresholds in cotton, but densities of one or more larvae per baiting site are considered damaging in summer grains.

Wireworm larvae are unlikely to be controlled with standard seed treatments, so where populations are high, an in-furrow insecticide treatment at planting should be considered (Table 14). Infestations detected after crop emergence cannot be controlled with baiting or surface spraying, so early detection is essential for effective management.

False wire worm larvae and adult beetles - Gonacephalem (left) & Pteroheleaus (right). Paul Grundy, Qld DAF

Black field earwigs

Black field earwigs are an occasional pest of seedling cotton. About 15 mm long, they predominantly feed on germinating seed and seedling roots, resulting in poor establishment. Nymphs look similar to adults.

Conduct bait sampling prior to planting to determine earwig presence. No thresholds are available for cotton; thresholds used for maize and sorghum suggest that control maybe warranted when more than 50 earwigs are found across 20 baits or 2-3 earwigs per bait sample.

If earwig numbers are high the application of insecticide treated grain baits at sowing may offer protection. In-furrow insecticide treatments have generally been ineffective if dense populations are present. The efficacy of seed dressings for black field earwig control is unknown.

Black field earwigs can be difficult to see in dark soils.

Symphyla

Symphyla are small (up to 7 mm), white, 'millipede-like' arthropods with 12 pairs of legs. Relatively common in most soils, they may be confused with other soil organisms such as diplurans or collembola (springtails).

Symphyla generally feed on decomposing organic matter but can feed on rootlets and root hairs and have been associated with crop establishment issues in some fields, often as part of a broader complex of soil pests. Damage is more likely in dry soil conditions. They can move up and down in the soil profile and distribution within a field is generally patchy. If plants show symptoms of damage, conduct a basic soil survey, keeping a close eye on newly broken-apart clods for movement. Symphyla are fast moving and will rapidly shift to avoid sunlight.

Symphyla are unlikely to be the lone cause of crop establishment issues. In the absence of other soil pests and diseases or under more optimal field conditions their impact may be minimal.

There are no recommended chemical control options. The in-furrow application of insecticide at planting will not provide protection for establishing seedlings as symphyla are active to depths of up to one metre and will easily avoid exposure. Standard seed dressings offer limited protection when high densities of soil pests are present.

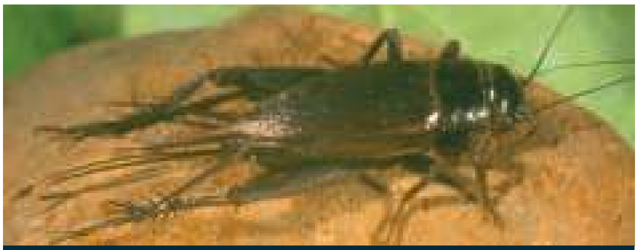
Plant fields where symphyla have been abundant last, so that the warmer conditions aid more rapid establishment. Roots that grow deeper into the profile more quickly are less likely to become stranded in dry soil through root pruning. If plants show signs of moisture stress where symphyla are present, a quick flush with irrigation may help. Irrigation can also decrease symphyla activity in the upper profile for about 7-14 days, which may assist crop recovery.

If establishment is low enough to warrant replanting, consider alternate fibrous-rooted crops such as maize or sorghum that are less susceptible.

A symphylan (left) versus a dipluran (right).
Paul Grundy, Qld DAF

Other soil pests

Black field cricket (*Teleogryllus commodus*) adults and late instar nymphs may occasionally damage cotton seedlings if occurring in large numbers, but damage leading to replanting is uncommon.



Black field cricket. J. Wessels

Cutworms (*Agrotis* spp.) chew stems at ground level and are typically found along field margins that adjoin pastures or where cotton has been sown into recently sprayed out weedy fallows. Significant damage is rare.

Cutworm larvae. P. Room

Whitegrubs are the larvae of scarab beetles that can feed on the roots of crops, causing a loss of vigour and promoting lodging. Damage in cotton is rare and likely only if sown into fields that were previously a weedy fallow or a summer sorghum crop.

Whitegrub attacking peanut. J. Wessels

TABLE 14: In-furrow application at planting for control of wireworm (refer to label for target species)

Active ingredient	MoA group	Overall impact on beneficials*	Comments#
Phorate	1B	High	Maximum 1 application per season.
Chlorpyrifos	1B	High	Use the higher rate with extreme population numbers. Use minimum spray volume of 20 L per sown ha. Maximum 3 applications per season.
Bifenthrin	3A	Very high	Use a coarse spray in a total volume of 60-100 L/ha. Maximum 1 application per season.
Bifenthrin/ chlorpyrifos	3A/1B	Very high	Apply as directed spray using a coarse spray in a total volume of 60-100 L/ha. Use the higher rate with extreme population numbers. Maximum 1 application per season.

#For all control options ALWAYS refer to the label for instructions.
*For more details about impact on beneficial insects (including bees), refer to Tables 5 and 6 in this guide.
Assessment of impact on beneficials is based on contact, which is unlikely to occur for pesticides applied at planting.

Stink bugs and stainers

Brown stink bug – *Dictyotus caenosus*
Green stink bug – *Plautia affinis*
Green vegetable bug – *Nezara viridula*
Harlequin bug – *Tectocoris diophthalmus*
Pale cotton stainer – *Dysdercus sidae*
Red cotton bug – *Dysdercus cingulatus*
Red banded shield bug – *Piezodorus hybneri*

Green vegetable bug (GVB) is the most common and most damaging of the stink bugs found in cotton. Other species of note are included above. Pale cotton stainers are occasional pests in southern regions. Red cotton stainers occur in northern Australia and their pest status is not yet confirmed but expected to be similar. There are also several other bug species that occur in cotton infrequently (e.g. green potato bug *Cuspicona simplex*, native brown shield bugs and stainer-like species in northern Australia), but their pest status is currently unknown.

Usually, infestation occurs around first open boll, as adults fly in from surrounding areas. Adults mate soon after arrival and the expanding population of developing nymphs can result in economic damage.

Several species of predatory shield bugs can also be present in the crop, so correct identification is essential to make the most appropriate management decisions.

Exotic stink bugs, including brown marmorated stink bug (*Halyomorpha halys*) and other *Dysdercus* spp. are considered high priority pests and if suspected should be reported to the plant pest hotline (see *Biosecurity* chapter).

Damage symptoms

Both adults and nymphs penetrate the boll wall to feed on cotton seeds. Cotton stainers will also feed on seeds in open bolls.

Bolls less than a week old are usually shed. Bolls up to 3 weeks old develop small black marks on the outer surface and may have warty growths on the inner boll wall similar to mirid damage. Significant damage can result in incomplete development of one or more sectors (locks), stained lint and reduced yield. Seed weight, oil content and viability can also decline, and the loss of seed viability should be a consideration when managing seed production crops.

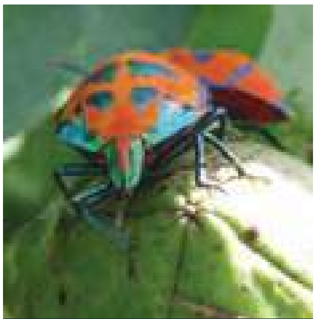
Juvenile and adult pale cotton stainers (left) and mating red cotton bugs (right). Lewis Wilson and Paul Grundy

Green vegetable bug. Paul Grundy

Green stink bug. Joe Wessels

Red banded shield bug. Joe Wessels

Brown stink bug. Joe Wessels



Harlequin bug. Tonia Grundy

Older bolls are not susceptible to damage by stink bugs, but stainers can still cause small dark marks on the inside of the boll wall, usually without external symptoms.

The mild, wet conditions that favour bug survival will also promote secondary infections by fungi and bacteria in cracked bolls. These infections can also cause tight lock and lint staining, so in older crops, do not automatically assume these symptoms are caused by bug damage.

Sampling

The crop is most susceptible to damage from flowering through until one open boll/m. Early instars are less damaging than older instars so it is important to note nymph size in order to use the thresholds correctly.

Internal damage to boll (left) and damage to cotton seed (right). Simone Heimoana, CSIRO

Shield bugs instars can change dramatically in colour and pattern as they develop. From left: 1st, 4th and 5th instar GVB nymphs. A parasitoid egg can be seen on the large nymph's right shoulder. Joe Wessels

GVB are most visible early to mid-morning. From flowering onwards, beat sheeting is twice as efficient as visual sampling, although it may still underestimate actual field populations as early instars can be difficult to dislodge. Adult females lay eggs in clusters, so distribution throughout both the field and canopy is quite patchy. Ensure that you take a sufficient number of samples to give a reasonable representation of the field.

Where bugs are observed feeding, cut open bolls of varying ages to monitor for signs of boll and lint damage, which may take a week to appear. Examine seeds for browned, dried areas.

Thresholds

During boll development, use an action threshold of 1 GVB adult per metre if sampling with a beat sheet (or 0.5/m visually), or damage to 20% of small bolls (up to 2 weeks old).

The damage potential of nymphs and other stink bugs is less than that of GVB adults, so their counts need to be multiplied by the appropriate GVB adult equivalent adjustment (see Table 15).

If stainers are present after first open boll and staining is observed, use a threshold of 30% affected bolls to prevent a colour downgrade.

TABLE 15: Converting GVB nymphs and other stink bugs to GVB adult equivalents

GVB nymphs and other stink bugs		GVB adult equivalent
Other stink bugs	Green stink bug	0.5
	Red banded shield bug	0.33
	Pale cotton stainer bug	0.33
	Brown stink bug	0.25
	Harlequin bug	0.25
Nymphs	1st or 2nd instar GVB nymphs (cluster of 10+)	1.0
	3rd instar GVB nymphs	0.5
	4th or 5th instar GVB nymphs	1.0

Key beneficials

GVB eggs are frequently parasitised by a small, introduced parasitoid (*Trissolcus basalis*). After hatching, Trissolcus larvae remain inside the GVB egg and continue to feed and mature, turning the egg black as the wasp develops.

Some predatory shield bug eggs are also dark but have a ring of spines near the top.

GVB nymphs are attacked by ants, spiders and predatory bugs.

Final (fifth) instar and adult GVB and red banded shield bugs are parasitised by the recently introduced tachinid fly, *Trichopoda giacomellii*. Eggs are laid externally, often around the pronotum (the protective plate behind the head), and the hatched larvae bore into the host, dramatically reducing the bug's feeding and egg production and ultimately killing them. The role of natural enemies on stainers in Australia has not been studied.

GVB with 4 *Trichopoda* parasitoid eggs. Hugh Brier, Qld DAF

Selecting an insecticide

Insecticide products registered for the control of GVB in Australian cotton are presented in Table 16. Avoid mid-season use of dimethoate for GVB control if possible as it also selects for organophosphate/carbamate resistance in aphids, particularly if using an OP/carbamate in early season furrow treatments for thrips control. SLW carry OP/carbamate resistance, so this action could also 'flare' their population.

There are few products registered for pale cotton stainer control apart from synthetic pyrethroids, however their status as an occasional pest is influenced by their susceptibility to insecticides used for the control of *Helicoverpa* and other pests such as mirids. Any decision to use broad-spectrum insecticides should take into account their impact on beneficial insects and the subsequent risk of flaring whitefly and other secondary pests.

Stainer-like bugs that may be present in northern crops. Top: *Aulacosternum nigrorubrum* adult and eggs. This species has been seen causing damage to cotton in the Northern Territory. Bottom: The seed bug *Graptostethus servus* is often confused with stainers, but is not considered a significant pest. Simon Ong

Resistance profile

No GVB resistance to insecticides has been detected in Australia.

Cotton stainers will react to selection pressure under laboratory conditions but there are few records of resistance to insecticides developing in the field.

Overwintering habit

A high proportion of GVB adults enter a dormant phase (bronze colour) during late autumn and overwinter in a variety of sheltered locations, for example under bark, in sheds, and under the leaves of unharvested maize crops. A small proportion will remain green and active, feeding on whatever hosts are available.

There is no resting stage in the cotton stainer's lifecycle; adults survive non-crop periods in surrounding vegetation, utilising malvaceous weeds, ratoon cotton and a range of Australian native species as alternate hosts.

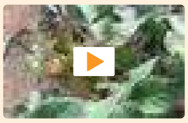
Alternative hosts

The preferred weed hosts of the spring GVB generation include turnip weed, wild radish, variegated thistle and early mungbeans. Key hosts for the late summer to early autumn generation include pulse crops (particularly soybean and mungbean) and blackberry nightshade.

Fuzzy cotton seed used for stockfeed is an important alternative source of food for cotton stainers. Avoid storing fuzzy seed in exposed places accessible to cotton stainers over long periods. Controlling volunteer and ratoon cotton is also important for limiting cotton stainers' access to alternative food sources.

USEFUL RESOURCES:

Qld DAF, Toowoomba
Paul Grundy 0427 929 172



Thrips in cotton: identification and damage
youtu.be/U9bCoVTgsN8

Images of stink (podsucking) bugs and predatory bugs
thebeatsheet.com.au/resources/insect-identification

TABLE 16: Control of green vegetable bug

Active ingredient	MoA group	Overall impact on beneficials*	Comments#
Fipronil	2B	**Moderate**	Use higher rate when higher infestations are present. Avoid repeated applications of this insecticide group. Do not apply to flowering crops.
Clothianidin	4A	**Moderate**	Use higher rate when heavy infestations are expected and longer control is required. Treated insects may remain on plant after application but will have stopped feeding. Maximum 2 applications per season. PER94474 for brown stink bug is available until 28 Februay 2025.
Acetamiprid	4A	**Moderate**	Apply with adjuvant as per label. May only provide knockdown and residual control for 7 days under heavy/sustained pest pressure.
Emamectin benzoate/ Acetamiprid	6/4A	**Moderate**	Use higher rate on heavier populations and for a faster knockdown. Use non-ionic surfactant or organosilicone adjuvant as per label. Maximum 2 applications per season.
Dinotefuran	4A	**Moderate**	Ensure good coverage. Performance can be reduced in stressed crops, or when senescing late season or when pests are not actively feeding in the upper crop canopy. Maximum 2 applications per season.
Dimethoate	1B	**High**	Use higher rates for heavier infestations. Maximum 2 applications per season.

#For all control options ALWAYS refer to the label for instructions.
*For more details about impact on beneficial insects (including bees), refer to Table 6 in this guide.

Thrips

Seedling thrips – *Thrips tabaci*
Tomato thrips – *Frankliniella schultzei*
Western flower thrips – *F. occidentalis*

Thrips are small torpedo-shaped insects that are primarily pests of cotton seedlings, but can also act as key predators of mite eggs later in the season. *Thrips tabaci* tends to be prevalent during establishment but is replaced by *Frankliniella* spp. as the season progresses and temperatures rise.

Damage symptoms

Thrips larvae and adults cause early season damage to terminals, leaves and stems. The most obvious damage is smaller, crinkled leaves and a visible 'silvering' on the undersides of leaves. At very high densities, thrips can also kill the growing terminal, which delays the plant's growth until it can establish a new terminal.

Occasionally thrips can also build to high numbers in flowers and on leaves mid-late season, particularly in crops with minimal pesticide use. High numbers on leaves can lead to stunting and damage especially along leaf veins, but late season thrips damage rarely justifies control.

Sampling

Use a hand lens to count the adult and larval thrips per plant on 20-30 separate seedlings. Also assess the severity of damage to the seedlings by estimating the percentage reduction in leaf area (if the damaged young leaves are less than 1 square centimetre then the reduction in seedling leaf area is usually greater than 80%). If thrips are present in high numbers (>30/plant), check the plant terminal. Complete blackening of the embryonic leaves means the terminal has died.

Adult thrips can migrate into the crop from surrounding vegetation, but the presence of larvae in crops that have had an insecticide seed or in-furrow insecticide treatment indicates that the population is actively breeding and the early insecticide offered poor control.

Severe thrips damage to seedlings can cause delayed maturity or yield loss, particularly in southern regions. Simone Heimoana

Thrips nymph on underside of leaf. Tonia Grundy, Qld DAF

Sample weekly from seedling emergence until thrips abundance declines and plants begin to recover (usually by about 4-8 nodes, but sometimes up to 10 nodes). During the mid to late season, monitor for the presence of thrips in flowers and on the undersides of leaves in the upper canopy. Also look for thrips when sampling mites, as the presence of thrips adults and larvae in mite colonies is a good indicator of potential natural control of the mites.

Thresholds

As thrips occur in cotton seedlings in most years, the most effective management option is to use a seed treatment or an at-planting insecticide applied with the seed. This protects plants during the establishment phase and has the advantage of minimal negative effects on beneficial species compared to an insecticide applied to the crop after emergence (see Tables 5 and 6).

Severe damage to leaves can result in delayed maturity or yield loss. In northern and central regions with warmer climates, the risk is lower because plants can outgrow and compensate for damage, so yield loss is only likely to occur about one year in every ten.

In cooler, shorter season areas (Darling Downs, Upper Namoi, Macquarie and Liverpool Plains), the risk of delayed maturity and/or yield loss is higher because there is less time to compensate, hence yield loss may occur one year in every two. Southern NSW regions have a similar risk, however other issues relating to a cool start and associated maturity delays can further compound the impact of thrips, so the ability of the crop to compensate after damage will need to be considered.

In all instances a seed treatment or an at-planting insecticide applied with the seed should provide sufficient control for plants to establish. Neonicotinoid (imidacloprid) resistance has been detected in seedling thrips from cotton, and may affect neonicotinoid seed dressing efficacy. Control may be required if significant leaf damage continues past 6-8 nodes.

Thrips populations will normally decline naturally in early December. In situations where populations of thrips remain high and plant growth is delayed by cool, wet weather, seed treatments or at-planting insecticides may run out and supplementary control may be necessary according to the threshold below. Western flower thrips are not controlled by the current seed treatments, but this species is not normally abundant in early season cotton.

THRESHOLD: Seedling to 6 true leaves
80% reduction in leaf area + 10 thrips/plant (adults and larvae)

Thrips found in cotton in the mid and late season are usually *Frankliniella* spp. Adult thrips feed on pollen, but are unlikely to affect pollination or fruit set. Eggs are laid on leaves and the hatching larvae may cause damage to the undersides, resulting in distorted, smaller leaves. However, high levels of feeding damage would be required to affect yield. Thrips larvae are also predatory, which may moderate their feeding on plants (for example tomato thrips nymphs can eat 2-6 mite eggs per day), so control should not be considered unless >30% of leaf area is damaged in the top 6 nodes in pre-cut-out crops or more than 50% of leaf area is damaged after the crop has cut-out.

Key beneficials

Predators – minute pirate bug, lacewings, ladybird beetles.

Selecting an insecticide

Insecticide products registered for the control of thrips in cotton in Australia are presented in Table 17. Insecticide seed treatments provide protection from thrips during crop establishment, however a neonicotinoid seed treatment should not be used if resistance to neonicotinoids in thrips is suspected. Consider the benefit of thrips as predators of spider mites when deciding whether to control thrips in cotton with an insecticide. **It should be noted that every western flower thrips tested in Australia since resistance screening commenced has been resistant to pyrethroids (Group 3A).**

In Australia, pyrethroid (3A) and organophosphate (1B) resistance has been detected in some seedling thrips in horticulture but resistance in tomato thrips has not yet been detected.

Resistance to fipronil (Group 2B) was detected for the first time in seedling thrips collected from cotton fields in 2024. Avoid using fipronil in fields where seed treatments containing this insecticide have been used or if the presence of resistant thrips are suspected.

Overwintering habit

Thrips prefer milder temperatures and remain active throughout winter. Populations decline at temperatures greater than 30°C.

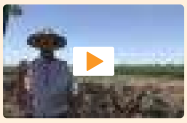
Alternative hosts

Thrips continue to feed and reproduce on a range of weed hosts during winter and spring. Adult thrips may migrate from these weeds into flowering wheat crops but generally don't reproduce there. In spring, as weeds and wheat crops dry out, large numbers of adults are forced to seek new hosts, and transfer to cotton. Cotton crops planted adjacent to cereal crops are particularly at risk of infestation by thrips.

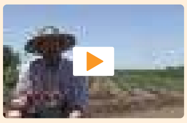
Thrips damage to lower nodes with terminal showing new growth without damage. This plant is likely to recover, however, continue to monitor. Lewis Wilson

USEFUL RESOURCES:

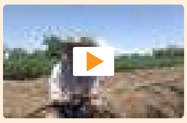
NSW DPI, Tamworth
Lisa Bird (02) 6763 1128 0438 623 906.



Thrips in cotton: identification and damage
youtu.be/e8B0wpimUvA



Thrips in cotton: sampling and management
youtu.be/FKkwWID4iQA



Thrips in cotton: friend or foe
youtu.be/UsWxHB94NN4

TABLE 17: Control of thrips (excluding seed treatments)

Active ingredient	MoA group	Resistance	Overall impact on beneficials*	Comments#
Seedling thrips and tomato thrips				
Fipronil	2B	Detected in seedling thrips	**Moderate**	Takes 3-4 days to reach full effectiveness. Use higher rates under high pressure. Avoid repeated use of this insecticide group.
Dimethoate	1B	Detected in seedling thrips	**High**	Do not harvest for 14 days after application. Maximum 2 applications per season.
Western flower thrips				
Spinetoram	5	Not detected	**Low**	Maximum 2 applications per season. Refer to mandatory no-spray zone on label.

Phorate (1B) is also registered for application at planting (Qld, NSW and WA only).
#For all control options ALWAYS refer to the label for instructions.
*For more details about impact on beneficial insects (including bees), refer to Table 6 in this guide.

Whitefly

Silverleaf whitefly – *Bemisia tabaci* (MEAM1)
Greenhouse whitefly – *Trialeurodes vaporiorum*

Silverleaf whitefly (SLW) is a major pest of mid to late-stage cotton. SLW honeydew is considered a serious contaminant of cotton lint, and harms Australia's export reputation. Management is also complicated by widespread resistance of this pest to several insecticide groups, and a high risk of resistance developing.

Greenhouse whitefly is an infrequent pest of cotton but have a different adult wing shape and hairs on the nymphs. Other native Bemisia species are also occasionally present in cotton crops but tend to have slower population growth than SLW.

Damage symptoms

SLW generally do not cause obvious damage to leaves unless populations are very high. Their main harm lies in the production of honeydew (excreted by both adults and nymphs), that consists of a mixture of sugars including sucrose, glucose, fructose, melezitose and trehalulose. In the field, SLW honeydew can be difficult to visually detect as it dries to a matte sheen that is not sticky to the touch. However, trehalulose melts at 48°C, which can result in downgrades or rejection for stickiness during processing.

Under moist conditions, honeydew can promote the growth of sooty mould fungi, and dark discolouration of the fibres can result in price discounts.

Adults and nymphs of SLW (left) and greenhouse whitefly (right).
📷 Richard Lloyd, Qld DAF

Sampling and thresholds

SLW can undergo rapid population growth, particularly when natural enemies have been disrupted by insecticides. **To reduce the amount of sampling time required and help make SLW management more efficient, the recommendations for SLW sampling and thresholds have been simplified**. The new recommendations are available at
cottoninfo.com.au/publications/2024-silverleaf-whitefly-sampling-and-thresholds

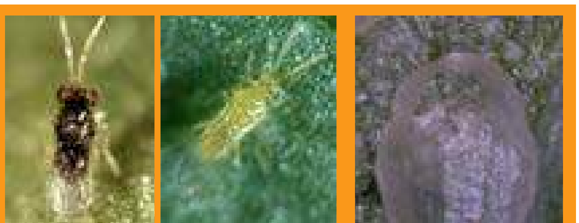
The critical control period is from mid flowering to open cotton or about 800-1050 Day Degrees (15_32 system). The objective is to have the resident population in check by the time lint is exposed. *Note: this method only applies to in-crop population build-up, and is not applicable if crops experience mass immigration of adults from nearby defoliated areas.*

Healthy SLW

Fourth instar nymph with healthy mycetomes

Red eye nymph development (the white wing buds appear just before emergence)

Parasitised SLW



Adult *Encarsia* (left) and *Eretmocerus* sp.

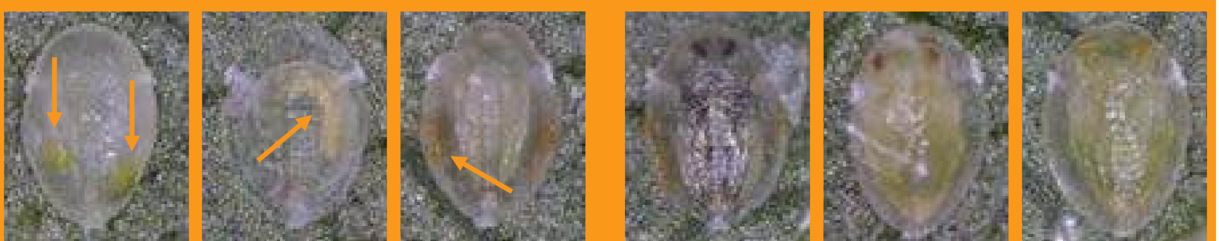
Empty nymph case with chewed exit hole

Empty pupal case (pushed open) and adult SLW

CottonInfo

With support from: CRDC

Signs of parasitism:



Displaced mycetomes

Parasitoid larva

Red faecal waste

Examples of parasitoid pupae (colours may vary)

Last revised April 2022

Using the new sampling and threshold guidelines:

1. Start sampling during early flowering (750 DD 15/32) to identify a SLW population baseline for comparison as the season progresses. Avoid field edges and take sufficient samples to represent the field (30 leaves or more).
2. Sample plants at least several metres apart. Take one main stem leaf per plant from the mid canopy (11-14 nodes down from the terminal) and look for large nymphs (3rd or 4th instar) on the underside of the leaf. **If two or more are present, the leaf is considered infested.** Calculate the proportion of infested leaves and consult the threshold matrix to see your risk area in relation to the DD crop development stage.
   - If in the 'Low risk' zone, no immediate action is needed. Continue to monitor the situation.
   - If in the 'Moderate risk' zone, assess the counts over 2-3 consecutive checks. If the population is increasing a control decision is likely.
   - If in the 'High risk' zone mid-flowering (after about 800 DD), management action is required.
3. Consider natural enemy conservation when making control decisions.
4. Assess nymph mortality (due to parasitism, predation or an applied insecticide) from cut-out or after a SLW insecticide has been used. Nymph viability is an important factor to consider in SLW management, particularly during the open boll phase.

While parasitism levels have not been specifically included in this threshold, they can provide a general indication as to future nymph density trends, particularly after crop cutout. Eretmocerus usually has a controlling impact on whitefly populations from first open boll onwards.

Parasitism in younger crops is usually very low, but if undisturbed by pesticides will go on to build up quickly, although it often lags behind the increase in SLW population. IGR products (pyriproxyfen & buprofezin) have limited impact on parasitoids and many predators, and are thus an ideal fit before first open boll, leaving a reduced SLW population with natural enemies largely intact. However, consider your timing carefully as these products have a restricted number of sprays per season. The activity of surviving parasitoids and other natural enemies is usually sufficient while bolls are opening to prevent a SLW population rebound.

Actively monitor nymph viability from crop cut-out onwards. Distinguishing healthy from parasitised or dead nymphs requires magnification and experience, but a new nymph viability app for smart phones has been released (Jan 2024) that can help to quickly assess nymph status with 80-85% accuracy.

Identifying parasitism in SLW youtu.be/SO0cedrGIQI

During defoliation, adult SLW will leave the crop, while falling leaves will take the nymphs with them to the ground. These displaced adult SLW relocate to nearby host crops and the nymph-based matrix will be of limited value for crops in this situation.

Late season considerations

SLW management involving late season mass-immigration of adults into crops with open bolls should be based on (a) expected time to defoliated leaf drop, (b) lint contamination level, and (c) prior chemical use from a resistance management perspective (i.e. avoid multiple applications from the same mode of action).

When selecting products for late season SLW management at or prior to the first pass of defoliant, consider potential efficacy and any control delay, residual impact and withholding periods (WHPs). If the risk of honeydew contamination is high, consider commencing defoliation earlier.

Also monitor for the presence of honeydew on lower leaves, particularly if there is open cotton, as this indicates some remedial action should be taken to prevent contamination of bolls. If defoliation is not due for 10-14 days and honeydew is collecting on the leaves, managing SLW numbers with a knockdown product may be prudent. If defoliation is 15-21 days away, consider using a knockdown spray in the first 7 days, followed by continued monitoring. Commencing defoliation earlier (at 50% open bolls) may be warranted if significant population resurgence is evident in the week post-treatment. If defoliation is more than 3 weeks away, the use of a systemic product with residual activity would be a wise choice as it would have efficacy on both nymphs and adults within the canopy.

Key beneficials

The tiny wasps, *Encarsia* and *Eretmocerus* species are important parasitoids of SLW nymphs. Predators of nymphs include big-eyed bugs, pirate bugs, lacewing larvae, apple dimpling bugs, brown smudge bugs and ladybird beetles. The augmentative release of *Eretmocerus* sp. The augmentative release of *Eretmocerus* sp. is a management approach that has recently been adopted by some growers.

Natural enemies can play a vital role in the successful management of whitefly. Avoid early season use of broad-spectrum insecticides, particularly synthetic pyrethroids and organophosphates.

Selecting an appropriate insecticide

The insecticides registered for control of SLW are presented in Table 18. One of the challenges in SLW management is the timing of insecticide application as it's often a compromise between delaying treatment to reduce the risk of re-infestation (to avoid the cost of additional sprays), versus the need to control populations prior to open cotton (reducing the risk of sticky cotton).

Considerations when applying insecticides to control SLW include:

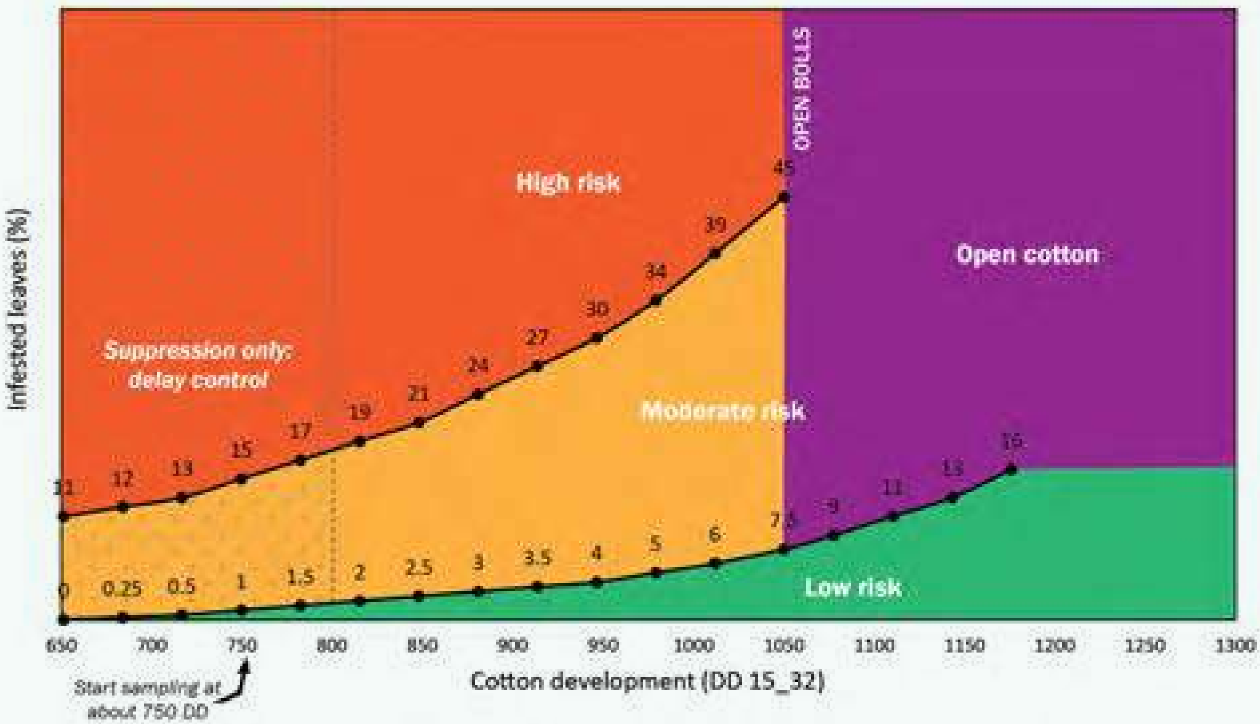
- Impact on natural enemies that can assist in controlling SLW that survive the insecticide.
- Mode of action of the insecticide (e.g. insect growth regulators may require up to several weeks to take full effect, so need to be timed to have completed control prior to open cotton).
- Coverage and insecticide activity. Post cut-out, insecticides with limited plant penetration and or poor application may not provide adequate control.

Resistance profile (SLW)

When SLW was first identified in Australia in 1994 it already possessed resistance to many older insecticide groups, including pyrethroids (Group 3A) and organophosphates (Group 1B). Selection for resistance in SLW populations can happen very quickly. Resistance to bifenthrin is geographically widespread but at a low frequency within populations. SLW have widespread, high frequency partial cross resistance to neonicotinoids (Group 4A). Resistant SLW can detoxify imidacloprid and clothianidin, but not acetamiprid or dinotefuran.

The severity of resistance to pyriproxyfen (Group 7C) has declined in recent years, but low level resistance is still widespread. Resistance to spirotetramat (Group 23) is widespread, but outside of horticultural regions remains

SLW SAMPLING AND THRESHOLDS 2024



AN EXPLANATION OF THE MATRIX ZONES

Crop stage	Sampling considerations and management actions		
Early to mid flowering (prior to 800 DD)	Monitor populations but do not spray for SLW. Preserve beneficials to keep pest populations low. Consider opportunities to suppress SLW if the need arises to control other pests, particularly prior to row closure. Prioritise selective/soft products if any spraying is undertaken.		
	ZONES		
	Low risk:	**Moderate risk:**	**High risk:**
Mid-flowering to first open bolls (800-1050 DD)	Insecticide use is unlikely to be required for SLW in fields with low population densities. Continue to consider opportunities for suppression if the need to control other pests arises. Due to inherent variability associated with sampling, one or two data points slightly above the low zone boundary does not constitute a 'breakout'. Continue to sample population development and preserve beneficials.	If population density is increasing for 2-3 consecutive checks (over 7-10 days) consider undertaking control action. At 800-1000 DD, a slower acting insect growth regulator (IGR) product is an appropriate choice, with low impact on beneficial insects that can continue to exert biological control well after insecticide residue efficacy has degraded. If the crop is nearing open bolls, a faster acting insecticide would be more appropriate. A follow up treatment may be necessary during later boll opening if natural enemies are disrupted and SLW populations recover. Actively preserve beneficials that will assist keeping SLW populations low.	A population that breaches the high risk zone for 2 consecutive checks (over 5-7 days) represents an unambiguous control scenario. Even with high numbers, there is enough time to act before lint contamination. Use slower acting products such as IGRs prior to 1000 DD. Applying IGRs prior to canopy closure will assist spray penetration and control efficacy. If the crop is nearing open boll, or has a dense closed canopy, a faster-acting systemic product may be more appropriate.
Open cotton (1050 + DD)	Continue monitoring SLW nymphs whilst also assessing nymph survival (e.g. parasitism). Also check for presence of honeydew in the lower canopy. Contamination risk should remain low but consider factors such as the influence of dry conditions or delays to crop defoliation	For populations above low risk, there is a continuing potential for open boll honeydew contamination. Continue monitoring SLW nymphs and importantly assess nymph viability as mortality due to parasitism and predation typically increases after cutout. Nymph populations may be less than 50% viable. Base management decisions on monitoring viable SLW nymph numbers, severity of honeydew on lower canopy, and climatic conditions (e.g. dry conditions can exacerbate lint contamination risk). The primary objective is to avoid or salvage sticky cotton. Focus on knockdown products if control is required. Displaced populations of adults from neighbouring defoliated cotton can also pose a honeydew contamination risk in later maturing crops and require control.	

at a low frequency. Very high level resistance has been recently detected in the Lockyer Valley. This resistance is due to a dominantly inherited target site mutation, meaning it can develop rapidly and once established, reversal is unlikely.

Compliance with the IRMS (pages 64-65) will help ensure the products available for SLW control remain efficacious into the future. **ENSURE ONLY SINGLE APPLICATIONS OF PYRIPROXYFEN AND SPIROTETRAMAT OCCUR WITHIN A SEASON**.

Overwintering habit

Whitefly does not have an overwintering diapause stage and relies on alternative host plants to survive. Generation times are temperature dependent – winter generation times are 40-45 days in central Queensland, 65-70 days in the Macintyre, Gwydir and Namoi valleys, and just over 100 days in Griffith.

Alternative hosts

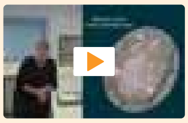
The availability of a continuous source of hosts is the major contributing factor to a severe whitefly problem. Even a small area of a favoured host can maintain a significant whitefly population. Preferred weed hosts include: sowthistle, melons, bladder ketmia, native rosella, rhynchosia, vines (cow, bell and potato), rattlepod, native jute, burr gherkin and other cucurbit weeds, Josephine burr, young volunteer sunflowers, Euphorbia weeds, poinsettia and volunteer cotton.

In cotton growing areas the important alternative crop hosts are soybean, sunflower and all cucurbit crops. Spring plantings of these crops may provide a haven for SLW populations to build up in and then move into cotton. Autumn plantings of these crops may be affected by large populations moving out of cotton. Do not plant cotton near preferred SLW host crops such as melons. Destroy crop residue from all susceptible crops immediately after harvest.

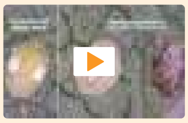
Minimising winter hosts, particularly sowthistle and volunteer cotton, helps reduce the base population at the start of the cotton season. Smaller base populations will take longer to reach outbreak levels and reduce the likelihood that a particular field will need to be treated.

USEFUL RESOURCES:

Qld DAF, Toowoomba
Jamie Hopkinson **0475 825 340** (resistance enquiries)
Paul Grundy **0427 929 172**



Silverleaf whitefly: implications for lint quality and colour
youtu.be/uVSSlqUg5q0



Identifying parasitism in silverleaf whitefly
youtu.be/SO0cedrGIQI

The new SLW recommendations are available as a factsheet at
cottoninfo.com.au/publications/2024-silverleaf-whitefly-sampling-and-thresholds

Honeydew can promote sooty mould growth, which can lead to colour downgrades. Silverleaf whitefly honeydew is also more likely to create problems with sticky cotton during ginning than honeydew from other sucking pests. Paul Grundy

TABLE 18: Control of silverleaf whitefly

Active ingredient	MoA group	SLW resistance	Overall impact on beneficials*	Comments#
Paraffinic oil	UNM	Unknown	**Very low**	Target low, early season populations. Apply in a minimum of 100 L/ha for ground applications. Use in combination with another registered insecticide when applying from the air. Multiple applications are more effective.
Pyriproxyfen	7C	Widespread – low	**Very low**	An IGR with translaminar movement that disrupts egg hatch, interferes with moulting from 4th instar nymph to adult, and reduces adult female fertility. Ensure good coverage. Maximum 1 application per season.
Clitoria ternatea extract	UNE	Unknown	**Low**	Ensure good coverage. Maximum 5 applications per season. Treatment effects may not be seen for 3 or more days. A repeat application may be required at 14-20 days if conditions favour pest development.
Buprofezin	17A	Not detected	**Low**	An IGR with contact and vapour activity that reduces adult female fertility and disrupts moulting of nymphs. Target the early nymph stages. Use sufficient volumes to achieve good penetration and coverage. Maximum 1 application per season.
Afidopyropen	9D	Not detected	**Low**	Suppression of both adult and nymph stages, however it is recommended to target the nymph stage.
Diafenthiuron	12A	Not detected	**Low**	Suppression only. Apply when population densities are low to moderate. Suppression may not be satisfactory once populations are high or migrating in. Maximum 2 applications per season.
Dimpropyridaz	36	Unknown	**Moderate**	Do not apply by aircraft. Offers residual control for up to 21 days. Maximum 2 consecutive applications and no more than 4 applications per season.
Cyantraniliprole	28	Not detected	**Moderate**	Target early developing populations. Maximum 2 applications per season.
Spirotetramat	5	Widespread – low (very high – extreme in Lockyer Valley)	**Moderate**	Controls nymphs and causes sterility in females. Has translaminar and systemic mobility in both phloem and xylem. Use the high rate for periods of high pest pressure, when rapid crop growth are evident, or when crops are well advanced. Ensure good coverage and use an adjuvant as per label. Do not re-apply within 14 days. Maximum 1 application per season.
Acetamiprid	4A	Rare – very low	**Moderate**	Apply with adjuvant as per label. Use higher rate when conditions favour a rapid increase in the whitefly population, during rapid crop growth or when crops are well advanced.
Emamectin benzoate/ acetamiprid	6/4A	Not detected/ Rare – very low	**Moderate**	Use before heavy populations become established. Activity is primarily on nymphs and therefore evidence will be slower than for typical contact insecticides. Use adjuvant as per label. Maximum 2 non-consecutive applications per season.
Dinotefuran	4A	Not detected	**Moderate**	Performance can be reduced in stressed crops, when senescing late season, or when pests are not actively feeding in the upper crop canopy. Maximum 2 non-consecutive applications per season
Bifenthrin	3A	Widespread – low Cross-resistance with other SPs.	**Very high**	Target the adult stage only. Do not spray if a high proportion of juveniles are present. Ensure good coverage. Maximum 1 application per season.

#For all control options ALWAYS refer to the label for instructions.
*For more details about impact on beneficial insects (including bees), refer to Table 6 in this guide.

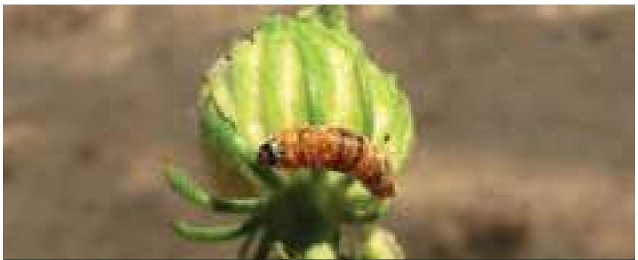
Other insect pests

Bollworms

While the term 'bollworm' is often used for *Helicoverpa*, several other species are also referred to as bollworms.

Rough bollworm (*Earias* spp.) larvae tunnel into squares, bolls or the main stem, destroying the growing point. While larvae can cause serious damage to unsprayed cotton, they are normally incidentally controlled by *Helicoverpa* sprays in conventional cotton and Bt toxins in Bollgard crops.

Pink spotted bollworm (*Pectinophora scutigera*) occurs in coastal and central Queensland, attacking cottonwood and bottle trees as well as cotton. **Pink bollworm** (*P. gossypiella*) occurs in cotton and other Malvaceae hosts in the Northern Territory and northern Western Australia. The larvae of both species tunnel into squares, flowers or bolls, with pupation occurring in bolls, stems or surface trash. Pink bollworm larvae can diapause while sheltering in bolls, lint, seed or the soil. While pink spotted bollworm does not have an overwintering diapause phase, larvae can survive by feeding on dry cotton seed in trash or cotton modules.



Rough bollworm larvae grow to about 18 mm long and their favoured host is bladder ketmia. Lewis Wilson

Pink spotted bollworm moth and larva (top), and damaged lint due to feeding and the entry of boll-rotting fungi. P. Room and D. Ironside

Leafhoppers (jassids)

Occasional pests of cotton, there are several species that can cause seedling damage or leaf stippling, but they are unlikely to reduce yield unless the stippling is extreme (e.g. to more than 50% of the leaf surface just before cut-out). Lucerne leafhopper is suspected to have caused leaf chlorosis in some fields in the 2021-22 season. Unnecessary sprays for leafhoppers may adversely affect beneficial species and flare other pests.

Cotton leafhopper and suspected lucerne leafhopper damage. Paul Grundy, Qld DAF

Redshouldered leaf beetle – *Monolepta australis*

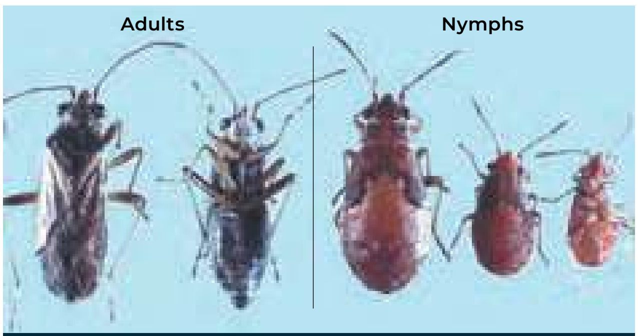
Rarely found in the majority of cotton-growing regions, redshouldered leaf beetle adults chew leaves, terminals, squares and the surface of cotton bolls. In the tropics (particularly after good rains), swarms of beetles can cause significant damage to patches of plants.

Adult redshouldered leaf beetles are about 6 mm long. Joe Wessels

Rutherglen bug (RGB) – *Nysius vinitor*

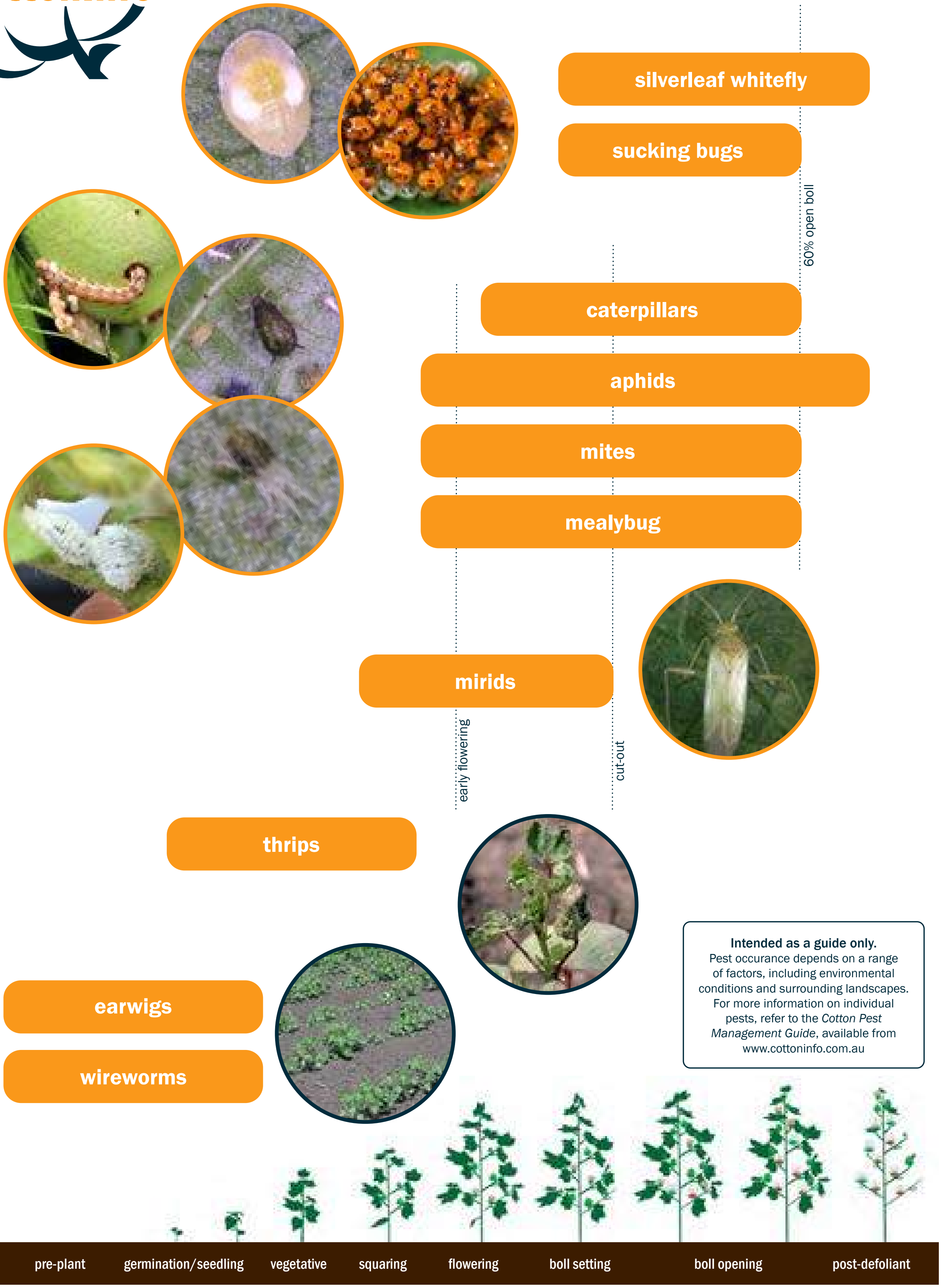
RGB's wide host range includes fruits, vegetables, oilseeds and grains, and many common weeds. Adult RGBs and the closely related grey cluster bug (*N. clevelandensis*) are often found in cotton, sometimes in large numbers, but generally do not feed and can't reproduce in the crop. Grey cluster bug tends to be present earlier in the season while RGB numbers increase mid to late season. Starving nymphs migrating from maturing sunflower or canola crops may damage border areas of adjacent cotton.

Cage experiments on 5 day old bolls demonstrated that boll blemishes were superficial and caused no impact to the developing seeds or lint. Damage such as blackened stamens or darkened seeds is unlikely to be caused by RGB, and the crop should be monitored for other sucking pests.



Adult Rutherglen bugs are 3-4 mm long; nymphs are reddish-brown. Qld DAF

What pest when?



Intended as a guide only.
Pest occurance depends on a range of factors, including environmental conditions and surrounding landscapes. For more information on individual pests, refer to the *Cotton Pest Management Guide*, available from www.cottoninfo.com.au

November 2023

Note: images not to scale

Insecticide Resistance Management Strategy (IRMS) for 2024-25

In every population of every pest species there is a small proportion of individuals with naturally occurring genetic resistance. These genes remain rare until they are selected for by a toxin, either from an applied pesticide or from within Bt cotton. Exposure controls the susceptible insects, leaving behind the resistant individuals, which can then build up as a larger proportion of the overall population.

Over-reliance on an insecticide can lead to an increase in the proportion of resistant individuals to the point where the insecticide fails to provide satisfactory control. This simple scenario is obviously more complex in a field situation as products applied not only select for resistance in the target pest, but also in other pests present.

The IRMS aims to assist users to:

- Lower the risk of inadvertent selection of resistance in pests that are not the primary target of the insecticide application.
- Delay the evolution of pest resistance to key chemical groups, by minimising the survival of individuals with resistance.
- Manage entrenched resistance problems, such as the now widespread resistance in silverleaf whitefly (SLW) to pyriproxyfen.

The cotton industry IRMS seeks to manage the risk of resistance in all major pests of cotton including aphids, mites, SLW and *Helicoverpa* spp. in both conventional and Bt cotton (note that in this document, the term 'insecticide' refers generally to pesticides used for insect or mite control). Additional resistance management requirements are also in place for managing the risk of *Helicoverpa* developing resistance to Bt cotton (see the RMP section on pages 66-74).

The IRMS includes all active ingredients commercially available for use in cotton at the time of publication and should be consulted for EVERY insecticide/miticide decision in both Bt and conventional cotton.

Key points for the 2024-25 cotton season

- **The IRMS structure has been simplified to match crop development stages** (it was originally based on the helicoverpa life cycle). The general principles of the IRMS are applicable to all growing regions.
- **Two-spotted mite resistance to diafenthiuron.** Given widespread medium to high resistance to Group 6 (e.g. abamectin) and Group 3A (bifenthrin), the emergence of diafenthiuron resistance restricts control options for mites in cotton. There is currently no control option available for early season cotton that fits with IRMS principles.
- **Adherence to IRMS for all SLW products.** Resistance to pyriproxyfen in SLW is low and stable in most regions. The regional 30 day pyroproxyfen window has been removed, reflecting the current stabilisation of resistance levels thanks to industry compliance. Continue to consider resistance risk when utilising any SLW product. Low levels of resistance to spirotetramat are widespread in most regions and could develop rapidly, with reversal unlikely if the resistance becomes entrenched. Note that pyriproxyfen and spirotetramat are still limited to one application per season, with the only exception a `double knock' use of spirotetramat for mealybug (2 applications 14 days apart).

Principles underlying the IRMS

- Monitor pest and beneficial populations. Consider species as well as abundance.
- Monitor fruit retention and determine if losses are due to pest damage or environmental factors.
- Use recommended thresholds for all pests (do not use 'insurance' sprays).
- Aim to use the most selective insecticide options first, delaying the use of broad-spectrum insecticides for as long as possible.
- Comply with all directions for use on product labels.
- Avoid repeated applications of similar products, even when targeting different pests. Rotate between mode of action (MoA) groups.
- Do not respray an apparent failure with the same product or another product from the same insecticide group.
- Do not exceed the maximum recommended use limits.
- Control weeds and cotton volunteers in fields and around the farm all year to minimise alternate hosts.
- Pupae bust as soon as possible after harvest.

- **Catastrophic aphid resistance to pirimicarb/ dimethoate.** Cotton aphid populations have gone from <1% resistance in 21/22 to ~30% resistant to pirimicarb/dimethoate, with spray failures reported in 22/23. Note there is cross resistance between Group 1A (dimethoate and phorate) and pirimcarb (Group 1B), but not chlorpyrifos. Do not follow an at-planting phorate treatment with pirimicarb or dimethoate as first foliar spray. Do not use pirimicarb and dimethoate in the same field. Avoid dimethoate usage until late season. If an end of season clean-up spray is required in fields that have had prior dimethoate, pirimicarb or neonicotinoid usage consider chlorpyrifos as an alternative option. Targeting aphids with diafenthuiron has contributed to mite resistance – always consider the presence of other pests when making control decisions
- **Fipronil bee risk.** While bees are susceptible to many insecticides used on cotton, fipronil risk to managed hives has been highlighted due to the extended residue risk. The industry recommends fipronil should not be used on flowering crops. Refer to label for statement about bees.
- **Consider your management options from within an area-wide perspective.** Keep up to date with insecticide resistance levels both in your region and more widely. Factor in pest mobility, and the proximity and growth stage of crops and other potential hosts in your local area when making management decisions.

To submit surviving aphids or mites for resistance testing, see the 'Sending samples for resistance testing' protocol on page 43.


MAGNET®
INSECT ATTRACTANT TECHNOLOGY
Approved alternative for pupae destruction as part of Bayer's Bollgard3® Resistance Management Plan
AgBiTech
Science. Nature. Viable Agriculture.
Developed by the Australian Cotton Industry and AgBiTech
Magnet® is a registered trademark of ABA Biologicals Pty Ltd. Bollgard® is a registered trademark of the Bayer Group.

More about resistance

The role of IPM, refuges and pupae-busting

IPM principles promote the conservation of beneficials to help prevent over-reliance on chemical control that leads to insecticide resistance and renders insecticidal control options ineffective. The benefits of preserving beneficials are particularly important for mites and SLW where there is increasing concern about resistance to key products. Early season pest control decisions can lead to flaring of these pests later in the season. Aim to preserve beneficials through the use of thresholds for all pests and consider the impact on beneficials when selecting insecticides. Refer to the *IPM* section on page 10 for more information.

Growing refuge crops is a pre-emptive resistance management strategy implemented to retard the evolution of field-scale resistance to Bt cotton (see the Bollgard RMP for more information). While the dilution effect of refuges is far less effective when insecticide resistance is already widespread and prevalent in the field population (such as with synthetic pyrethroids), there may be some benefit from the unsprayed refuge options for new chemistries.

Pupae busting is an effective, non-chemical method of preventing resistance carryover in diapausing *H. armigera* pupae. In conventional cotton, it is recommended that pupae busting be conducted as soon as possible after harvest. For Bollgard crops, refer to the pupae-busting requirements for your region in the current Resistance Management Plan (RMP).

Cross-resistance versus multiple resistance

Cross-resistance occurs when selection for resistance against one pesticide also confers resistance to another pesticide, either from the same mode of action or a different group. For example, the mechanism for pirimicarb resistance (Group 1A) in aphids also gives resistance to dimethoate (Group 1B). Cross-resistance is important as it means that a pest could be resistant to a chemical to which it has never been exposed.

Multiple resistance means that an insect is resistant to more than one MoA group. For instance, *H. armigera* can have metabolic resistance to synthetic pyrethroids (Group 3A) and nerve insensitivity to organophosphates (Group 1B).

The development of both cross-resistance and multiple resistance can be minimised by following the IRMS. For example, in the strategy for aphids, there is a break between the use of pirimicarb and dimethoate during which other chemistries should be used to minimise the number of pirimicarb-resistant aphids being exposed to dimethoate.

What about insecticide mixtures?

Insecticide tank mixtures are high-risk and a controversial strategy for managing resistance. They can undermine the IRMS by repeatedly selecting for resistance to their common components and across multiple chemical groups. When mixtures are used frequently, it also becomes difficult to determine whether each component is contributing equally to efficacy.

Some mix partners provide more than additive kill (synergism), but this is not always the case. As a general rule, mixtures are unnecessary in situations where individual products provide adequate control.

Insecticide mixes with herbicides or fungicides may affect the efficacy of the components if they have different application specifications. Different nozzles are required for insecticides, fungicides and herbicides, to ensure effective droplet sizes and application volumes which are not equal for these pesticides. 'Insurance' sprays may render pesticides ineffective due to poor application and contribute to resistance buildup.

For mixtures to be effective, their components should:

- Be equally persistent;
- Have different modes of action (and not be subject to the same routes of metabolic detoxification);
- Not be subject to resistance in the majority of the target pest population; and,
- Be tank-mix compatible.

It is illegal to use rates above those recommended on the label of an insecticide either alone or in mixtures.

Efficacy will not always improve at rates above the highest label rate or if two insecticides of the same chemical group are applied as a mixture.

What to do if you suspect a spray failure

Carefully assess the situation (the presence of live pests does not necessarily indicate insecticide failure). What is the insecticide's mode of action? Has it been given enough time to work? Was it applied correctly and in the right conditions?

Stomach poisons such as thiodicarb, foliar Bt, NPV and indoxacarb may not give maximum control until 5-7 days after application. Similarly, propargite, abamectin and diafenthiuron are slow acting and may take 7-10 days or longer to achieve maximum control. Insect growth regulators (IGRs) such as pyriproxyfen can take up to three weeks. In some cases pests may have ceased feeding following a treatment even though infestation levels remain high, meaning little if any economic damage to the crop.

A wide range of variables influence insecticide efficacy, including species complex, population density and age, crop canopy structure, application timing, the application method, carrier and solution pH (and their effects on coverage and the insecticide dose delivered to the target), environmental conditions, assessment timing and insecticide resistance expressed in the pest population. The interaction of all these factors determines the outcome of a pesticide application. While it is not possible to optimise all of these variables all of the time, the more compromises that are made, the greater likelihood of unsatisfactory efficacy.

It is also important to maintain realistic expectations of the efficacy that can be achieved. Satisfactory control of medium and large *Helicoverpa* larvae is unlikely, regardless of the insecticide treatment used. If a field failure is suspected to be due to insecticide resistance, contact the relevant researcher for advice on how to collect and send in samples:

- **Helicoverpa, mites, mirids, aphids and thrips: Lisa Bird 02 6763 1128.**
- **Whitefly: Jamie Hopkinson 07 4529 4152.**

Sending samples for testing can help confirm or rule out resistance as the cause of the spray failure and is an important part of assessing the presence of resistance across the industry.

After any spray failure, do not follow with an application that includes a product from the same insecticide MoA group.

The IRMS includes multiple pests

The IRMS aims to minimise selection across consecutive generations of the pest, therefore pest life cycles determine the length of the 'windows'. As the life cycles of *Helicoverpa* and various sucking pests are very different, the strategy for one will not manage resistance for the other.

Helicoverpa

Most chemicals are restricted to windows of 1-2 generations to account for the practicalities of pest control. To counteract this compromise there are additional restrictions on the maximum number of applications for each chemical group.

Mites and aphids

The resistance strategy for short life cycle pests depends on rotation between different MoA groups to avoid selection over successive generations. Non-consecutive use of chemistries is particularly important for aphids as they reproduce asexually (all offspring from a resistant aphid will be resistant). There are also restrictions on the maximum number of uses for individual products and chemical groups to further encourage rotation of chemistries.

Mirids

The industry has begun resistance monitoring in mirids as a precaution. Many of the products registered for mirid control in cotton include registration for the control of other pests, so it is critical that mirid control decisions also consider sub-threshold populations of other pests that are present. Using dimethoate for mirid control can inadvertently select for both dimethoate and pirimicarb resistance in aphids. Use of neonicotinoid products for mirid control (particularly if also used as a seed treatment) can inadvertently select for resistance in aphids.

When selecting an insecticide, consider the options remaining for subsequent aphid control, if required.

Silverleaf whitefly (SLW)

The IRMS includes all commercially available products registered for use against SLW in cotton. While the regional 30 day pyroproxyfen window has been removed, the product is still limited to a single application per season.

In-season troubleshooting

Ratification of the IRMS prior to the start of each season is the responsibility of Cotton Australia's Transgenic and Insect Management Strategy (TIMS) Committee. A Troubleshooting sub-committee is empowered to act on TIMS' behalf during the cotton season to respond to emergency requests to vary the IRMS for a district (or part of a district) for the remaining season. A request can be initiated by any grower or consultant, but will not be considered unless it is presented with clear evidence of discussion and majority support at a local level. For further information contact Cotton Australia (02 9669 5222).

IRMS in grains

Resistance management strategies developed for key grains pests should be used in conjunction with the Cotton IRMS.

ipmguidelinesforgrains.com.au/ipm-information/resistance-management-strategies

For other resistance management strategies and a list of insecticide MoA groups visit CropLife Australia at croplife.org.au

A quick look at insecticide mode of action (MoA) groups

Insecticide MoA groups commonly used in Australian cotton

MOA GROUP	ACTIVE
1A (carbamates)	carbaryl methomyl pirimicarb thiodicarb
IB (organophosphates)	chlorpyrifos dimethoate phorate
2B (fiproles)	fipronil
3A (pyrethroids)	bifenthrin cyhalothrin (gamma- and lambda-) cypermethrin (incl alpha- and beta-) deltamethrin esfenvalerate permethrin
4A (neonicotinoids)	acetamiprid clothianidin dinotefuran imidacloprid thiamethoxam
4C (sulfoximines)	sulfoxaflor
5 (spinosyns)	spinetoram
6 (avermectins)	abamectin emamectin benzoate
7C (juvenile hormone mimics)	pyriproxyfen
9B	pymetrozine
9D (pyropenes)	afidopyropen
10B	etoxazole
11A	Bacillus thuringiensis
12A	diafenthiuron
12C	propargite
16	buprofezin
22A (oxadiazines)	indoxacarb
23	spirotetramat
28 (diamides)	chlorantraniliprole cyantraniliprole
29	flonicamid
31 (baculoviruses)	Helicoverpa sp. viruses
36	dimpropyridaz
UNE (botanical extracts)	Clitoria ternatea extract
UNM (mineral oils +)	paraffinic oils

Insecticides are classified by how they affect arthropods. Grouping products by their mode of action (MoA) and further into subgroups with distinct chemical structures (denoted by letters) allows the user to see which products act on the pest in a similar way and choose products that are less likely to select for target site resistance.

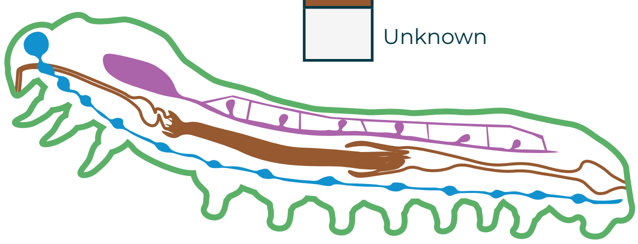
The potential for cross-resistance is higher between the more closely related actives within a subgroup, however cross-resistance can also occur within the wider group (for example between 1A and 1B in aphids).

Rotating actives is a key part of the IRMS for cotton. Where possible, avoid consecutive applications of the same product, even if targetting different pests and do not respray an apparent control failure with a product from the same group.

Colours used in the table highlight the physiological target of the MoA group. Common names for groups are displayed if they are different from the registered active products.

Physiological target:

- Nerve / Muscle
- Growth / Development
- Respiration
- Midgut
- Unknown



Example diagram of an insect cross-section showing some of the systems potentially affected by insecticides, including the respiratory, digestive and nervous systems.

For more information on the MoA classification system, or to search for groups online (or via an app) visit the Insecticide Resistance Action Committee website:
irac-online.org/mode-of-action

CRDC
COTTON RESEARCH AND DEVELOPMENT CORPORATION

Insecticide Resistance Management Strategy 2024/25

Best practice product windows and use restrictions to manage insecticide resistance in insect pests of Australian cotton

EMERGENCE TO FIRST FLOWER | FLOWERING | FIRST OPEN BOLL TO 60% OPEN

← Canopy closure

INCREASING SELECTIVITY DECREASING

CONSIDER IMPACT ON BENEFICIALS & BEES (TABLE 5 CPMG)

- **Helicoverpa viruses** (Gemstar®, Helicovex®, Vivus®) Group 31
- **Pirimicarb** Group 1A (avoid consecutive usage) — Note 1
- **Paraffinic oil** Group UNM
- **Pyriproxyfen** Group 7C — Use an alternative from 5% open cotton — Note 5, 6
- **Sero-X®** Group UNE
- From late squaring — **Etoxazole** Group 10B
- **Buprofezin** (Applaud®) Group 16 — Use an alternative from 5% open cotton — Note 5, 8
- **Chlorantraniliprole** Group 28 (max 4x Group 28 per season)
- **Afidopyropen** (Versys®) Group 9D
- **Spinetoram** (Success Neo®) Group 5
- **Diafenthiuron** Group 12A — Note 4, 5
- **Pymetrozine** Group 9B
- **Indoxacarb** Group 22A (use until 31 January)
- **Dimpropyridaz** (Efficon®) Group 36
- **Cyantraniliprole** (Exirel®) Group 28 (max 4x Group 28 per season)
- **Spirotetramat** Group 23 — Note 5, 7
- **Flonicamid** (MainMan®) Group 29
- **Abamectin** Group 6 (max 3x Group 6 per season) — Note 3
- **Emamectin benzoate** Group 6 (max 3x Group 6 per season)
- **Propargite** Group 12C
- **Sulfoxaflor** (Transform®) Group 4C — Note 2
- **Fipronil** Group 2B — *Do not apply to flowering crops* — Note 11, 12
- **Neonicotinoids** (acetamiprid, clothianidin, dinotefuran, imidacloprid, thiamethoxam) Group 4A — Note 2, 5, 11, 12
- If using mixes, consider each group's risk — **Acetamiprid + Emamectin** Group 4A + Group 6
- **Carbamates** (methomyl, thiodicarb) Group 1A — Note 9
- **Phorate** 1B — Note 1
- **OPs** (chlorpyrifos, dimethoate) Group 1B — Note 1
- **Synthetic pyrethroids** Group 3A — Note 5, 10

Canopy closure →

How to use the IRMS

The IRMS aims to reduce the chance that highly mobile pests would be repeatedly exposed to the same insecticide/miticide mode of action group by limiting the timing of insecticide availability. The strategy focuses on different crop stages (before, during, and after flowering), with particular attention to canopy closure. From a broader management perspective, it's important that crops are sown at a similar time within a region. This helps prevent mobile pests, such as silver leaf whitefly, from moving between fields and repeatedly encountering the same chemical treatments where crops have very different growth stages within the same district. If late-sown crops require management, where practical choose products that align with the average crop development stage for your region.

Products are listed in order of decreasing selectivity. For all pest species, aim to use the most selective option, delaying or avoiding the use of broad-spectrum products.

See CottonInfo's website for the latest resistance monitoring results.

Use restrictions

The colours of insecticide windows represent the maximum number of applications per crop per season for any given product or product group. Note: some products in the 'avoid repeated use' may have a maximum application number stated on the label.

- No more than 1 application per season
- No more than 2 applications per season
- No more than 3 applications per season
- Avoid repeated applications of same group

Additional restrictions are included to the right of the table; these link to the specific footnotes below.

IRMS notes:

Mirids: No resistance issues identified, but insecticides targeting mirids also select for resistance in secondary pests (aphids, mites & SLW).

Aphids: High level of caution recommended. Rapid increase in resistance to pirimicarb/dimethoate and field failures are now likely.

1. Widespread early season dimethoate use has caused catastrophic pirimicarb resistance in aphids leading to field failures. Do not use pirimicarb and dimethoate in the same field. If phorate is applied at planting DO NOT use pirimicarb or dimethoate as an early season spray due to cross resistance.
2. Failures of neonicotinoids against aphids have been confirmed. DO NOT follow a neonicotinoid seed treatment with a foliar neonicotinoid when aphids are present. If there is an alternative do not follow a neonicotinoid with sulfoxaflor.

Mites: A high level of caution is recommended as mite control options are becoming limited. In northern NSW there is moderate to high resistance to abamectin and diafenthiuron. See IRMS for product window recommendations and note that there will be product rotation recommendations for northern NSW developed for 2024/25 following CGA pre-season consultation. Note that there are no miticides recommended for use prior to late squaring. Ensure cotton is sown into clean fields (be aware that planting into patches of herbicide-treated weeds can result in early season mite infestation due to displacement). If encountering severe mite infestation on newly emerged cotton please contact your local CottonInfo REO or IPM Technical Lead (Paul Grundy 0427 929172) to discuss options.

3. Addition of abamectin to mirid sprays has caused high level resistance in mites. Base miticide decisions on thresholds and do not apply prophylactically with mirid sprays.
4. Moderate to severe resistance to diafenthiuron has been identified in mites. DO NOT use more than 1 application per season irrespective of target pest (refer to label).

Silverleaf whitefly: Pyriproxyfen resistance stabilised but emerging resistance in other SLW products (e.g Spirotetramat). Continue adhering to IRMS recommendations for all SLW products. SLW has low resistance to pyrethroids in all regions.

5. Refer to 2024 SLW fact sheet www.cottoninfo.com.au/publications/2024-silverleaf-whitefly-sampling-and-thresholds for additional guidance.
6. Resistance to pyriproxyfen is low but widespread. To avoid loss of product efficacy, ensure all on-farm use is within a 30 day window and DO NOT use more than 1 application of pyriproxyfen per season.
7. Spirotetramat resistance has increased and been detected in most regions. Note that resistance levels are EXTREME in Lockyer and Bowen regions. The dominant target site resistance mechanism means resistance can develop rapidly and reversal of resistance is unlikely. DO NOT use spirotetramat more than once per season unless targeting mealybugs.
8. Unless targeting mealybugs, buprofezin usage should not exceed one application per field.

Helicoverpa armigera: Resistance stabilised. Continued adherence to IRMS recommended.

9. Additional applications can be made if targeting *Helicoverpa* moths using Magnet®.
10. High SP resistance is present in *Helicoverpa armigera* populations. Expect field failures. Low resistance is present in SLW.

Thrips: Moderate levels of resistance have been detected to fipronil in cotton seedling thrips. Avoid usage on establishing crops. Continued adherence to IRMS recommended.

11. Imidacloprid (neonicotinoid) and fipronil resistance in cotton seedling thrips is likely. If resistance is suspected, phorate is an appropriate at-planting alternative. Consider alternatives to neonicotinoids and fipronil for first foliar spray.

Statement on bees

12. Refer to label statement about bees.

ALWAYS FOLLOW LABEL DIRECTIONS.
CONSIDER IMPACT ON BENEFICIALS & BEES (Table 6 in the *Cotton Pest Management Guide 2024-25*).
IMPLEMENT AN IPM STRATEGY INCLUDING GOOD FARM HYGIENE AND CONTROL OF OVERWINTER HOSTS.
PUPAE BUST CONVENTIONAL COTTON CROPS AFTER HARVEST.

Bollgard 3 Resistance Management Plan (RMP)

Resistance is the greatest threat to the continued availability and efficacy of Bt cotton in Australia. The RMP was established as a pre-emptive measure to mitigate the risks of resistance developing to any of the insecticidal proteins contained in Bt varieties, and aims to prevent field level changes in resistance.

Crops with multiple toxins should be relatively robust, especially if the 'stacked' toxins kill insects in different ways. But the resilience of a stack depends on how well each toxin controls larvae and the levels of resistance to each toxin at the time that the technology is introduced. Bollgard 3 cotton contains Cry1Ac, Cry2Ab and Vip3A, however with over 90% of the industry using this technology, it is not impossible that *Helicoverpa* could adapt. It is therefore imperative that the RMP is implemented effectively by all growers to ensure the longevity of the product.

Current status of Bt resistance in Australia

The frequency of Cry1Ac resistance genes is still relatively low, the baseline frequency of Cry2Ab and Vip3A resistance genes for F1 screening in *H. armigera* and *H. punctigera* populations is currently about 2%. Additionally, the expression of Cry1Ac and Vip3A varies throughout the season and is not always high enough for each insecticidal protein to individually control susceptible insects. None of the resistance genes identified confer cross-resistance to the other insecticidal proteins.

The data for current frequencies is sourced from Bayer's 2022-23 monitoring program. Unless otherwise stated, other information around trends in resistance frequencies draws on data collected over time from CSIRO and Bayer. The frequencies of these recessive resistance genes are currently not at a level that impacts performance of the technology (there is currently no resistance to Bollgard 3 that affects its performance against *H. armigera* or *H. punctigera*).

Cry1Ac: A gene present in field populations of *H. armigera* has the potential to confer high-level resistance to Cry1Ac. This largely recessive gene occurs at a low frequency – probably less than 5 in 10,000 (<0.05%). It also has a high fitness cost (i.e. resistant individuals develop slowly and are more likely to die) but this disadvantage is unlikely to greatly impact on the development of resistance.

At least 2 different forms of resistance to Cry1Ac have been isolated from field populations of *H. punctigera*. Frequency of both is 1 in 1000 (0.1%).

Cry2Ab: A recessive gene that confers high level resistance to Cry2Ab is present in field populations of *H. armigera*. The mechanism is likely to be an alteration of a binding site in the gut of the insect. The current estimate of resistance frequency is approximately 2% or less.

A recessive gene that confers high level resistance to Cry2Ab is present in field populations of *H. punctigera*, and demonstrates the same broad characteristics as the *H. armigera* Cry2Ab-resistance, and occurs at a frequency of approximately 1%.

Vip3A: At least two different types of Vip3A resistance have been identified in both *H. armigera* and *H. punctigera* populations. Data supplied by CSIRO and Bayer suggests that the frequency of all Vip3A resistances is around 1 in 100 (1%).

Both CSIRO and Bayer data sets show that there is no significant difference in the frequencies of Cry2Ab and Vip3A resistance alleles over the longer term. Irrespective of changes through time, the frequencies of Cry2Ab and Vip3A in *H. armigera* and *H. punctigera* are higher than expected and of concern. Until the widespread adoption of Bt cotton there was presumably little exposure of *Helicoverpa* to this toxin, and therefore minimal selection for resistance. Although the Cry2Ab and Vip3A toxins are present in some Australian soils, they are not common compared to the Cry1Ac toxin, yet resistance to the Cry1Ac toxin in *Helicoverpa* is rare.

H. punctigera has the capacity to develop resistance to insecticide sprays but it has been presumed that any resistance selection in cotton regions was kept in check by dilution from susceptible immigrants from central Australia each spring. There may be some recent changes to the ecology of *H. punctigera* that could impact on their ability to develop resistance including a greater tendency to overwinter in cotton regions and less immigration of inland individuals than in the past due to low rainfall inland.

How is resistance monitored?

CSIRO, with funding support from CRDC, implemented a monitoring program from 2003-18, that adapted to new varieties and circumstances each season. Bayer also invests in an annual program monitoring field populations of *Helicoverpa* spp. for resistance of all three proteins contained in Bollgard 3 cotton (Cry1Ac, Cry2Ab and Vip3A), providing an early warning of the onset of resistance. The programs have been used by industry to make decisions about the need to modify the RMP each season to ensure its ongoing effectiveness.

Originally, all resistance monitoring used F2 screens (which involve testing the grandchildren of pairs of moths raised from eggs collected from field populations). This method detects all previously isolated and potentially new types of resistances but takes about 10 weeks and is very labour-intensive, so protocols were developed to halve the testing time. F1 screens involve testing the offspring of single-pair matings between a moth from resistant strains maintained in the laboratory and a moth raised from eggs collected from field populations. This method works as the various isolates of Cry2Ab, Cry1Ac and Vip3A detected to date are of the same kind. Both methods are still utilised to measure known forms of resistance and to detect any new forms present in *Helicoverpa* populations.

Although some individuals that carry two copies of the resistance genes (homozygotes) have been detected for all toxins in both species, the vast majority of detected resistant individuals carry only one copy (heterozygotes) and therefore are controlled by Bollgard 3. Any homozygote (resistant to one of the proteins in Bollgard 3 cotton) is also controlled by Bollgard 3.

A molecular tool for Bt resistance testing using historical samples is currently under development, supported by CSIRO, CRDC and Bayer.


ADAMA
Skope®
Choose a wider view.

A helicoverpa larva damaging a maturing boll is no longer a common sight in Australia, thanks to insecicidal protein technology and the industry's adherence to the RMP.
Paul Grundy, Qld DAF

Elements of the Bollgard 3 RMP

The RMP imposes limitations and requirements for management on farms that grow Bollgard 3 cotton. Its five elements are:

- Mandatory growing of refuges;
- Control of volunteer and ratoon plants;
- Planting window or planting restrictions;
- Restrictions on the use of foliar Bt; and,
- Mandatory cultivation of crop residues.

In theory the interaction of all of these elements should effectively slow the evolution of resistance. While there have been no reported field failures of Bt cotton due to resistance in Australia, the higher than expected baseline frequency of Cry2Ab and Vip3A is a major concern, and it is imperative that all Bollgard 3 users are responsible stewards of the technology. In particular, it is critical that close attention is paid to managing associated refuges, and that if required, effective pupae busting occurs in a timely fashion.

Bayer and the TIMS Bt Technical Panel will continue to work together to annually assess new information on resistance frequencies in *Helicoverpa* species and provide background information and recommendations for the Cotton Australia convened TIMS Committee.

For full details of how to practically implement the RMP, please refer to the RMP document, your Technology Service Provider (TSP) or your Bayer Territory Business Manager.

RMP tactics

1. Using refuges

While the use of planting windows and use of two or three Bt genes are aimed at reducing selection pressure for Bt resistance, refuge crops are used to balance or counter the selection that will still occur. Refuge crops assist genetic dilution by generating significant numbers of susceptible moths (SS) that have not been exposed to selection pressure from the Bollgard 3 insecticidal proteins. Moths produced in refuge crops disperse to form part of the local mating population where they reduce the chance that resistant moths (RR) emerging from Bollgard 3 crops will meet and mate. The offspring from matings between one resistant and one susceptible moth carry one gene from each parent (RS) and are referred to as heterozygotes. In the cases of Bt resistance identified so far, heterozygotes and homozygotes are still controlled by Bt cotton.

It is crucial that the timing of the production of moths from refuges matches that of Bollgard 3 crops.

Refuge crop areas must be in close proximity to the Bollgard 3 crop(s) to maximise the likelihood that moths emerging from the Bollgard 3 crop will mate with susceptible moths from the nearby refuge crop. During the summer cropping season a significant part of the *Helicoverpa* population may move only a few kilometres, depending on the mix of crops and their attractiveness at the time of moth emergence. Therefore the best location for a refuge crop is within 2 km of a Bollgard 3 crop, with a road or drain between the two to minimise the movement of large larvae from the refuge to the crop.

Managing resistance is a population level activity, and every refuge makes an important contribution to both the overall RMP for the valley and, because *Helicoverpa* disperse widely, for the whole industry. It is imperative that all refuges produce their quota of susceptible (SS) moths. Bayer audits the quality of refuges on every farm that grows Bollgard 3 to ensure that they are well maintained and effective.

The relative sizes of refuge crops required are based on *Helicoverpa* moth emergence for different crop types, and use a refuge of 10% unsprayed cotton as an initial reference point for Bt crops. On average, pigeon pea produces twice as many moths as the same area of unsprayed cotton, hence only a 5% refuge of pigeon pea is required.

The introduction of Bollgard 3 enabled refuge requirements to be reduced to 5% unsprayed cotton and 2.5% pigeon pea, representing the industry's confidence in the robustness of a 3 gene product in managing resistance risk combined with an industry commitment to improve the quality of refuges. Note that a recent review of the CQ system has seen refuge requirements for longer grown crops revert back to Bollgard 2 levels. Bollgard 3 refuges must be a minimum of 0.5 ha and at least 24 m wide to account for possible insecticide drift onto the refuge.

The productivity of refuges will vary considerably across regions and seasons. Improving the production potential of each individual refuge is an integral component of the RMP. Growers must ensure that on farm refuge management is a priority. Looking after refuges, including nutrition, weed control, timely irrigation and all factors that make the refuge 'attractive' to female moths laying eggs, is the key to ensuring that they are effective. Guidelines on refuge management are provided in the RMP and the following unsprayed pigeon pea refuge agronomy guide (pages 75-76).

Note that the term 'unsprayed' encompasses all management activities which are likely to reduce the survival of *Helicoverpa* in the refuge. For example, insecticides with activity against *Helicoverpa*; inundative beneficial releases; or, food sprays to attract natural enemies; cannot be used.

2. Controlling volunteers and ratoons

It is important to prevent both the establishment of conventional cotton in Bollgard 3 fields and the presence of Bollgard 3 cotton volunteer plants in a conventional crop or unsprayed refuge. Larger larvae are less susceptible to Bollgard technology. Heterozygous (RS) larvae that emerge from eggs laid on conventional cotton may grow and during their development move onto Bollgard 3 cotton plants. In this way RS larvae become exposed to Bt insecticidal protein at later growth stages when they can survive to produce offspring. This will lead to an increase in the frequency of resistant individuals (both RS and RR) in the population. If the field is designated as a refuge crop, the presence of the Bollgard 3 cotton volunteers will diminish the value of the refuge.

3. Planting windows

The planting window limits the number of generations of *Helicoverpa* exposed to Bollgard 3 cotton in any one season, restricting the selection pressure to develop resistance.

In developing the Bollgard 3 RMP, late crops were identified as having the highest potential to increase resistance risk due to increased length of exposure. So the emphasis shifted toward using mitigation tactics that reduce the risk of late crops and Bollgard 3 volunteers, with less emphasis on reducing season length at the start of the growing season. However, planting windows still remain an important mitigation tactic for Bollgard 3, particularly in warmer climates where cotton and *Helicoverpa* can survive and reproduce all year round.

4. No Bt sprays

Preventing the use of foliar Bt on all refuges (sprayed and unsprayed), reduces the exposure of *Helicoverpa* to Bt outside the plant and maximises the likelihood of producing moths that are susceptible (SS) rather than resistant (RR) to Bt. This is an important part of the RMP because susceptible refuge moths are presumed to mate with any resistant moths in the population to produce heterozygotes (RS) that are killed by Bt cotton.

5. Pupae destruction

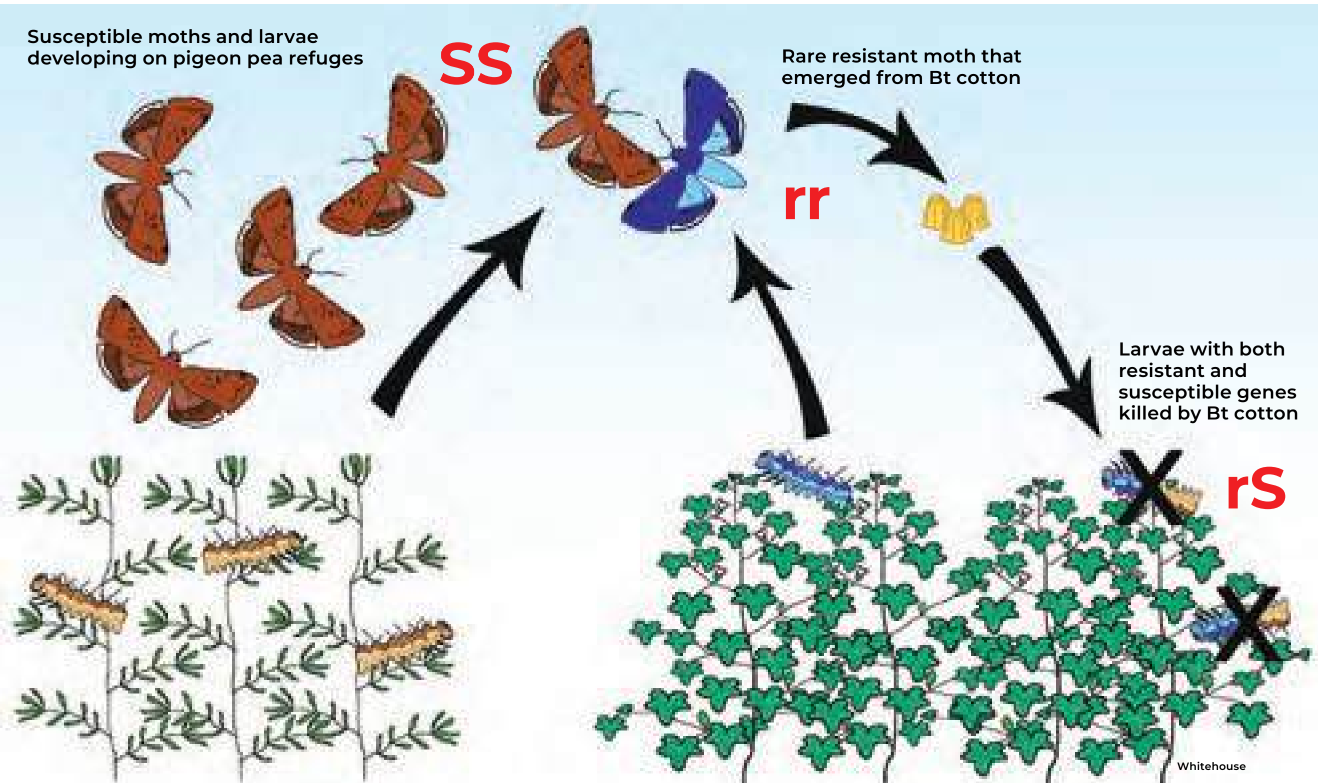
Pupae busting is a highly effective mitigation tactic for reducing resistance risk in areas where *Helicoverpa* have a diapause stage, provided it is performed well and at the right time. Although minimal larvae are expected to survive in Bollgard 3 cotton, those that do are most likely carrying resistance genes and are precisely the ones that must be killed so that the next generation of moths (emerging the following spring) are not carrying resistance alleles.

Introducing a defoliation date for Bollgard 3 that determines whether a field requires pupae busting ensures only those fields most likely to contain highest risk pupae in diapause are being cultivated. Based on the *Helicoverpa* 'Diapause Induction and Emergence model' that was developed from field research, 31 March is when the likelihood of diapause occurring is 50% (NSW and Southern Queensland). Growers who defoliate earlier are still encouraged to pupae bust. A review of research into pupae busting also indicated that the majority of pupae were found within the hill, closer to the plant line, compared to the furrow, so the pupae busting guidelines have been changed to reflect this. Overall, the changes are intended to make pupae busting more targeted and effective while also improving the practicalities of the operation for growers. Refer to the RMP for details on pupae busting requirements for Bollgard 3.

Do not pupae bust unsprayed refuges. Once Bollgard 3 crops begin flowering and are highly attractive to *Helicoverpa* moths, the corresponding refuge should not be cultivated (e.g. for weed control, row formation etc). Destruction of refuges must not occur until after the destruction of corresponding Bollgard 3 crops.

Sprayed refuges and late conventional cotton crops should be pupae busted as soon as possible after picking to manage resistance to other insecticide products.

In warmer areas (central Queensland and northern Australia), *Helicoverpa* pupae produced late in the cotton season do not remain in the soil, but emerge within 15 days of pupating, so trap crops are required as an alternative. Trap crops of pigeon pea are planted after the cotton and are timed to be at their most attractive after the cotton has cut-out. Moths emerging from Bollgard 3 cotton fields at the end of the season will be attracted to the trap crops and are likely to lay their eggs there. Once the cotton has been harvested, the trap crop should be destroyed, removing the food source from the larvae (which will then die) and the soil then cultivated to destroy any pupae. It is critical to time the destruction so that it corresponds with the period of most effective kill of the range of life stages of *Helicoverpa*. See the RMP for more details.



Mandatory growing of refuges is an important part of the Bollgard 3 RMP.

Guidelines for Helicoverpa management in Bollgard 3 cotton

Since 2005–06 there have been occasional reports of larvae surviving for several weeks at threshold levels in Bt fields. All affected fields were at mid-flowering to late-flowering and included *H. armigera* and *H. punctigera*.

Work conducted by CSIRO and Bayer demonstrated that this survival was not due to Bt resistance or because of the absence of Bt genes in the cotton. Larvae exhibit strong behavioural responses to the Bt insecticidal protein in Bt cotton plants, and attempts to avoid the Bt toxins can result in movement of larvae within and between plants, resulting in an apparent feeding preference for flowers. These behaviours, coupled with the sometimes temporal and spatial variability of Bt toxin expression, can result in some larvae becoming established.

For resistance management reasons, larvae that reach thresholds in Bollgard 3 fields should be controlled by spraying. However, work conducted by Bayer suggests that a yield penalty associated with larvae survival in Bollgard 3 fields is unlikely. Bt cotton plants could tolerate up to 100% square loss at early flowering, up to 100% square removal alone or in combination with 30% boll damage at peak flowering, and 30% boll damage at late flowering, without impacting yield or quality. Therefore Bt cotton seems to compensate well for damage caused by larvae and the current threshold can be used in most situations without causing significant yield reduction.

It is critical that the distribution and proportions of fields that are affected by surviving larvae, and the number of fields that are sprayed to control *Helicoverpa* is recorded. Part of the end of season general survey of Crop Consultants Australia (CCA) members includes questions about control of *Helicoverpa* in Bollgard 3 fields.

If you experience above threshold levels of *Helicoverpa* in your Bt fields please immediately contact:

- **Sharon Downes (CSIRO): 0427 480 967**
- **Amanda Padovan (CSIRO): 0400 358 051 or**
- **Kristen Knight (Bayer): 0429 666 086**

Insecticide selection for Bollgard 3 crops

When controlling *Helicoverpa* within Bollgard 3 crops, insecticide selection should comply with the cotton industry's Insecticide Resistance Management Strategy (pages 64-65). The beneficial/pest ratio (described on page 31) should also be given careful consideration before applying insecticides. If an insecticide is required, choose the most effective product that is the least disruptive to the beneficial complex (refer to Table 6). While foliar Bt can be used on Bollgard 3 crops, it is a requirement of the Bollgard 3 cotton Resistance Management Plan that foliar Bt not be used on any refuge crops.

Helicoverpa thresholds

Do not include eggs or any larvae <3 mm long in spray threshold counts. For economic management of *Helicoverpa*, larval populations should be controlled with an insecticide if a threshold of:

- 2 larvae/m >3 mm long are found over 2 consecutive checks; or,
- 1 larvae/m >8 mm long is found in any check.

Application of these thresholds requires careful and accurate assessment. Checks should be made over the whole plant including the terminals, squares and especially flowers and small bolls. Be sure to objectively assess larval size. A complete description of the sampling protocols for *Helicoverpa* can be found on page 31.

For the Bollgard 3 Schedule, refer to your Technology User Agreement (TUA). Information on the Resistance Management Plan for Bollgard 3 cotton is available at bollgard3.com.au

Both RMPs, including contact details for Bayer's Territory Business Managers, can be downloaded from bollgard3.com.au.

RESISTANCE MANAGEMENT PLAN

CENTRAL & SOUTHERN QUEENSLAND, NEW SOUTH WALES & VICTORIA

Developed by Monsanto Australia Pty Ltd

The Resistance Management Plan is based on three basic principles: (1) minimising the exposure of *Helicoverpa* spp. to the *Bacillus thuringiensis* (Bt) proteins Cry1Ac, Cry2Ab and Vip3A; (2) providing a population of susceptible individuals that can mate with any resistant individuals, hence diluting any potential resistance; and (3) removing resistant individuals at the end of the cotton season. These principles are supported through the implementation of five elements that are the key components of the Resistance Management Plan. These elements are:

1. Planting timing restrictions;
2. Refuge crops;
3. Control of volunteers and ratoon cotton;
4. Pupae destruction/trap crops; and
5. Spray limitations

Growers of Bollgard 3 cotton are required to practice preventative resistance management as set out below. Compliance with the Resistance Management Plan is required under the terms of the Bollgard 3 Technology User Agreement and per the Conditions of Registration for Bollgard 3 under the *Agricultural and Veterinary Chemicals Act 1994.*

1. PLANTING TIMING RESTRICTIONS

Victoria, New South Wales and Southern Queensland

All Bollgard 3 crops and refuges must be planted into moisture or watered-up between August 1 and before December 31 each year, unless otherwise specified in this Resistance Management Plan.

Central Queensland

Planting Window 1:

All Bollgard 3 crops and refuges must be planted into moisture or watered-up between August 1 and before October 31 each year, unless otherwise specified in this Resistance Management Plan. Bollgard 3 can only be planted from August 1 to October 31 each year. Seed cannot be planted wet or dry prior to August 1.

- All growers who plant Bollgard 3 cotton between August 1 and October 31 (planting window 1) and intend to grow their Bollgard 3 cotton for longer than 230 days (measured from the first day of planting for each field to the date of complete crop destruction, defined as slashed or mulched and controlled to prevent regrowth) must plant 10% irrigated unsprayed cotton refuge (or its equivalent – must be irrigated) of the Bollgard 3 area that will be grown longer than 230 days. Growers intending to grow Bollgard 3 cotton fields for longer than 230 days are required to comply with the timing conditions stipulated in "General conditions for all refuges" section (a).
    - e.g., The additional refuge required for irrigated Bollgard 3 cotton grown longer than 230 days must be planted within 3 weeks of the first sowing date of Bollgard 3.
- Any Bollgard 3 fields that are planted between August 1 and October 31 (planting window 1) that only have an associated 5% unsprayed cotton refuge (or its equivalent) must be destroyed 230 days (or prior) after planting (measured from the first day of planting for each field).
    - e.g., A Bollgard 3 field that begins planting on August 1 that only has an associated 5% unsprayed cotton refuge (or its equivalent) must be completely destroyed by March 18.
- Any Bollgard 3 cotton that is planted in planting window 1 and is grown for greater than 230 days with only a 5% unsprayed cotton refuge (or its equivalent) will be recorded as non-compliant and be issued with a Resistance Risk Management Plan (RRMP).

Planting Window 2:

Any Bollgard 3 crops planted into moisture or watered-up after October 31 and up to December 31 must plant additional refuge as specified in Table 3 and 4. Bollgard 3 cannot be planted dry prior to December 31 if not watered up.

2. REFUGES

Growers planting Bollgard 3 cotton will be required to grow a refuge crop that is capable of producing large numbers of *Helicoverpa* spp. moths which have not been exposed to selection with the Bt proteins Cry1Ac, Cry2Ab and Vip3A. These unselected moths are expected to dominate matings with any survivors from Bollgard 3 crops and thus help to maintain resistant alleles to the Bt proteins Cry1Ac, Cry2Ab and Vip3A at low frequencies.

All refuge options are based on the requirement of a 5% unsprayed cotton refuge or its equivalent, as determined by the relative production of *Helicoverpa* spp. from each of the refuge types as described in Tables 1 and 2 for irrigated and dryland production scenarios, respectively.

For each area of irrigated Bollgard 3 cotton planted, a grower is required to plant one or more of the following:

Table 1. Irrigated Bollgard 3 cotton refuge options

CROP	CONDITIONS	% OF BOLLGARD 3
Cotton	Irrigated, sprayed conventional cotton	100
	Irrigated, unsprayed conventional cotton	5
Pigeon pea	Fully irrigated, unsprayed	2.5

Table 2. Dryland Bollgard 3 cotton refuge options

CROP	CONDITIONS	% OF BOLLGARD 3
Cotton	Dryland or irrigated, sprayed conventional cotton	100
	Dryland or irrigated, unsprayed conventional cotton	5
Pigeon pea	Dryland or fully irrigated, unsprayed. Dryland pigeon peas can only be planted with an approved plan from Monsanto Australia	2.5

Table 3: Irrigated Bollgard 3 cotton refuge options for Central Queensland planted in planting window 1 and grown for longer than 230 days OR planted in planting window 2 (after October 31)

CROP	CONDITIONS	% OF BOLLGARD 3
Cotton	Irrigated, sprayed conventional cotton	100
	Irrigated, unsprayed conventional cotton	10
Pigeon pea	Fully irrigated, unsprayed	5

Table 4: Dryland Bollgard 3 cotton refuge options for Central Queensland planted after October 31

CROP	CONDITIONS	% OF BOLLGARD 3
Cotton	Dryland or irrigated, sprayed conventional cotton	100
	Dryland or irrigated, unsprayed conventional cotton	10
Pigeon pea	Dryland or fully irrigated, unsprayed. Dryland pigeon peas can only be planted with an approved plan from Monsanto Australia	5

Note: *Unsprayed means not sprayed with any insecticide that targets any life stage of* Helicoverpa *spp.*

Bt products must not be applied to any refuge (including sprayed cotton).

If the viability of an unsprayed refuge is at risk due to early or late season pressure by Helicoverpa *spp., or any other caterpillar species, contact Monsanto Australia immediately. With prior approval from Monsanto Australia, a non-Bt heliocide can be applied.*

For the purposes of this Resistance Management Plan, conventional cotton includes any cotton varieties that do not have Bt proteins in the plant that control Helicoverpa *spp. larvae.*

General conditions for all refuges:

(a) Refuge crops are to be planted and managed so that they are attractive to *Helicoverpa* spp. during the growing period of the Bollgard 3 cotton varieties.

Irrigated: It is preferable that all refuge is planted within the 2 week period prior to planting Bollgard 3. If this is not possible, refuge planting must be completed within 3 weeks of the first day of sowing of Bollgard 3. At this time, sufficient refuge must have been planted to cover all of the Bollgard 3 cotton proposed to be planted for the season (including Bollgard 3 already planted and any that remains unplanted). If additional Bollgard 3 is planted after this date which is not already covered by refuge, additional refuge must be planted as soon as possible and no more than 2 weeks after sowing of the additional Bollgard 3.

Dryland: A dryland refuge must be planted within the 2 week period prior to the first day of planting Bollgard 3 cotton.

(b) Pigeon pea refuges should not be planted until the soil temperature reaches 17°C, which is a requirement for germination, and should also be planted into moisture to ensure successful germination. If soil temperatures are not suitable to allow germination of pigeon peas in line with condition (a), an alternative refuge must be planted in its place within the prescribed period (under (a) above).

(c) All refuges should preferably be planted into a fallow or rotation field that has not been planted to Bt cotton in the previous season to avoid volunteer and ratoon cotton. See Refuge Management Guide for all unsprayed refuges.

(d) Once Bollgard 3 cotton begins to flower, the corresponding refuge must not be cultivated and ideally should begin to flower.

(e) All refuges are to be planted within the farm unit growing Bollgard 3 cotton no more than 2 km from the associated Bollgard 3 cotton field. For any cases where it may not be possible to plant the refuge within 2 km from the associated Bollgard 3, approval must be sought from Monsanto Australia.

(f) To minimise the possibility of refuge attractiveness being affected by herbicide drift, non-herbicide tolerant refuges should be separated from herbicide tolerant Bollgard 3 cotton crops by a sufficient distance to minimise such drift, but no more than 2 km from the Bollgard 3 cotton.

(g) To account for possible insecticide drift, the options for the width of refuge crops vary according to spray regime. If any sprayed conventional cotton is grown on the same farm unit, Bollgard 3 refuge crops must be at least 48 metres wide and each refuge area must be a minimum of 2 hectares. If sprayed conventional cotton is not grown on the same farm unit, Bollgard 3 refuge crops must be at least 24 metres wide and each refuge area must be a minimum of 0.5 hectares. Different unsprayed refuge options may be planted in the same field as a single unit; however, a sprayed conventional cotton refuge must not be planted in a field that is also planted to an unsprayed refuge type unless a sufficient buffer is in place to prevent insecticide drift.

(h) In all regions, destruction of refuges must only be carried out after Bollgard 3 has been harvested (refer to section 4 Pupae Destruction).

(i) Refuges for dryland Bollgard 3 cotton crops must be planted in the same row configuration as the Bollgard 3 crop unless the refuge is irrigated. If an irrigated option is utilised for a dryland Bollgard 3 crop, then that refuge may be planted in a solid configuration. Dryland cotton is measured as Green Hectares.

3. CONTROL OF VOLUNTEER AND RATOON COTTON

Volunteer and ratoon cotton may impose additional selection pressure on *Helicoverpa* spp. to develop resistance to the Bt proteins Cry1Ac, Cry2Ab and Vip3A produced by Bollgard 3 cotton.

As soon as practical after harvest, Bollgard 3 cotton crops must be destroyed by cultivation, root cutting or herbicide so that they do not continue to act as hosts for *Helicoverpa* spp.

Growers must ensure that volunteer and ratoon plants are removed prior to flowering from all fields, including fallow areas, Bollgard 3 crops, conventional cotton crops and all refuges. **The presence of Bollgard 3 volunteers/ratoon cotton in any refuge will diminish the value of the refuge and must be removed as soon as possible.**

Note: *The refuge should preferably be planted into fallow or rotation fields that have not been planted to cotton in the previous season.*

4. PUPAE DESTRUCTION/ TRAP CROPS

Victoria, New South Wales and Southern Queensland

To further mitigate the risk of resistance, each grower of Bollgard 3 must undertake *Helicoverpa* spp. pupae destruction in fields with a higher probability of carrying over wintering pupae according to the following key guidelines:

- If first defoliation of a Bollgard 3 field occurs on or before March 31, the Bollgard 3 field must be slashed or mulched and controlled to prevent regrowth within 4 weeks of harvesting.
- If first defoliation of a Bollgard 3 field occurs after March 31, the Bollgard 3 field must be slashed or mulched and controlled to prevent regrowth within 4 weeks of harvesting and pupae busting must be complete by July 31 for all valleys except for all regions including the Lachlan, Murrumbidgee, Menindee and Murray Valleys and Victoria where pupae busting must be complete by August 31.
- Ensure disturbance of the soil surface to a depth of 10 cm to a distance of 30 cm both sides of the plant line.

Option for an alternative pupae destruction management

If opting to apply a registered attract and kill for Helicoverpa instead of pupae destruction:

- Grower must advise Monsanto if opting in for attract and kill strategy, contact your TSP for opt in dates and process.
- For growers in the Lachlan, Murrumbidgee, Menindee, Murray Valleys and Victoria, grower must apply three (3) weekly applications commencing no earlier than February 10 with the final application being no later than March 1.
  - For all other valleys (excluding Central Queensland) contact your local Bayer Cotton Territory Business Manager.
- Application must be made by an applicator accredited and approved by AgBiTech
- Grower must make applications as per the label of the registered attract and kill for Helicoverpa.

If for any reason the attract and kill applications are not completed as required in the RMP i.e.

- All three applications are not completed (i.e. due to weather or applicator availability only 2 out of 3 applications are made).
- Applications are not completed on the correct dates.
- Incorrect products or rates are used.
- A registered attract and kill product is not available (i.e. out of stock).
- All affected fields will be recorded as non-compliant and a Resistance Risk Management Plan (RRMP) will be issued to the grower to bring affected field(s) back into compliance with the RMP.

Central Queensland

Crop destruction

All Bollgard 3 crops must be slashed or mulched and controlled to prevent regrowth within 4 weeks of harvesting.

End of season management of refuges/trap crops

End of season pupae busting practices are not effective in the Central Queensland region as *Helicoverpa* spp. are less likely to diapause. A late summer trap crop (pigeon pea) must be planted for all Bollgard 3 cotton grown in Central Queensland. The planting configuration of the trap crop should be the same as that of the Bollgard 3 crop. Irrigated Bollgard 3 must have an irrigated trap crop.

Table 5 shows the requirements for the late summer pigeon pea trap crop. **Dryland Bollgard 3 growers who do not have any irrigated cotton on their farm should contact Monsanto Australia for alternative options.**

Refuge and late summer trap crops have different purposes. Where a pigeon pea refuge is utilised, the full pigeon pea refuge area must be managed to become the late summer trap crop. If unsprayed cotton is used as the refuge, an additional area of 1% pigeon pea must be planted as the late summer trap crop. Requirements for late summer trap crops are detailed in Table 5 below.

Table 5: Late summer pigeon pea trap crop requirements in Central Queensland

CRITERION	TRAP CROP*
Minimum area & dimension (Requirement)	A minimum trap crop of 1% of planted Bollgard 3 cotton crop is required. If sprayed conventional cotton is grown on that farm unit: the trap crop must be at least 48 m x 48 m. If no sprayed conventional cotton is grown on that farm unit: the trap crop must be at least 24 m x 24 m.
Planting time	The trap crop should preferably be planted 4 weeks after the associated Bollgard 3. **Note:** if growers choose to plant their trap crop to coincide with the planting of pigeon pea refuges, they must manage the trap crop in such a way that it remains attractive to *Helicoverpa* spp. 2–4 weeks after final defoliation.
Planting rate**	35 kg/ha (recommended establishment greater than 4 plants per meter)
Insect control	The trap crop can be sprayed with virus after flowering, while avoiding insecticide spray drift, except where a pigeon pea refuge is converted to a trap crop. In this case the full 2.5% (or 5% if cotton is planted in the later window after October 31) pigeon pea refuge area managed to become the late summer trap crop can only be sprayed with virus after the first defoliation of Bollgard 3 cotton.
Irrigation	The refuge/trap crop must be planted into an area where it can receive the additional irrigation required to keep the trap crop attractive to *Helicoverpa* spp. until after the cotton is defoliated.
Weed control	The trap crop should be kept free of weeds and particularly volunteer Bollgard 3 cotton. When using the full pigeon pea refuge area as the trap crop, weed control must not be carried out by cultivation once flowering of the associated Bollgard 3 cotton crop has commenced.
Crop destruction	The trap crop must be destroyed 2–4 weeks (but not before 2 weeks) after final defoliation of the Bollgard 3 cotton crop, (slash and pupae bust – full soil disturbance to a depth of 10 cm across the entire trap crop area). All Bollgard 3 and associated trap crops must be destroyed by July 31.

* A pigeon pea trap crop is to be planted so that it is attractive (flowering) to *Helicoverpa* spp. after the cotton crop has cut out, and as any survivors from the Bollgard 3 crop emerge. Planting pigeon pea too early (e.g. before November) or too late (e.g. mid December) is not adequate for cotton crops planted during September through to October.

** The planting rate is a recommendation based on a minimum of 85% seed germination.

Failed crops – all regions

Bollgard 3 crops that will not be grown through to harvest for various reasons and are declared to, and verified by, Monsanto as failed must be destroyed within two weeks after verification, in such a way that prevents regrowth. Crops that are abandoned before March 31 (except for Central Queensland) should be slashed and mulched within 4 weeks.

5. SPRAY LIMITATIONS

Insecticide preparations containing Bt may be used on Bollgard 3 cotton throughout the season BUT NOT on any refuge crops.

An unsprayed refuge should not be planted in the same field as any crop sprayed with a rate of insecticide that is registered for *Helicoverpa* spp., with the exception of Bollgard 3. Sprayed crops and unsprayed refuges that are planted in adjacent fields must be separated by sufficient distance to minimise the likelihood of insecticide drift onto the unsprayed refuge.

If the viability of an unsprayed refuge is at risk due to early or late season pressure by *Helicoverpa* spp., or any other caterpillar species, contact Monsanto Australia immediately. With prior approval from Monsanto Australia, a non-Bt heliocide can be applied.

Note: *If any grower encounters problems in complying with the Resistance Management Plan, please contact Monsanto Australia.*

For further background information on the various components of this plan see the 'Bollgard 3 Resistance Management Plan' section in the current *Cotton Pest Management Guide*.
The Resistance Management Plan (RMP) for Northern Australia can be found at bollgard3.com.au

Managing unsprayed pigeon pea refuges

Establishing and growing an attractive refuge is a mandatory component of the Resistance Management Plan (RMP) for Bollgard 3. The purpose of a refuge is to generate significant numbers of *Helicoverpa* moths that have not been exposed to selection pressure from any insecticidal Bt proteins. Attractive, fully irrigated, unsprayed flowering pigeon pea will, on average, produce twice as many moths as the same area of unsprayed non-Bt cotton. As well as producing high numbers of moths, it is also crucial that moth production from refuges has synchrony with Bollgard 3 cotton crops. A well-watered refuge with adequate nitrogen is most likely to sustain larvae through to pupation and consequently produce the most moths. This is the key to delaying Bt resistance.

Note that pigeon pea refuges serve a different purpose than pigeon pea trap crops. For more information on trap crops, see page 69.

The following information is intended to assist growers to establish and maintain effective pigeon pea refuges. Refer to the RMP for guidance on mandatory refuge requirements.

Field selection

Pigeon pea can be grown on many soil types but can be susceptible to waterlogging, so select fields that have good post-irrigation/rainfall drainage. Avoid fields that were sown to cotton during the previous season to reduce the likelihood of volunteer and ratoon cotton occurring in refuges. The presence of Bollgard 3 cotton in refuge areas diminishes the resistance mitigation potential of the refuge. Similarly, selecting fields with a low weed seed bank enables easier management of weeds that could compete with the pigeon pea and reduce refuge effectiveness.

Ideally, refuges should be sown adjacent to the Bollgard 3 crop. Ensure sufficient separation to buffer against the drift of herbicides or insecticides applied to the cotton or other crops onto the refuge area.

As with many other legumes, pigeon pea can have allelopathic effects on subsequent crops, so take this into account when making field selections.

Crop establishment

Timing

Similar to mungbean and soybean, a minimum soil temperature of 17°C and rising is optimal for pigeon pea establishment. In most cotton production regions these conditions occur during October-November. Under the RMP, pigeon pea should be sown within the two week period prior to planting Bollgard 3, or if not possible, completed within 3 weeks of the first day of sowing (irrigated crops only).

Sowing and inoculation

Use peat-based Group J inoculation formulations just prior to planting seed to help rootzone colonisation by rhizobium bacteria, and follow all label requirements and directions regarding storage, handling and application to maximise effectiveness. Crops with good nodulation may

Sunrise™ (left) is a strongly indeterminate variety compared with the varieties traditionally used for refuges. Paul Grundy

be less susceptible to waterlogging. Nodulation is likely to be higher in the presence of mycorrhizal fungi (AMF) and lower in soils with high background nitrogen.

Match pigeon pea row spacing to that of the corresponding Bt cotton crop.

Ongoing recycling and saving of seed from undamaged refuges caused an evolutionary shift towards pigeon peas that flower much later (or at times not at all). Sunrise™ is a variety of pigeon pea ideal for refuges that exhibits excellent vigour under furrow irrigation across a range of soil types and commences flowering in early January (or within 75 days of sowing). Sunrise™ is strongly indeterminate and has the ability to flower repeatedly, particularly after sustaining insect attack.

Sunrise™ seed production is undertaken by Associated Grains to ensure that the planting seed available to industry has excellent germination characteristics and remains true to type to preserve the heritage of this variety for years to come. Sowing rates for Sunrise™ typically fall within 25-40 kg/ha (depending on germination statistics and field conditions at the time of planting). Growers concerned about crop residues should consider using planting rates at the higher end to promote plants with thinner stalks, which makes later crop destruction much easier.

Comparisons between Sunrise™ pigeon peas and the original pea cultivar type Quest (under commercial conditions at a range of sites over several seasons) have demonstrated that Sunrise™ flowers much longer than the determinate Quest, and on average generates 2-3 times more pupae per hectare of refuge.

Seed bed preparation and planting

Ensure that the seedbed has good tilth to maximise seedling emergence and establishment. Seed should not be sown deeper than 5 cm. Levelling of any seed trenches created during planting is important, particularly when residual herbicides have been used and/or the field is to be watered up. The use of press wheels with light pressure has been shown to improve emergence.

Pre-irrigation

Pre-irrigation and planting into moisture is generally recommended over watering up. Some growers choose to water up the refuge with the rest of the field, then replant into this moisture if a replant is required.

Crop nutrition

A well-grown inoculated crop of pigeon pea can add up to 38 kg/ha of nitrogen, although the refuge may reduce N in soils with high background levels. Pigeon pea is much more sensitive to phosphorus deficiency than cotton. In soils with long cropping histories where soil P may be depleted, pigeon pea is likely to respond to the addition of phosphorus and zinc.

Weed management

Pigeon pea are poor competitors with weeds during establishment, particularly when planted under cool conditions.

As well as herbicides (Table 19), inter-row cultivation can be a useful tactic. However, because cultivation can inadvertently kill (the Bt-susceptible) *Helicoverpa* pupae present in the soil, it is a requirement that once Bt cotton begins to flower, the corresponding refuge should not be cultivated.

The presence of volunteers/ratoon Bollgard 3 cotton in any refuge will diminish the value of the refuge and must be removed as soon as possible.

Irrigation

Pigeon pea can be very sensitive to waterlogging on heavier soil types. Select a site with good drainage, avoid irrigation prior to heavy rainfall predictions and only water every second row. Use the same best management tactics on pigeon pea as used on cotton crops, e.g. getting water on and off the field in a timely and effective manner.

Being a drought-tolerant plant, pigeon pea generally has a lower water requirement than cotton. However, ensure crops do not become moisture stressed as this reduces attractiveness and truncates the flowering period. Sunrise™ is an indeterminate variety, and in some circumstances irrigating too frequently can prolong the vegetative growth stage, delaying the onset of flowering. A good rule of thumb is to plant Sunrise™ on a full profile of moisture and then supply the first in-crop irrigation as the plants begin to develop flower buds. On lighter loamy soil types with lower moisture holding capacity (<140 mm PAWC) or in hotter climates, two irrigations prior to flowering may be required. Sunrise™ should be exhibiting signs of budding by the time it reaches 50-70 cm in height. After the initiation of buds, Sunrise™ can be irrigated on a similar schedule to the adjacent cotton to prolong flowering and ensure rapid regrowth after insect attack.

Larvae in pigeon pea refuge. Johnelle Rogan

Destruction and harvest of pigeon pea refuge crops

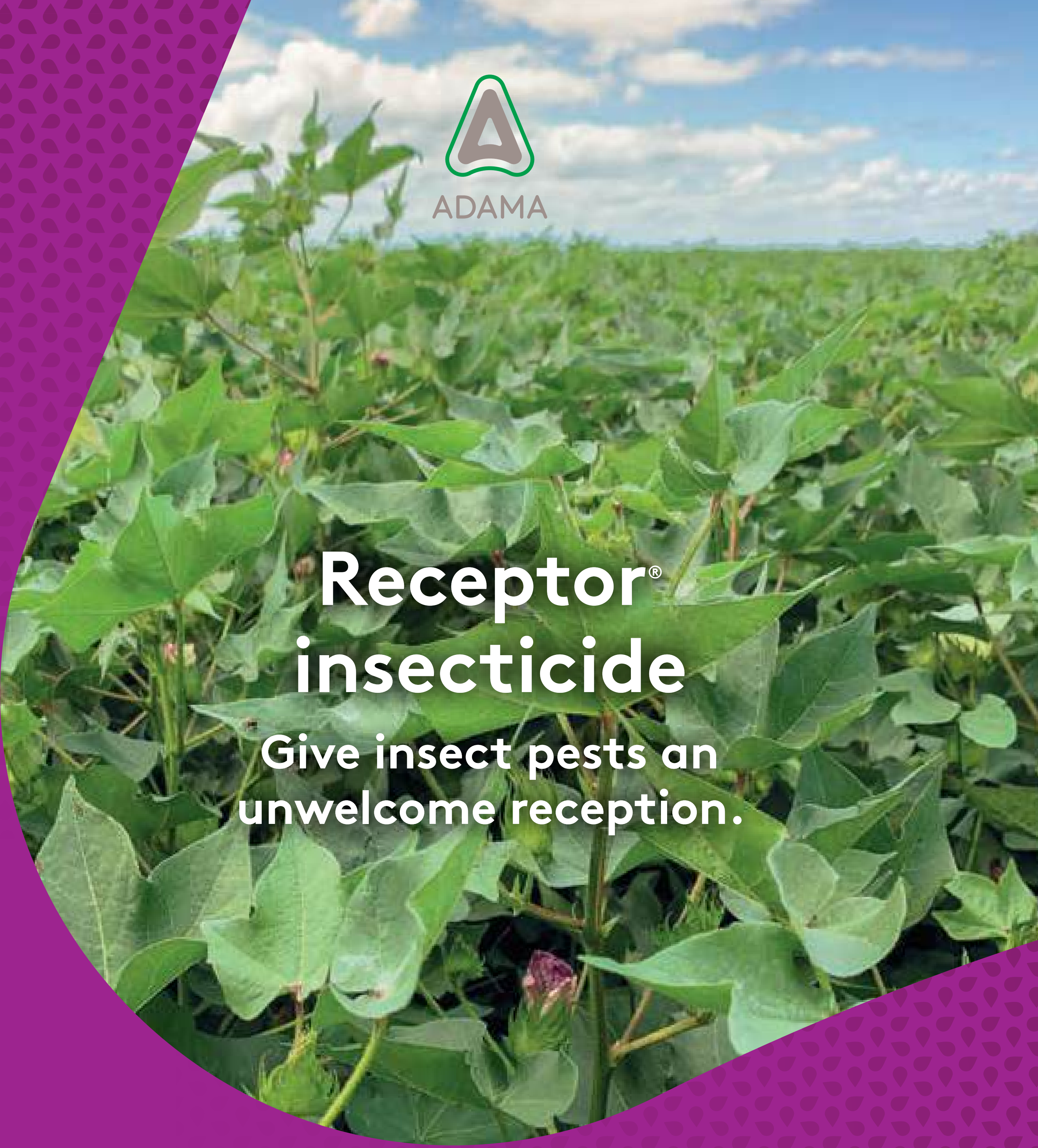
Only harvest/destroy a pigeon pea refuge after the corresponding Bollgard 3 cotton crop has been fully picked. In NSW and Southern Queensland, soil disturbance should only occur after Bollgard 3 cotton fields have been pupae busted (to ensure maximum emergence of pupae from refuges).

In Central Queensland soil disturbance of refuge crops can only occur 2 weeks after the final defoliation of the Bollgard 3 cotton. CQ growers using pigeon pea for trap crop purposes should refer to the late summer pigeon pea trap crop requirements of the RMP for full details.

Do not feed crop product or crop residue to livestock.

TABLE 19: Herbicides available for use in pigeon pea

Active ingredient	MoA group	Comments
Prometryn	5 (C)	Use of these products in pigeon pea trap crops is under permit PER13758 (valid until 31 August 2026). Only apply to pigeon pea crops that are to be destroyed at the end of the season or to be harvested for seed for refuge replanting. Do not feed crop product or residues to livestock. Unless otherwise stated in the permit, use must be in accordance with the product label.
Butroxydim	1 (A)	
Fluazifop-p	1 (A)	
Haloxyfop	1 (A)	
Sethoxydim	1 (A)	
Clethodim	1 (A)	
Quizalofop	1 (A)	
Trifluralin	3 (D)	Apply up to the maximum rate pre planting and incorporate. NSW and ACT only.
Diquat	22 (L)	Harvest aid
Diquat/ paraquat	22 (L)	Apply pre-sowing, in minimum 50-100 L water. Apply specified rates for certain weeds at particular growth stages, refer to label.
Pendimethalin	3 (D)	Incorporate into the soil within 24 hours of application. Use higher rate on heavy textured soils or those high in organic matter. May be applied by aerial or ground spraying. In Macquarie Valley area, only apply by air when ground is too wet for ground application.
Metribuzin	5 (C)	Furrow irrigated: apply after furrowing out, within 2 weeks before sowing and incorporate. For post-emergence: apply to actively growing seedling stage weeds provided crop plants have at least 2 trifoliate leaves. Do not spray if rain is likely to fall within several hours. Overhead irrigated: apply pre-emergence then irrigate.



Receptor is a pro-insecticide that provides highly effective control of key insect pests in cotton.

- Controls Two Spotted Mite and Cotton Aphid, and suppresses Silverleaf Whitefly.
- Translaminar movement and vapour activity
- Target pests are immediately paralysed
- Knockdown and residual activity (7–14 days)
- Minimal impact on beneficials

Scan here for more information

INSECTICIDE

ADAMA.COM

Integrated Weed Management (IWM)

It is important to strategically plan how different tactics will be utilised to give the best overall results controlling existing weeds and reducing the weed seed bank. A short term approach to weed management may reduce costs for the immediate crop or fallow, but is unlikely to be cost effective over a five or ten year cropping plan. Over this duration, problems with species shift and the development of herbicide resistant weed populations are likely to occur where weed control has not been part of an integrated plan.

Develop a strategy

Having good records on crop rotations, herbicides and other tactics used as well as weed species present will help in developing a plan that identifies where there are particular risks in the system and also where there might be opportunities to incorporate additional tactics. The Herbicide Resistance Management Strategy (available in the *Herbicide resistance management* section of this chapter) can help to inform the effectiveness of combinations of tactics on reducing the weed seed bank as well as the risk of herbicide resistance.

Know your enemy

Consider what weed species are present. Ensure that weeds are correctly identified, and consider which tactics, or combination of tactics, are going to be most effective for your weed spectrum. Key resources that can assist with these decisions include:

USEFUL RESOURCES:

Weeds of Australian Cotton app.
cottoninfo.com.au/weeds-australian-cotton-app

Weed ID guide
cottoninfo.com.au/publications/weedpak-weed-id-guide

WEEDpak
cottoninfo.com.au/publications/weedpak

Identify any particular problem areas. Managing these patches more intensively may help prevent a problem weed or resistance from spreading.

Timing and targeting

Often the timeliness of a weed control operation has the largest single impact on its effectiveness. For example, herbicides are far more effective on rapidly growing small weeds, and may be quite ineffective in controlling large or stressed weeds. Ensure that products are available and equipment is fit-for-purpose. See the spray application chapter for more information on ensuring that sprays hit the target and control weeds effectively.

Think about the whole farming system

It is important to consider weed management in the context of other in-crop agronomic issues, other crops and across the whole farm.

The Australian modes of action (MoA) classification system for herbicides changed from letters to numbers in 2021. Original MoA groups are included for your information.

Consider crop competition

An evenly established, vigorously growing cotton crop can compete strongly with weeds, especially later in the season. Delaying planting on weedy fields until last gives more opportunity to control weeds that emerge prior to planting, and better conditions for cotton emergence and early vigorous growth. In irrigated crops, weed-free periods of 8-9 weeks from planting provide enough time for cotton to out-compete most later emerging weeds and significantly reduce weed seed production.

Plan weed management to fit with other operations

Look for opportunities in the cropping system to coordinate weed control tillage with other operations, such as pupae busting, fertiliser incorporation, seed bed preparation and irrigation furrow maintenance.

Consider the wider impacts of weeds

Weed management is also an important consideration for pest and disease management. Many cotton pests rely on weed hosts and cotton volunteers prior to migrating into cotton fields. Some weeds and cotton volunteers/ratoons can act as a reservoir for plant viruses such as cotton bunchy top disease which can cause significant loss of yield. Some weeds can also allow disease inoculum to build up in the soil, increasing the risk for subsequent crops.

Mix it up with rotation crops

Rotation crops provide an opportunity to introduce a range of different tactics into the system, particularly herbicide groups that are not available in cotton. Mixing rotations may also vary the time of year non-selective measures can be used and the time of year that crop competition suppresses weed growth. Rotation between summer and winter cropping provides opportunities to use cultivation and knockdown herbicides in-fallow year round. Where cotton is grown in rotation with other crops, such as winter cereals or maize, retaining the stubble cover from these rotation crops for as long as possible reduces weed establishment and encourages more rapid breakdown of weed seed on the soil surface. In terms of the HRMS, treat rotation crops like a fallow and aim to use at least 2 non-glyphosate tactics within the crop.

Don't forget non-crop areas

Weeds in non-crop areas on the farm such as channels, tail drains, fence lines and roadsides can develop and introduce herbicide resistance into the farming system. Manage these areas as a fallow, using a range of tactics including residual herbicides, cultivation and chipping of weeds. Glyphosate (9/M) is also registered for many non-crop situations, but its use should be avoided where possible to minimise the risk of resistance. **DO NOT** rely on glyphosate only to manage weeds in these areas.

TABLE 20: Control of weeds in dry channels

Active ingredient	Mode of action group
Amitrole + ammonium thiocyanate	34(Q)
Imazapyr	2(B)
Pendimethalin	3(D)
Flumioxazin	14(G)
Diuron	5(C)

Glyphosate is also registered. Note: This information is provided as a guide only. Use in dry channels may not be a registered use for all products with that active. ALWAYS CHECK THE LABEL.

Dryland cotton

Weeds are very efficient at robbing the soil of vital moisture and nutrients. Tactics such as controlling weeds in winter crops pre-cotton and maintaining a clean winter fallow are crucial to provide sowing opportunities. It is vital to run the weed seed bank down in the previous winter crop or fallow to minimise in-crop weed management costs. Include residual herbicides in fallows and use pre-emergent herbicides at planting to provide ongoing in-crop weed control and reduce the reliance on glyphosate.

Rotating to other modes of action (MoA) for knockdown weed control is an important management strategy to prolong the life of glyphosate. For example, newer Group 14(G) herbicides provide additional control options pre-sowing (see page 82 for the range of tactics available). Cultivation is often seen as detrimental in dryland systems due to moisture losses from cultivation passes.

Late in-crop strategic cultivation to remove weed escapes is an ideal time to introduce non-chemical weed control, where the impacts of moisture loss are reduced. Alternatively, consider including cover crops to reduce weed numbers and improve soil health while also trapping and storing valuable soil moisture. As with irrigated cotton, ensure that any surviving weeds are prevented from setting seed.

Come Clean. Go Clean.

To minimise the entry of new weeds into fields, clean down boots, vehicles, and equipment between fields and between properties (pickers and headers require special attention). Regularly check washdown areas for germinating plants. Eradicate any new weeds while they are still in small patches and monitor patches frequently for new emergences. More biosecurity information is available at cottoninfo.com.au/biosecurity

Weed seeds can be carried in irrigation water. Control weeds that establish on irrigation storages, supply channels and head ditches.

Control survivors before they set seed

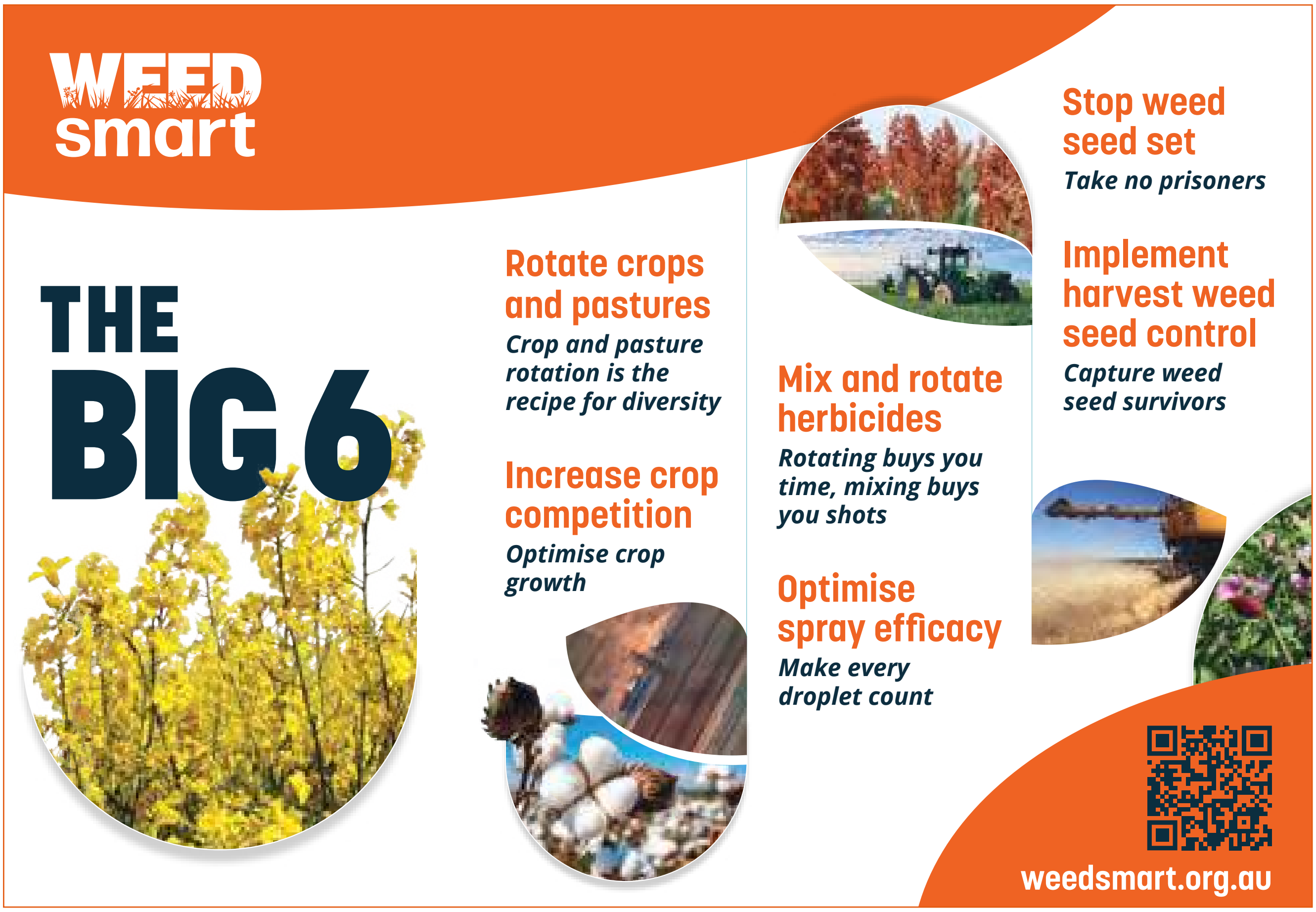
To be effective in preventing resistance, weeds that survive a herbicide application must be controlled by another tactic before they are able to set seed. Monitor the field after each spray application to assess efficacy. Weeds may need to be closely examined, as some are capable of setting seed while very small and many weeds respond to varying day-length, so a winter weed emerging in late winter or spring may rapidly enter the reproductive phase of growth in response to lengthening daylight hours.

Preventing survivors from setting seed is critical to the longer term success of an IWM strategy.

In terms of survivor control, research indicates that high efficacy with an alternative tactic is good, but high frequency control is better than reliance on efficacy. Cultivation after glyphosate application is predicted to achieve 80% survivor control, whereas cultivation plus chipping is predicted to achieve 99.9% survivor control. Other tactics for survivor control could be equally as effective, such as shielded or spot-spraying with an effective knockdown herbicide.

Manual chipping

Ideally suited to dealing with low densities of weeds, especially those that occur within the crop row, manual chipping is normally used to supplement inter-row cultivation or spraying. As a tool to prevent survivors setting seed, chipping has been shown to be a very cost effective option.



<table>
<tr><th colspan="5">TABLE 21: Herbicide plant-backs from rotation crops to cotton</th></tr>
<tr><th>Active ingredient</th><th>MoA</th><th>Plant-back to cotton</th><th colspan="2">Notes</th></tr>
<tr><td>Aminopyralid + fluroxypyr</td><td>4(I)</td><td>9 months*</td><td colspan="2">Plant-back interval on black cracking clay soils.</td></tr>
<tr><td>Aminopyralid + picloram + 2,4-D</td><td>4(I)</td><td>12 months* (northern NSW, Qld)</td><td colspan="2">Under drought conditions conduct a bioassay before planting the next crop.</td></tr>
<tr><td rowspan="2">Atrazine</td><td rowspan="2">5(C)</td><td>6 months</td><td colspan="2">Rates <1.4 kg/ha.</td></tr>
<tr><td>18 months</td><td colspan="2">Rates 1.4 to 3.3 kg/ha.</td></tr>
<tr><td rowspan="2">Atrazine + S-Metolachlor</td><td rowspan="2">5(C) + 15(K)</td><td>6 months</td><td colspan="2">Rates <3.2 L/ha.</td></tr>
<tr><td>18 months</td><td colspan="2">Rates <3.2 L/ha. On alkaline soils, undertake a bioassay or analytical test.</td></tr>
<tr><td rowspan="2">Chlorsulfuron</td><td rowspan="2">2(B)</td><td rowspan="2">18 months</td><td colspan="2">Where soil pH is 6.6-7.5 and 700 mm of rain has fallen.</td></tr>
<tr><td colspan="2">If soil pH >7.5, only grow cotton after growing a test strip.</td></tr>
<tr><td rowspan="3">Clopyralid</td><td rowspan="3">4(I)</td><td>3 months*</td><td>Rates <30 g/ha.</td><td rowspan="3">Clopyralid plantback times may be extended significantly if cotton is to be planted into moderate to heavy stubble loads from crops previously treated with clopyralid.</td></tr>
<tr><td>6 months*</td><td>Rates 30 to 120 g/ha.</td></tr>
<tr><td>24 months*</td><td>Rates >120 g/ha.</td></tr>
<tr><td rowspan="2">Diuron</td><td rowspan="2">5(C)</td><td rowspan="2">Refer to label</td><td colspan="2">Do not replant treated areas within 2 years of application of diuron unless otherwise stated on the label.</td></tr>
<tr><td colspan="2">Do not replant treated areas to any crop within 1 year after last spray except cotton (along with maize or grain sorghum) which may be planted in the spring following year.</td></tr>
<tr><td>Flumetsulam</td><td>2(B)</td><td>2 years</td><td colspan="2">For NSW and Qld a minimum of 50 mm and preferably 100 mm rain or more must have fallen over the warm months of the year.</td></tr>
<tr><td rowspan="2">Flumioxazin</td><td rowspan="2">14(G)</td><td>0 months</td><td colspan="2">For zero plant-back for knockdown spike rates of 45 g/ha or below.</td></tr>
<tr><td>2 months</td><td colspan="2">For residual rates above 210 g/ha.</td></tr>
<tr><td>Imazamox</td><td>2(B)</td><td>10 months</td><td colspan="2">Must have 800 mm of rainfall or irrigation.</td></tr>
<tr><td>Imazamox + imazapyr</td><td>2(B)</td><td>34 months</td><td colspan="2">Registered for use in Clearfield® (or imidazolinone herbicide tolerant) crops – refer to label for varietal constraints.</td></tr>
<tr><td rowspan="2">Imazethapyr</td><td rowspan="2">2(B)</td><td>22 months</td><td colspan="2">Dryland cotton.</td></tr>
<tr><td>18 months</td><td colspan="2">Irrigated only (providing rainfall and irrigation exceeds 2000 mm)</td></tr>
<tr><td>Isoxaflutole</td><td>27(H)</td><td>7 months</td><td colspan="2">350 mm rainfall (excluding flood/furrow irrigation) between application and planting the subsequent crop.</td></tr>
<tr><td>Mefenpyr-diethyl + iodosulfuron-methyl sodium</td><td>2(B)</td><td>12 months</td><td colspan="2">Rainfall <500 mm may result in extended re-cropping intervals for summer crops sown in the following season.</td></tr>
<tr><td rowspan="2">Metribuzin</td><td rowspan="2">5(C)</td><td>6 months</td><td colspan="2">Rates <1.5 L/ha. Could be longer if there have been long dry periods between crops.</td></tr>
<tr><td>12 months</td><td colspan="2">Rates >1.5 L/ha.</td></tr>
<tr><td>Metsulfuron methyl</td><td>2(B)</td><td>Unknown</td><td colspan="2">Registered for use in wheat, barley, triticale and as a desiccant in chickpea.</td></tr>
<tr><td>Metsulfuron-methyl + mefenpyr-diethyl</td><td>2(B)</td><td>12 months</td><td colspan="2">Rainfall of less than 500 mm following application may result in extended re-cropping intervals for summer crops sown in the following year.</td></tr>
<tr><td>Picloram + 2,4-D</td><td>4(I)</td><td>12 months</td><td colspan="2">(Nth NSW & Qld). Do not use on land to be cultivated for growing susceptible crops within 12 months of application. Based on normal rainfall.</td></tr>
<tr><td>Pyroxasulfone</td><td>15(K)</td><td>5 months</td><td colspan="2">At least 150 mm rainfall. Less total rainfall between application and planting of the following crop than 150 mm may require extended plant-back period.</td></tr>
<tr><td>Simazine</td><td>5(C)</td><td>9 months</td><td colspan="2">When up to 2.5 kg/ha are used. When rates exceed 2.5 kg/ha, plantings may not be possible for very long periods of time afterwards.</td></tr>
<tr><td>Sulfosulfuron</td><td>2(B)</td><td>Unknown</td><td colspan="2">Registered for use in wheat and triticale.</td></tr>
<tr><td rowspan="2">Triasulfuron</td><td rowspan="2">2(B)</td><td>15 months</td><td colspan="2">Soil pH <7.5; 700 mm rainfall between application and sowing the plant-back crop.</td></tr>
<tr><td>18 months</td><td colspan="2">Soil pH 7.6-8.5.</td></tr>
<tr><td>Tribenuron methyl</td><td>2(B)</td><td>Unknown</td><td colspan="2">Registered for use in fallows.</td></tr>
<tr><td rowspan="2">Triclopyr + picloram + aminopyralid</td><td rowspan="2">4(I)</td><td>4 months*</td><td colspan="2">Rates 0.2 L/ha.</td></tr>
<tr><td>6 months</td><td colspan="2">Rates 0.4 L/ha.</td></tr>
<tr><td colspan="5">*Plant-back period may be significantly longer under drought conditions (i.e. less than 100 mm of rainfall over 4 or more months).
This is a guide only – always read and follow product label directions.
Residual herbicide activity can be influenced by application rate, soil clay content, temperature, humidity, rainfall, soil moisture and soil organic matter.
Where fields have been treated with herbicides with no plant-back recommendations to cotton, determine cotton tolerance by growing through to maturity on a smaller scale before sowing larger areas.</td></tr>
</table>

Spot spraying

Spot sprayers may be used as a cheaper alternative to manual chipping for controlling low densities of weeds in-crop. Ideally, spray weeds with a relatively high label rate of a herbicide from a different herbicide group to the herbicides most recently used to ensure that all weeds are controlled. This intensive tactic can be particularly useful for new weed infestations where weed numbers are low, or where weeds are outside the field and difficult to get to, such as roadside culverts.

New weed detection technologies provide an opportunity to use spot spraying (optical sprayers; e.g. See & Spray™, WeedSeeker® and WEED-IT) across large areas of fallow. This can provide opportunity to reduce herbicide costs, while still ensuring robust label rates are applied to problem weeds. In addition, the development of green-on-green technology has the potential to add flexibility into the spraying operation by targeting weeds in-crop. Refer to the herbicide label for plant-back limitations relevant to the rate applied. Follow manufacturer recommendations for speed and nozzle type, as well as allowable products to ensure each application is effective. Permits for herbicide application in fallow are available on the APVMA website.
portal.apvma.gov.au/permits

Fallow management

Weed management in the fallow is an important component of a weed management plan. Summer fallows following a Roundup Ready Flex® cotton crop where only glyphosate was used for weed control poses the greatest risk to glyphosate resistance developing. Continued use of glyphosate for controlling summer weeds means that these weeds are only exposed to one mode of herbicide action. The Herbicide Resistance Management Strategy recommends at least two non-glyphosate tactics in summer fallows in addition to two non-glyphosate tactics in the cotton crop. Residual herbicides and double knock tactics provide good alternatives in fallows (Table 21). For larger weeds that may be tolerant to herbicides, a strategic cultivation or manual chipping is recommended. Set up field activities such as fertiliser placement and bed cultivators to have adequate soil disturbance to eradicate weeds during these mechanical tasks, and this will lessen the pressure to control weeds with further actions.

In-crop tactics

Pre-plant/at planting

Prior to planting there is an excellent opportunity to incorporate a non-glyphosate herbicide or combination of herbicides, or to integrate cultivation with a pre-planting operation such as seed bed preparation. In irrigation systems, consider utilising pre-irrigating to cause a flush of weeds to emerge and be controlled using a non-glyphosate tactic before the cotton emerges.

Herbicides from Groups 5(C), 14(G), 4(I), 22(L), 9(M), 10(N) and 34(Q) can be used to target weeds that have emerged in the field (see the Integrated weed management tactics diagram on page 82). This can be made more effective when used as a double knock.

Residual herbicides remain active in the soil for months and can act on successive weed germinations. This can be particularly effective in managing the earliest flushes of in-crop weed, when the crop is too small to compete. Broadleaf and grass weeds can be targeted with residual herbicides from Groups 5(C), 3(D) or 15(K).

Most residual herbicides need to be incorporated into the soil for optimum activity. Adequate incorporation of some residual herbicides is achieved through rainfall or irrigation, but others require cultivation. Soil surfaces that are cloddy or covered in stubble may need some pre-treatment such as light cultivation or burning to prevent 'shading' during application. Ash from burnt stubble may inactivate the herbicide, and therefore must be dissipated with a light cultivation or rainfall prior to herbicide application.

Crop safety is an important consideration when using residuals. How the herbicide moves in the soil following incorporation will depend on soil type, bed formation, solubility of the herbicide, the ability of the herbicide to bind to the soil and organic matter content, and the volume and timing of rainfall/irrigation, in addition to the method of applying irrigation. Growers can influence crop safety by the choice of herbicide, when it is applied, application rate, planting depth, planting date (to promote rapid crop establishment) and moisture management. Always follow label direction and if you are inexperienced in the use of residuals in cotton you should discuss your circumstances with your consultant, chemical supplier or the manufacturer.

The persistence of residual herbicides needs to be considered in order to avoid impacts on rotation crops. Persistence is determined by a range of factors including application rate, soil texture, organic matter levels, soil pH, rainfall/irrigation, temperature and the herbicide's characteristics. It can be quite complex.

TABLE 23: Efficacy of knockdowns in winter fallows measured 6 weeks after treatment

Herbicide	Weed control (%)			
	1-month-old		3-month-old	
Glyphosate + Tordon 75-D® (fb) Spray.Seed®	99	(97-100)	97	(92-100)
Glyphosate + 2,4-D (fb) Spray.Seed®	96	(93-100)	93	(87-97)
Glyphosate + 2,4-D (fb) Alliance®	96	(92-99)	90	(78-100)
2,4-D (fb) Spray.Seed®	97	(97-98)	83	(68-97)
Amitrole®#	90	(84-95)	96	(95-97)
Glyphosate + Tordon 75-D®	93	(86-99)	84	(62-98)
Glyphosate + 2,4-D	84	(62-100)	76	(63-96)
2,4-D#	88	(81-95)	53	(48-57)
Spray.Seed®#	84	(78-89)	22	(13-30)

Brackets indicate the range of efficacy across the experiments.
fb = followed by a 7-day interval
# = applied in only two of the four field experiments
Source: Steve Walker (QAAFI, University of Queensland), Michael Widderick, Andrew McLean and Jeff Werth (Qld DAF).

TABLE 22: Examples of plant-backs to cotton for Group 4 herbicides used in seedbed preparation

Active ingredient	2,4-D amine 700 g/L			dicamba 700 g/L			fluroxypyr 333 g/L			triclopyr 600 g/L
Rate (L/ha)	0.5	0.5-1.0	1.0-1.5	0.14	0.20	0.40	0.375	0.75	1.50	0.16
Plant-back[1] (days)	10	14	21	7	7	14	14	14	28	14

[1] If applied to dry soil, at least 15 mm rain is required before plant-back period begins.

Integrated weed management tactics

NON GLYPHOSATE WEED TACTICS FOR THE COTTON FARMING SYSTEM

An integrated weed management system relies on a large number of interrelated, complementary components including both chemical and non-chemical tactics as well as cultural practices such as rotation, crop competition, farm hygiene, and crop scouting.

2 non-glyphosate tactics in fallow + 2 non-glyphosate tactics in crop & NO SURVIVORS

NON-GLYPHOSATE TACTICS

Fallow

Strategic cultivation
Double knock
Optical sprayers
Patch management
Cover crops

Non-glyphosate options[2]

Group 5/C
bromoxynil, terbuthylazine

Group 14/G
flumioxazin, pyraflufen, saflufenacil

Group 27/H
isoxaflutole

Group 22/L
paraquat, paraquat/diquat

Group 22-L/34-Q
amitrole/paraquat

Group 10/N
glufosinate

Group 4/I
2,4-D, dicamba, fluroxypyr

Rotation Crops[4]

Crop competition
Rotate MoA
Plant back restrictions
Cover crops

Pre/at plant

Cultivation

Knockdown MoA

Group 5/C
bromoxynil

Group 3/D
chlorthal dimethyl

Group 14/G
pyraflufen, flumioxazin, saflufenacil, oxyflurofen, carfentrazone

Group 4/I
dicamba, fluroxpyr

Group 22/L
paraquat, paraquat/diquat

Group 22-L/34-Q
amitrole/paraquat

Group 10/N
glufosinate

Residual MoA[4]

Group 5/C
fluometuron, prometryn, terbuthylazine, diuron

Group 3/D
pendimethalin, trifluralin

Group 15/K
S-metolachlor, metolachlor

Post-emergent[1]

In-crop cultivation
Manual chipping
Rogueing

Post-emergent OTT MoA

Group 1/A[3]
sethoxydim, clethodim, butroxydim, propaquizafop, haloxyfop

Group 15/K
S-metolachlor5

Lay-by, directed or shielded spray

Group 5/C
fluometuron, prometryn, terbuthylazine, diuron

Group 3/D
pendimethalin

Group 14/G
flumioxazin5

Group 15/K[5]
S-metolachlor

Maturing crops

Aim for 100% control of survivors
Cultivation, chipping or spot spraying

NO SURVIVORS

Survivors — aim for 100% control

In fallow survivor control

Cultivation, chipping or spot spraying

Refer above for NON glyphosate options

Optical sprayer

Pre-plant survivor control

Cultivation, chipping or spot spraying
flumioxazin
pyraflufen-ethyl
carfentrazone-ethyl
bromoxynil

Post-emergent

Inter-row cultivation, chipping or spot spraying

Post-harvest

Root cutting for crop destruction

Cultivation, chipping or spot spraying
carfentrazone-ethyl
pyraflufen-ethyl
bromoxynil
fluroxypyr

COMMENTS

- Survivors MUST be controlled by another tactic prior to seed set.
- Read and follow label directions.
- Rotate herbicide mode of action (MoA).
- Come Clean. Go Clean. to stop weed seeds.
- Scout fields for weed survivors.
- Keep accurate field records.
- Ensure effective volunteer/ratoon management.
- DO NOT rely on glyphosate to control weeds in non-field areas.
- Take a farming systems approach to weed management, including winter, summer and non-field areas.

1. Mix full rates of different MoA. Rotate to alternative MoA in following years. Additional herbicides available for XtendFlex® varieties only - see *Herbicide tolerance* section for more details.
2. APVMA permits: 88120, 90223, 91513 for fallow use.
3. Group 1/A herbicides already exhibit widespread resistance. Controlling survivors is esssential.
4. Refer to label for plant-back restrictions to following crop.
5. Limited formulations are registered for this use. Please check label.

For example, it is not usually the volume of rain, but the length of time the soil is moist that is the critical factor. Microbes that degrade many herbicides live near the soil surface and require moist soil to flourish. A couple of storms, where the soil surface dries out quickly, won't contribute as much to residue breakdown as a period of rain that moistens the soil surface for days. Refer to product labels for more information. If you suspect that a residual may still be active in the lead up to planting, look for the presence of susceptible weeds in the treated paddock or pot up soil from treated and untreated areas, sow the susceptible crop and compare emergence. Where there is a concern, consider planting an alternative crop that is tolerant of the herbicide, or if cotton is to be used, plant the paddock last and pre-irrigate if it is to be irrigated. Always ensure that best practice is followed in terms of capture and management of runoff water.

Post-emergence

Once cotton has emerged there are still many opportunities to incorporate different tactics. Check labels for application restrictions based on node development.

When targeting the over the top (OTT) application of glyphosate (Roundup Ready Flex®), aim to treat actively growing weeds, and do not allow weeds to become too large. Avoid using the same herbicide to control successive generations of weeds, and ensure survivors are not able to set seed. Do not apply more than the allowable number of OTT applications. Refer to the *Herbicide tolerance technology* section later in this chapter for more information.

Grass selective herbicides (Group 1/A) can be applied over the top of cotton, however repeated use is likely to lead to the development of Group 1(A) resistance. It is important that in managing glyphosate resistance, that resistance to other herbicides doesn't develop. Use Group 1(A) herbicides sparingly and ensure any survivors are controlled before they set seed, using another tactic, such as manual chipping.

Some metolachlor registrations now include over the top use in-crop from 4 node up to 18 node crop growth and can be used with glyphosate to provide additional residual control of grass weeds. If leaf spotting is a concern, use a directed or shielded spray. Other lay-by/shielded spray options include herbicides in Groups 5(C), 3(D), 14(G), 15(K) and J(15). Check label to confirm usage is allowed for each product in your situation and for crop safety directions.

In-crop cultivation, and (if required) chipping, provide important non- herbicide options for controlling herbicide survivors. Cultivating when the soil is drying out is the most successful strategy for killing weeds and will reduce the damage to soil caused by tractor compaction and soil smearing from tillage implements. Take care during set-up to minimise the crop damage. Note that inter-row cultivation may exacerbate issues with some soil-borne pathogens.

Post-harvest

Some weeds are likely to be present in the crop later in the season – even in the cleanest crop. These weeds will produce few seeds in a competitive cotton crop, but can be very problematic in skip-row configurations and can take advantage of the open canopy created by defoliation and picking. Removing crop residues and weeds as soon after picking as practical greatly reduces the opportunity for these weeds to set seed. See also *Management of volunteer and ratoon cotton.*

Notes on herbicide use

Registration of a herbicide is not a recommendation for the use of a specific herbicide in a particular situation.

TABLE 24: Cotton herbicide plant-backs to rotation crops

Active ingredient	Plant-backs from cotton to rotation crops (months)																					
	Cereal grain-crops							Legume crops											Other crops			
	Barley	Maize	Millet	Oats	Sorghum	Triticale	Wheat	Adzuki bean	Chickpea	Cowpea	Faba bean	Field pea	Lablab	Lupin	Lucerne	Mungbean	Pigeon pea	Soybean	Canola	Safflower	Linseed	Sunflower
Chlorthal dimethyl	8	8	8	8	8	8	8	8	8	8	8	8	8	8	FH	FH	8	FH	8	8	8	8
Diuron	24	24	24	24	24	24	24	24	24	24	24	24	24	24	12	24	24	24	24	24	24	24
Fluometuron	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Fluometuron + prometryn	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Halosulfuron-methyl	24	2	24	24	2	24	3	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Metolachlor	6	0	6	6	0[1]	6	6	6	6	6	6	6	6	6	6	6	6	0	6	6	6	0
Norflurazon[2]	24	21	—	24	21	24	24	—	3	—	24	—	—	—	—	21	—	3	—	18	18	27
Pendimethalin	6	0[3]	12	12	12	—	—	—	—	—	—	—	—	—	6	—	—	—	6	—	—	—
Prometryn	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
S-Metolachlor	6	0	6	6	0[1]	6	6	6	6	6	6	6	6	6	6	6	6	0	6	6	6	0
Trifloxysulfuron sodium	6	22	22	6	22	22	6	22	18	22	7	22	22	22	22	9	15	15	22	22	22	22
Trifluralin	12	12	12	12	12	12	12	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH

1 Concep® II treated seed only.
2 For rates up to 3.5 kg/ha. Where rates up to 4.2 kg/ha are used, increase period by 6 months.
3 Maize can be resown immediately after use in a failed crop provided the seed is sown below the treated band of soil.

FH = following cotton harvest
— = no information
Further information available in Weed control in Summer and Winter Crop Publications from NSW DPI.

The information in this publication is presented as a guide only to assist growers in planning their herbicide programs. Satisfy yourself that the product (or products) used is the best choice for the crop and weed. Carefully study the container label before using any herbicide, and note any specific instructions relating to the rate, timing, application and safety.

IMPORTANT – avoid spray drift

Take every precaution to minimise the risk of causing or suffering spray drift damage:

- Plan your crop layout to avoid sensitive areas.
- Ensure spray contractors have details of any nearby sensitive areas.
- Consult with neighbours to minimise risks from spraying near property boundaries, refer to SataCrop at satacrop.com.au.
- Carefully follow all label directions.
- Pay particular attention to weather conditions before application (and use the WAND tower network to identify potential hazardous inversion conditions).
- Use buffer zones to reduce the impact of spray drift or over-spray.
- Keep detailed records.

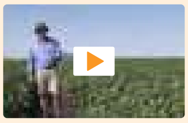
See the *Spray application* chapter for more details.

For more information: Refer to IWM tactics diagram on page 82.

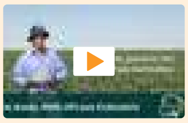
USEFUL RESOURCES:

The ***Australian Cotton Production Manual*** also includes information on weed control tactics.
cottoninfo.com.au/publications/2024-australian-cotton-production-manual

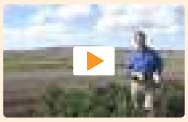
For information of the change in MoA classification visit
croplife.org.au/resources/programs/resistance-management/herbicide-moa-alignment



Late season weeds
youtu.be/4gqLpEu5uTE



Integrated weed management (IWM) in cotton
youtu.be/AH3jwf0TY60



Sources of weed seed
youtu.be/TLSpFIZZaqU

A patch of glyphosate-resistant awnless barnyard grass, likely to have started near a road. Consider whole of farm use of herbicides. T.Cook, NSW DPI

Key weeds

Watch out for these common weeds of cotton with a high risk of herbicide resistance. Make your herbicide decisions early and target young growth stages. Controlling larger plants with glyphosate may be too late, as seeds may have already set.

Graham Charles, NSW DPI

Liverseed grass (*Urochloa panacoides*) is a prolific seeding annual summer grass favoured by reduced tillage systems. Fresh seed has a strong dormancy and therefore most seed germinates in the season following seed production. Emergence usually occurs in one large flush in spring. Seed viability on the surface is short but persistence increases with seed burial.

Graham Charles, NSW DPI

Awnless barnyard grass (*Echinochloa colona*) is an annual summer grass germinating multiple times during the season and is capable of producing >40,000 seeds per plant. Dormancy breaks down after four to six months and seedlings emerge between October and March. In a zero-till system, stopping seed set will quickly reduce seed numbers in the soil.

Graham Charles, NSW DPI

Flaxleaf fleabane (*Conyza bonariensis*) is an annual or short-lived perennial plant germinating from the soil surface. It has become a difficult weed to control with the move to reduced or zero tillage. Individual plants can produce >100,000 seeds. Plants can grow to 1 metre tall and commonly have a branching habit. It can emerge in late autumn or early winter, growing very slowly above ground but at the same time developing an extensive root system allowing it to grow quickly when spring temperatures increase.

Graham Charles, NSW DPI

Eric Koetz, CottonInfo/NSW DPI

Feathertop Rhodes grass (*Chloris virgata*) is a small-seeded surface-germinating annual that can produce >40,000 seeds per plant. It germinates after small amounts of rain and can produce viable seed within 6 weeks of emergence.


Graham Charles, NSW DPI

Sowthistle (*Sonchus oleraceus*) is a surface-germinating, prolific seed producer, up to 25,000 per plant and with no innate dormancy (able to germinate straight away), although 30-50% of seed buried below 2 cm will persist and remain viable. It flourishes in zero-till situations and seed is readily dispersed by wind. Able to germinate and set seed year-round, it requires multiple control efforts.


Eric Koetz, CottonInfo/NSW DPI

Annual ryegrass (*Lolium rigidum*) is predominantly a winter annual that has developed widespread herbicide resistance to a number of modes of action. Reports are emerging of germinations in irrigated cotton fields over spring/summer, exposing annual ryegrass to more herbicide pressure. Stopping seed set for two years will deplete the seed bank to very low levels.


Eric Koetz, CottonInfo/NSW DPI

Windmill grass (*Chloris truncata*) is a short-lived perennial species that has recently been identified as being resistant to glyphosate. It is summer-dominant and a prolific seeder (>20,000 seeds per plant). Germination occurs throughout spring-summer and autumn, however peak emergence occurs with increasing soil moisture in September-October. The increase in prevalence of this weed coincides with zero tillage practices as most of the seed is dispersed by wind onto the soil surface. Seed persistence in the soil is short lived and seeds struggle to emerge from deeper than 3 cm. If you can stop seed-set for 12-24 months the soil seedbank will be depleted. A double knock tactic is most effective on this weed, especially when applied at early tillering.


Tonia Grundy, Qld DAF

Eric Koetz, CottonInfo/NSW DPI

Red pigweed (*Portulaca oleracea*) is a prostrate annual herb germinating in spring and summer that often forms dense mats and flowers from September through to March. Red pigweed is becoming harder to control with glyphosate and is appearing as a more common weed in surveys of field edges. It spreads via very small seeds that normally don't move far from the parent.

Herbicide resistance management

The Australian lettering mode of action (MoA) classification system for herbicides changed in 2021 to match the international numbering system. Both systems are included in this edition for ease of reference. A searchable database of Australian herbicide classifications is available at

croplife.org.au/resources/programs/resistance-management/herbicide-moa-alignment

Weed populations are naturally genetically diverse, so it is likely that a small number of individuals may exist that are able to survive exposure to a particular herbicide mode of action (MoA). When a herbicide from this MoA is used upon the population, individuals that have this gene present may survive and set seed, whereas the majority of plants without the gene (susceptible plants) are killed. While it might only be one or two individuals surviving at first, continued use of the same MoA herbicide will result in an ever-increasing proportion of the population being able to survive those herbicide applications. In Australia, herbicides are currently grouped according to their MoA which is represented by a number code on the label (see box above) and are ranked according to their resistance risk. Research has shown that weeds can develop resistance to any single control tactic used alone, not only herbicidal ones. For example, regular mowing of annual bluegrass, Poa annua, in golf courses selected strains for lower grass seed heads, which is essentially a resistance to mechanical control.

There are currently 533 unique cases (species x mode of action) of herbicide resistant weeds globally across 273 species. Weeds have evolved resistance to 21 of the 31 known herbicide sites of action and to 168 different herbicides. Herbicide-resistant weeds have been reported in 101 crops in 72 countries. While historically the Australian cotton industry has had a strong integrated weed management system, the extensive use of herbicide tolerant cotton varieties since 2006 has led to an over-reliance on glyphosate. More than half of the confirmed glyphosate-resistant weed species in Australia listed in Table 25 occur widely in cotton farming systems.

Surviving glyphosate resistant awnless barnyard grass plants amongst dead susceptible plants and dead plants of other species.

Why the need for an industry-wide strategy?

Experience with conventional insecticide resistance has encouraged a proactive culture to resistance issues in the Australian cotton industry. The increased use of glyphosate and escalating incidence of resistance has brought about the need for an industry-wide Herbicide Resistance Management Strategy (HRMS). This strategy draws together available information, enabling growers and agronomists to understand and manage the risks of herbicide resistance in Australian cotton farming systems.

How was the HRMS strategy developed?

The strategy was developed by the TIMS Herbicide Tolerant Crops Technical Panel to help the Australian cotton industry manage the risk of herbicide resistance, especially the risks associated with glyphosate. The strategy indicates how different combinations of weed control tactics affect the timeframe to resistance developing as well as their impact on the weed seed bank.

The modeling used as the foundation of the HRMS is based on barnyard grass control in glyphosate tolerant cotton where three over the top (OTT) glyphosate applications are made in any one season. The time to resistance developing and effect on the weed seed bank was predicted using combinations of weed control tactics used in-crop and in the summer fallow phase for both irrigated and dryland cropping systems. The models indicate that in irrigated cotton, crop competition provides higher weed control than in dryland systems, and demonstrate that the weed control tactics used in the summer fallow phase have the greatest impact on the time to glyphosate resistance developing.

HRMS review

The HRMS is reviewed annually in light of weed field surveys, CCA and grower surveys and in consultation with registrants of glyphosate registered for over the top (OTT) use in Roundup Ready Flex®. XtendFlex® will be considered in next year's review.

TABLE 25: Glyphosate-resistant weeds in Australia

Grasses	First documented
Annual ryegrass (*Lolium rigidum*)	1996
Awnless barnyard grass (*Echinochloa colona*)	2007
Liverseed grass (*Urochloa panicoides*)	2008
Windmill grass (*Chloris truncata*)	2010
Great brome (*Bromus diandrus*)	2011
Red brome (*Bromus rubens*)	2014
Sweet summer grass (*Brachiaria eruciformis*)	2014
Feathertop Rhodes grass (*Chloris virgata*)	2015
Winter grass (*Poa annua*)	2017
Northern barley grass (*Hordeum glaucum*)	2018
Wild oats (*Avena* spp.)	2018
Johnson grass (*Sorghum halapense*)	2019
Broadleaf weeds	
Flaxleaf fleabane (*Conyza bonariensis*)	2010
Wild radish (*Raphanus raphanistrum*)	2010
Sowthistle (*Sonchus oleraceus*)	2014
Prickly lettuce (*Lactuca serriola*)	2014
Tridax daisy (*Tridax procumbens*)	2016
Tall fleabane (*Conyza sumatrensis*)	2017
Willow-leaved lettuce (*Lactuca saligna*)	2017
Capeweed (*Arctotheca calendula*)	2021

Glyphosate resistant barnyard grass was confirmed in 2007. This infestation 'blow-out' was due to an extremely wet summer that prevented access to the paddock and hence no effective treatment at an early growth stage. T.Cook, NSW DPI

Why does the HRMS focus on glyphosate?

The strong reliance on glyphosate in the current farming system and the increasing number of cases of glyphosate resistance has meant that for the first HRMS, glyphosate was the key focus. Tables 26 and 27 show resistance has also been identified in Group 22/L (paraquat) and 4/I (2,4-D) herbicides to weeds common in cotton farming systems. The HRMS has been updated with notes to address risks from other MoAs, especially the emerging concerns around Group 1(A) resistant grass species such as feathertop Rhodes grass, annual ryegrass and windmill grass.

It is important to note that the principles behind the strategy, particularly the use of a diverse range of tactics and the control of survivors are applicable to other groups as well as Group 9/M (glyphosate). There is concern that glyphosate resistance may result in reliance on other herbicidal groups, leading to multiple resistance, for example, reliance on the repeated use of Group 1 grass selective herbicides can quickly lead to development of Group 1 resistance.

A NSW DPI survey has confirmed Group 1 resistance in windmill grass (*Chloris truncata*), feathertop Rhodes grass (*Chloris virgata*) and barnyard grass (*Echinochloa crus-garli*) in three cotton growing regions.

How to use the HRMS

Given that modelling shows glyphosate resistance takes around 19 years to develop when used alone in an irrigated cotton cropping system and 13 years in dryland, it is important to identify the likelihood of resistance development in your own operation. The HRMS enables you to determine which other weed control tactics can be incorporated into your management system by providing guidance as to how much extra time they will give you until resistance develops, and demonstrating the effect they will have on the weed seed bank, which is critical to effectively managing resistance.

Non-cropping areas and the HRMS

Areas adjacent to cotton fields such as irrigation channels, head ditches, tail drains, roadways, fence lines and areas next to stock routes can be a significant entry source for resistant weed seeds. Where possible, use a range of tactics to manage weeds in these non-crop areas, and do NOT rely on glyphosate to manage weeds in these areas. Prevent survivors of herbicide application from setting seed.

Why does the strategy include weed seed bank as well as herbicide resistance risk?

The key to good weed management is having low weed seed bank numbers. Not only does this reduce impact on the crop, but it also reduces the herbicide resistance risk. The more weed seeds present, the more likely that an individual containing herbicide resistance genes will be present and hence become a problem.

Seed bank control/resistance risk

A high weed burden contributes to herbicide resistance risk, as the more weeds that are present, the more likely that a resistant individual will be present and multiply. Strategies are best aimed at driving down the seed bank and preventing seed bank replenishment. Seed levels are usually classified as:

- Very high control = <10 seeds/m^2
- High control = 10-100 seeds/m^2
- Medium control = 100-500 seeds/m^2
- Low control = 500-1500 seeds/m^2
- Very low control = >1500 seeds/m^2

Do I have to adhere to the HRMS?

The HRMS is not intended to be prescriptive, and is aimed to be an industry mechanism for communicating the herbicide resistance risks from different tactics. It has been designed to present the risk related to a range of tactical combinations, to allow growers and consultants to make their own informed decisions.

Assessing your own risk

For a more detailed assessment of the resistance risks for individual paddocks, use Qld DAF's Online Glyphosate Resistance Toolkit at cottoninfo.com.au.

TABLE 26: Species that have developed resistance to paraquat (Group 22/L) in Australia

Species	Common name	Year	State	Crop	Resistance to other MoAs/herbicides
Hordeum glaucum	Northern barley grass	1983	Vic	Lucerne	Diquat (22/L)
Arctotheca calendula	Capeweed	1984	Vic	Lucerne	Diquat (22/L)
Hordeum leporinum	Barley grass	1988	Vic	Lucerne	Diquat (22/L)
Vulpia bromoides	Silver grass	1990	Vic	Lucerne	Diquat (22/L)
Mitracarpus hirtus	Small square weed	2007	Qld	Mangoes	Diquat (22/L)
Lolium rigidum	Annual ryegrass	2010	SA	Pasture seed	1(A)/9(M) – 2 populations
Gamochaeta pensylvanica	Cudweed	2015	Qld	Tomatoes, sugarcane	
Solanum nigrum	Blackberry nightshade	2015	Qld	Tomatoes, sugarcane	
Eleusine indica	Crowsfoot grass	2015	Qld	Tomatoes, sugarcane	
Conyza bonariensis	Flaxleaf fleabane	2016	NSW	Grape vines	
Conzya sumatrensis	Tall fleabane	2018	Qld	Wheat/fallow	

TABLE 27: Weed species with populations resistant to 2,4-D (Group 4/I)

Species	Year	State	Crop	Herbicide	Also resistant to MoAs
Wild radish *Raphanus raphanistrum*	1999	WA	Winter cereal	2,4-D	
	2006	SA	Winter cereal	2,4-D, MCPA	2(B), 12(F)
	2009	Vic	Winter cereal	2,4-D	2(B)
	2010	WA	Winter cereal	2,4-D	2(B), 12(F), 9(M)
	2011	Vic	Winter cereal	2,4-D	
	2011	NSW	Winter cereal	2,4-D	
	2013	NSW	Winter cereal	2,4-D	
	2020	WA	Winter cereal	2,4-D	2(B), 27(H), 27(H)
Indian hedge mustard *Sisymbrium orientale*	2005	SA	Winter cereal	2,4-D, MCPA	2(B)
	2015	SA	Winter cereal	2,4-D	12(F)
	2016	Vic	Winter cereal	2,4-D	
	2016	Vic	Winter cereal	2,4-D	2(B), 12(F)
Sowthistle *Sonchus oleraceus*	2015	Vic	Winter cereal	2,4-D	
	2015	SA	Winter cereal	2,4-D, dicamba, clopyralid	
Capeweed *Arctotheca calendula*	2015	SA	Winter cereal	2,4-D	

This tool allows you to check what your current level of risk is for developing glyphosate-resistant weed populations on your farm. The tool allows you to enter information on your current practices (including crop rotation, crop density, and weed control tactics) and to identify which weed species you usually have to control. It will then calculate a glyphosate resistance risk score for the paddock, and a level of risk for each weed identified.

The Barnyard Grass Understanding and Management (BYGUM) tool, available via cottoninfo.com.au, enables the resistance risk from summer weed control to be considered in the context of economics and seed bank management. This weed management scenario testing tool combines biological, agronomic and economic factors to examine the economics of current summer grass management strategies and compare with new tactics.

What does herbicide resistance look like?

Resistance begins with the survival of one plant and the seed that it produces. Early in the development of a resistant population, resistant plants are likely to occur only in isolated patches. These are often surrounded by dead 'susceptible' plants of the same species, or other species usually controlled by the herbicide applied. This is the critical time to identify the problem. For other resistance mechanisms, the symptoms may appear as a 'sick' plant that subsequently recovers and may look similar to 'underdosing' or poor application. If a higher application rate is required to kill these individuals in subsequent years this indicates non-target site resistance is present. Many of the symptoms of herbicide resistance can also be explained by other causes of spray failure. Regularly maintain and calibrate spray equipment, spray under appropriate conditions and keep good records to ensure maximum spray efficacy. Resistant weed seeds can also be transported into a management unit through irrigation channels, vehicle tyres, or blow in on the wind (in the case of species such as fleabane), and consequently can be relatively widespread before they are noticed.

An annual ryegrass survivor. Eric Koetz, CottonInfo/NSW DPI

The ultimate super-weed?

Palmer amaranth (*Amaranthus palmeri*) can grow more than 2 metres high. It is highly competitive with an extended germination/emergence window, rapid growth, and drought tolerance. It can survive in a wide range of environments and produces prolific amounts of seed (~1 million per plant). Populations in the USA (where it is referred to as 'pigweed') have developed resistance to multiple classes of herbicides with different modes of action, including glyphosate, 2,4-D, dicamba and glufosinate, making it very difficult and expensive to control.

While not currently present in Australia, Palmer amaranth would thrive in our cotton cropping areas. Report suspicious plants to the Exotic Plant Pest Hotline on 1800 084 881.

Palmer amaranth on a field edge. Eric Koetz, NSW DPI

Why should I get weeds tested?

Testing a plant population for the presence of herbicide resistant individuals is an important tool for growers and advisors. The results from these tests can confirm if there is still efficacy within some of the MoA groups. Generally, seed is collected from the suspect plants and is sent for testing (see below).

An alternative sampling method is to collect actual plants from the field for the 'Quick Test'. This process is limited to grass weeds only and is best targeted at seedlings or small plants as large numbers need to be collected and posted. Upon arrival they are potted up and once re-established, herbicide treatments are applied. In mid-summer conditions, plants are less likely to survive the trip than if collected in cooler times of the year. It is recommended to take seed samples from the surviving plants in summer and mark these sites to enable seedling collections in the following autumn or spring if they are needed. The timeline for obtaining results from sending seed samples can be several months. Results are usually available by the end of April when samples are received before January. When plants are sent for Quick Tests, results are usually available within 4-8 weeks.

Collecting samples (seed test):

- Collect 2000-3000 seeds from plants you suspect are resistant. Barnyard grass = 1 cup full.
- If testing >3 modes of action, collect additional seed.
- Avoid collecting large amounts of seed from just a few large plants.
- Follow a 'W' shaped pattern stopping every ~20 m if survivors are widespread. If survivors are localised, collect from within this area.
- Shake seed heads into a bucket to ensure only ripe seed is collected.
- Store samples in a paper bag at room temperature, away from sunlight, moisture and heat.
- Post as soon as possible.

Collecting plant samples (quick test):

- For each mode of action to be tested: collect 50 plants/field from areas where you suspect resistance.
- Gently pull out plants and wash roots.
- Wrap in paper towel. Do not moisten.
- Place in waterproof plastic bag.
- Collect weeds early in the week, and Express Post as soon as possible. Do not store or post over the weekend. If plants cannot be posted on the same day, store overnight in the fridge.

Sending samples to resistance testing services

Contact the testing service via their website and complete the sample registration request so they know to expect the sample. Follow the instructions above and send samples together with sample registration, contact details, field and weed management history and testing required to one of the testing services below:

Dr Peter Boutsalis
Plant Science Consulting (Seed or Quick test)
22 Linley Avenue, Prospect SA 5082
0400 664 460
info@plantscienceconsulting.com
csu.edu.au/weedresearchgroup/herbicide-resistance

Dr John Broster
Charles Sturt University (Seed test only)
Herbicide Resistance Testing Service,
PO Box 588,Wagga Wagga NSW 2678
(02) 6933 4001
jbroster@csu.edu.au

The Glyphosate Resistance Toolkit can be found at
cottoninfo.com.au/glyphosate-resistance-toolkit

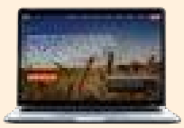
How do I manage glyphosate resistant weeds?

The strategy to **manage** glyphosate resistant weeds is similar to the strategy to **prevent** glyphosate resistance – integrate a range of different tactics throughout the weed lifecycle to rapidly deplete the soil weed seed bank, and prevent further seed set/recruitment. This means that the HRMS is just as relevant to managing resistant weeds as it is preventing them. If detected early, managing known patches of herbicide resistant weeds by applying an intensive program of different tactics and ensuring weeds do not set seed, may be effective in preventing the problem from spreading.

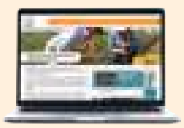
Information on resistant weeds has been partially sourced from I.Heap, The International Survey of Herbicide Resistant Weeds. May 2024.

USEFUL RESOURCES:

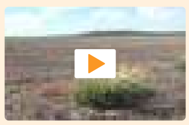
Glyphosate Resistance Toolkit
cottoninfo.com.au/glyphosate-resistance-toolkit



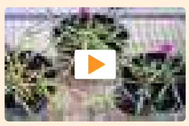
Weedsmart
weedsmart.org.au



The BYGUM (barnyard grass understanding & management)
cottoninfo.com.au/barnyard-grass-understanding-and-management-bygum



Minimising glyphosate resistance
youtu.be/cke-mamGe2o



A demonstration of weed resistance
youtu.be/y7Jj1laiSLk

Herbicide Resistance Management Strategy (HRMS) 2024-25

The most effective way to delay resistance is to use:

2 non-glyphosate tactics targeting both grasses and broadleaf weeds during the cotton crop **+** 2 non-glyphosate tactics targeting both grasses and broadleaf weeds during the summer fallow

and ensure NO survivors
(control survivors of glyphosate applications and do not allow them to set seed)

Explanatory notes

The HRMS is designed as a tool to manage the risk of herbicide resistance in irrigated and dryland farming systems incorporating herbicide tolerant (HT) cotton, to delay glyphosate resistance.

The strategy has been developed in response to the escalating problem of glyphosate herbicide resistance. This version of the HRMS focuses on a glyphosate tolerant cotton system; however the future availability of multi-trait herbicide tolerant varieties has not been considered in the design of the strategy, and may require a more sophisticated strategy to follow into the future.

Increased time to resistance

Research indicates that typically glyphosate failure may appear in grass weeds after 13 years (dryland) and 19 years (irrigated) in a glyphosate only system. Resistance in broadleaf weeds is slower to emerge and usually takes around 18 years in both irrigated and dryland systems when cotton is grown in rotation with a summer fallow. Glyphosate resistance is delayed by 4-6 years if residual + double knock regularly implemented in summer fallow.

Cropping system

The HRMS models two systems,

- Continuous back to back irrigated glyphosate-tolerant cotton with no summer fallow; and,
- Dryland glyphosate tolerant cotton grown every second year, alternating with long summer fallows.

With many farms now reporting glyphosate resistance, it is important to note that the strategies identified to avoid resistance are similar to those required to manage it.

However, research has found that to eradicate populations, additional tactics such as patch management are required.

In the dryland scenario, rotation cropping should be considered similar to a fallow, with two non-glyphosate tactics recommended. Rotation crops provide an opportunity to incorporate other tactics, rotate herbicide groups, vary the time of year crop competition suppresses weeds and produce stubble loads that reduce subsequent weed germinations.

In-crop tactics

- The control of survivors and use of two non-glyphosate tactics is critical to the HRMS.
- Aim for 100% control of glyphosate survivors after glyphosate application. Cultivation after glyphosate application is predicted to achieve 80% survivor control, whereas cultivation plus chipping is predicted to achieve 99.9% survivor control. Other tactics for survivor control could be equally effective, such as shielded or spot-spraying with an effective knockdown herbicide.
- A key principle of herbicide usage in an IWM system is to rotate herbicide groups.
- Residual herbicides need back up, such as tillage, chipping and non-glyphosate knockdowns. When using residuals, consider plant-back periods and crop safety.

Summer fallow tactics

- Summer fallows (and rotations) may include any two non-glyphosate tactics such as residual or knockdown herbicides or tillage that are effective on the weed species present.

Other management recommendations:

- Control weeds in adjacent areas (channels, tail drains, fencelines and roadsides) to minimise the seed bank and eliminate unknown weed seed sources. Do NOT rely on glyphosate to manage weeds in non-crop areas.
- Be aware of weed seed contamination sources (e.g. waterways, vehicle/machinery, and farm inputs). Establish and maintain COME CLEAN. GO CLEAN to prevent introduction and transport of resistant seeds.
- Monitor and follow up to ensure weeds that survive glyphosate applications are controlled using a non-glyphosate tactic before they are able to set seed. Get suspect weed survivors tested for resistance.
- Patch control – control weeds in isolated patches.
- Use IWM best practice when employing tactics, including:
  - Regular scouting and correct weed identification;
  - Good record keeping;
  - Timely implementation of tactics;
  - Rotating herbicide mode of action groups;
  - Always following label recommendations; and,
  - Considering other aspects of crop agronomy.

Assessing your own risk

Refer to page 91 of this publication for information on how to get weeds tested for resistance. For more information and tools on herbicide resistance and weed management in cotton refer to: cottoninfo.com.au or weedsmart.org.au

Hit weeds where it hurts:
Use WeedSmart BIG 6 (page 79).

Irrigated back-to-back cotton

Risk	In-crop tactics 3 x OTT glyphosate applications PLUS	Seed bank control*	Comments
← High - Resistance risk - Low → ← Decreasing - Survivor control – Increasing →	Very high survivor control after each OTT glyphosate	Very high	Control all survivors of OTT glyphosate applications. Don't use glyphosate alone to control the last in-crop flush
	2 x strategic in crop cultivations	Very high	Time the second cultivation to control last weed flush and escapes prior to row closure
	Pre-plant residual plus residual layby	Very high	Consider plant-back period restrictions
	Very high survivor control after first OTT glyphosate	Very high	Control survivors from first flush which has highest weed germination
	Grass selective in-crop herbicide + cultivation	High	Resistance to Group A herbicides may already be present in some populations. Controlling survivors is essential; follow with cultivation
	Moderate survivor control after first OTT glyphosate only	Low	Survivors allowed to set seed will increase the speed of selection for resistance. Test survivors for glyphosate resistance
	Glyphosate only	Very low	Survivors allowed to set seed will increase the speed of selection for resistance. Test survivors for glyphosate resistance

Dryland cotton every second summer

Risk	Risk Summer fallow tactics	In-crop tactics 3 x OTT glyphosate applications PLUS	Seed bank control* in cotton phase	Comments
← High - Resistance risk - Low → ← Decreasing - Survivor control – Increasing →	2 non-glyphosate tactics	Very high survivor control after each OTT glyphosate	Very high	The most effective scenario for delaying glyphosate resistance
	Glyphosate only fallow	Very high survivor control	Very high	Very high frequency & efficacy of survivor control is required if in-crop only tactics are used
	2 non-glyphosate tactics	Moderate survivor	High	Lower intensity in-crop tactics can give excellent results if backed up with robust control in summer fallows. Specific, frequent, well-timed control of glyphosate survivors provides long term resistance delay/management
	Glyphosate only fallow	2 strategic cultivations	Low	Time last cultivation to control late flushes and escapes
	Glyphosate only fallow	Pre-plant residual + layby	Very low	These tactics give limited increased time to resistance and poor seed bank control
	Glyphosate only fallow	Moderate survivor control after each OTT	Very low	
	2 non-glyphosate tactics	Glyphosate only	Very low	
	Glyphosate only fallow	Glyphosate only	Very low	

***Seed bank control key (seeds/m^2): Very high <10; High 10-100; Medium 100-500; Low 500-1500; Very low >1500.**

Key points:

- Glyphosate (Group 9/M) resistance has been confirmed and is widespread in the following common cotton weeds: windmill grass, fleabane, sowthistle, feathertop Rhodes grass, awnless barnyard grass, liverseed grass.
- Annual ryegrass is a significant issue in Southern valleys and is emerging as a problem in Northern NSW. There are reports of cross resistance to glyphosate and Group 1(A) herbicides.
- Group 1(A) resistance is widespread throughout broadacre farming systems and is increasing in cotton farming systems, especially in hard to control weeds such as feathertop Rhodes grass, annual ryegrass and windmill grass.
- Emerging herbicide resistance to Group 22(L) (paraquat) has been reported in other farming systems, especially in grasses. Resistance has not been reported in cotton farming systems, however the increase in double knock strategies makes it essential that all survivors of a double knock involving paraquat need to be controlled. Two populations of tall fleabane collected during surveys have tested as resistant to a glyphosate + paraquat double knock.
- Increasing use of Group 4(I) herbicides in summer fallows is a concern with a population of sowthistle reported as resistant to 2,4-D in winter cereals.

TABLE 28: Resistance risk for herbicides used in cotton						
Herbicide active ingredient	**Pre plant**	**At plant**	**Post plant**	**Mode of action**	**Years to resistance**	**Resistance status**
Amitrole + paraquat	Y	N	N	34(Q) + 22(L)	>15	**Rare**
Amitrole + ammonium thiocyanate	Y	N	N	34(Q)	>15	**Rare**
S-Metolachlor or Metolachlor [1]	Y	Y	Y	15(K)	>15	**Rare**
Saflufenacil	Y	N	N	14(G)	>15	**Rare**
Glufosinate-ammonium	Y	N	N[3]	10(N)	10-15	**Rare**
Dicamba[2]	Y	N	N[3]	4(I)	10-15	**Rare**
Fluroxypyr	Y	N	N	4(I)	10-15	**Rare**
Fluroxypyr+ aminopyralid	Y	N	N	4(I)	10-15	**Rare**
Diuron	Y	Y	Y	5(C)	10-15	**Rare**
Fluometuron	Y	Y	Y	5(C)	10-15	**Rare**
Fluometuron + prometryn	Y	Y	Y	5(C)	10-15	**Rare**
Prometryn	Y	Y	Y	5(C)	10-15	**Rare**
Triclopyr	Y	N	N	4(I)	10+	**Rare**
Triclopyr + picloram	Y	N	N	4(I)	10+	**Rare**
Triclopyr + picloram + aminopyralid	Y	N	N	4(I)	10+	**Rare**
Carfentrazone-ethyl	Y	N	N	14(G)	10	**Rare**
Flumioxazin[4]	Y	N	Y*	14(G)	10	**Rare**
Oxyfluorfen	Y	N	N	14(G)	10	**Rare**
Isoxaflutole[2]	Y	N	N	27(H)	10	**Rare**
Paraquat	Y	Y	Y	22(L)	>15	**Occasional**
Paraquat + diquat	Y	Y	N	22(L)	>15	**Occasional**
Norflurazon	Y	N	N	12(F)	15+	**Occasional**
2,4-D[2]	Y	N	N	4(I)	10-15	**Occasional**
Pendimethalin[5]	Y	Y	Y	3(D)	10-15	**Occasional**
Trifluralin	Y	Y	N	3(D)	10-15	**Occasional**
Chlorthal dimethyl	Y	Y	Y	3(D)	10-15	**Occasional**
Bromoxynil	Y	N	N	5(C)	10-15	**Occasional**
Glyphosate[6]	Y	Y	Y	9(M)	>12	**Widespread**
Butroxydim	N	N	Y	1(A)	6-8	**Widespread**
Clethodim	N	N	Y	1(A)	6-8	**Widespread**
Fluazifop-p	N	N	Y	1(A)	6-8	**Widespread**
Haloxyfop	N	N	Y	1(A)	6-8	**Widespread**
Propaquizafop	N	N	Y	1(A)	6-8	**Widespread**
Halosulfuron-methyl	N	N	Y	2(B)	4	**Widespread**
Trifloxysulfuron sodium	N	N	Y	2(B)	4	**Widespread**

Lowest resistance risk
Moderate resistance risk
Highest resistance risk

Note that Group 1(A) herbicides already exhibit widespread resistance in several species. Controlling survivors is essential.

Always read the label for detailed use patterns and application rates.
[1] Bouncer® and Dual Gold® formulations.
[2] See label for rainfall required before plant-back period begins.
[3] XtendFlex® varieties only, using specific formulation registrations.
[4] Valor® formulation only.
[5] Rifle® formulations.
[6] Roundup Ready Flex® varieties only.

Refer to Tables 21, 22 and 24 for plant-back periods.

Herbicide tolerance technology:

XtendFlex® cotton Bayer Crop Science

Cotton varieties containing the XtendFlex® herbicide tolerance trait (XtendFlex cotton) provide growers with greater flexibility to use additional herbicide modes of action to target glyphosate-resistant weed populations and hard-to-kill weed species. Varieties containing the XtendFlex cotton trait are tolerant to glyphosate, dicamba, and glufosinate-ammonium herbicides.

Weed resistance management in XtendFlex® cotton

Herbicide resistant weeds have been a reality in Australia for decades – no herbicide is immune, and while the problem is significant, it is also manageable. Prudent management of XtendFlex® cotton technology and mitigation of resistance risks, will ensure these options for weed control are available to Australian cotton growers well into the future.

Growing XtendFlex cotton

There are several requirements that growers need to be aware of when planting XtendFlex cotton, These registered products are: Roundup Ready® Herbicide with PLANTSHIELD®, Roundup Ready PL Herbicide with Plantshield Technology, XtendiMax® 2 Herbicide with VapourGrip® Technology (XtendiMax 2), Roundup Xtend® 2 Herbicide with VapourGrip Technology and Nufarm BIFFO® Herbicide.

The requirements are designed to support the longevity and effectiveness of the trait and herbicides, these include:

- Completion of an XtendFlex® cotton accreditation course prior to planting cotton containing the XtendFlex® herbicide tolerance trait for the first time.
- Reporting any suspected glyphosate, dicamba or glufosinate resistant weed species to a Bayer representative or Nufarm where Nufarm BIFFO® Herbicide has been used.
- Implementing an integrated weed management (IWM) strategy
- Completion of the XtendFlex® cotton spray applicator training when applying XtendiMax® 2 Herbicide in XtendFlex® cotton.

Reporting suspected resistance

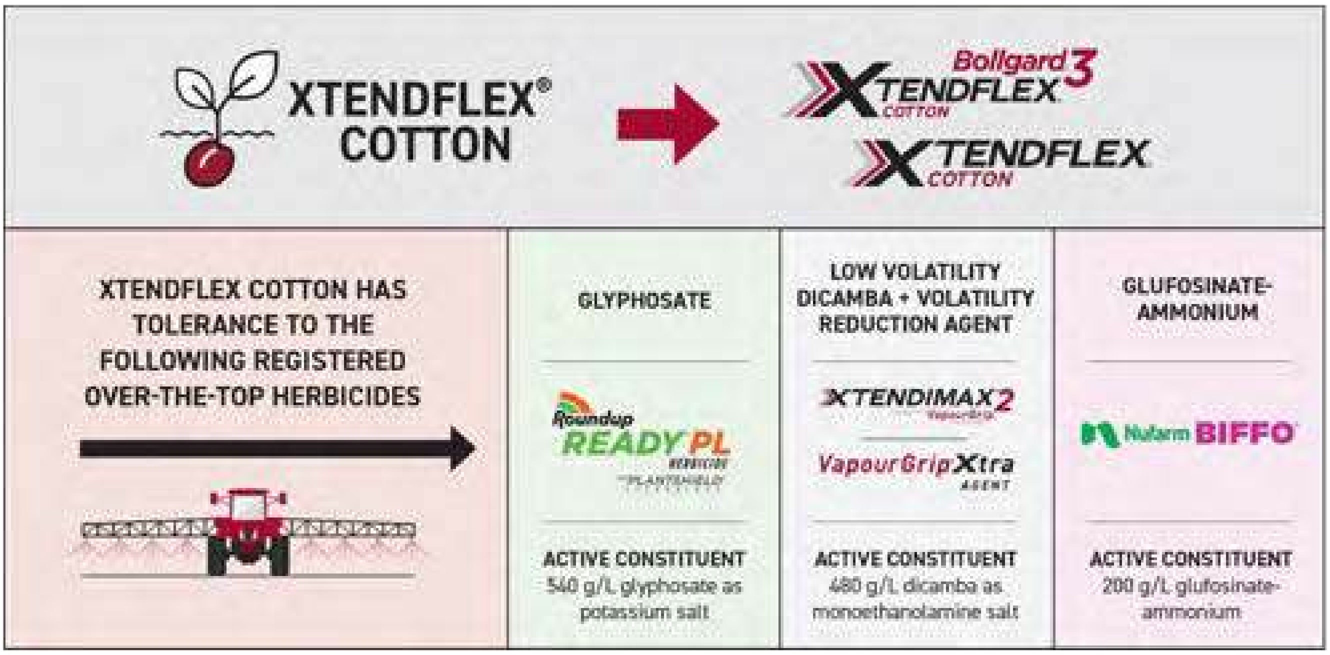
Naturally occurring populations of some weeds may possess biotypes with resistance to glyphosate, dicamba or glufosinate. Growers should be aware of this prior to using any of the registered OTT herbicides in XtendFlex® cotton and should aim to decrease the development and spread of resistant populations. If you suspect resistant biotypes are present, they should be sampled and tested. Contact the local Bayer Territory Business Manager for assistance with this process.

The weed resistance management plan (WRMP) aims to reduce the likelihood of weed resistance to glyphosate, dicamba or glufosinate herbicides developing, it does not guarantee that resistance will not occur.

Understanding your herbicide resistance risk

Each field planted to XtendFlex® cotton has its own unique risk of weed populations resistant to dicamba, glufosinate or glyphosate developing, based on herbicide usage history, the weeds present and their population density, and other historical rotations and agronomic management strategies employed.

As a part of any sound IWM plan, growers are encouraged to assess their resistance risk prior to planting XtendFlex®, cotton when making decisions about weed management strategies.



On-farm factors that change resistance risks

Factors that decrease resistance risk:

- Monitoring and preventing herbicide weed control escapes from setting seed.
- Planning and implementing an IWM strategy to reduce the weed seed-bank.
- Strategic use of alternative knockdown herbicides and tillage in fallows prior to sowing.
- Use of alternate herbicide modes of action including residual herbicides in crops and fallows.
- Use of a double-knock glyphosate followed by tillage or an appropriate double-knock partner such as paraquat (Group L) based products at effective rates.
- Applying stewardship plans when growing herbicide tolerant crops.
- Farm hygiene to prevent importing and moving herbicide resistant weed seeds.

Factors that increase resistance risk:

- Frequent glyphosate, glufosinate, or dicamba-based chemical fallow applications not followed by double-knocks to ensure no weed survivors.
- Continuous reliance on glyphosate, glufosinate, and mixtures with dicamba as a knockdown prior to sowing.
- Lack of tillage
- Lack of use of alternative herbicide modes of action in fallows and crops.
- Allowing survivors of glyphosate, dicamba or glufosinate applications to set seed.
- High weed numbers
- Lack of crop competition on weeds.
- Over-reliance on herbicide tolerant crops as a weed control mechanism.

Resistance management principles for XtendFlex® cotton

Incorporating a range of cultural and herbicide management practices will maximise the control of any potential herbicide resistant weed populations. The implementation of these practices should also result in a reduction in the weed population entering the XtendFlex® cotton cropping phase.

Key IWM principles for XtendFlex® cotton are:

1. Aim to enter the XtendFlex® cotton cropping phase of your rotation with a low weed burden.
2. Integrate as many different weed control options (chemical and cultural) as possible through all phases of the crop rotation.
3. Make every herbicide application count – use registered rates at the correct application growth stage and always assess its effectiveness.
4. Rotate herbicides with different modes of action throughout the fallow and crop rotation.
5. Regularly monitor the effectiveness of resistance management practices.
6. Test weed populations for herbicide resistance status as a part of ongoing IWM.
7. If planting into a paddock with suspected glyphosate, dicamba or glufosinate resistant weed populations growers must have a plan to manage such weeds.
8. Stop weed seed set by aiming for 100% control of any survivors.

Growers should aim to prevent seed set from any weeds surviving glyphosate, dicamba or glufosinate herbicide applications to prevent resistance development and spread – never use the same herbicide/herbicide group twice on the same weed, or weeds growing from seed produced by a surviving weed.

Table 29 outlines some key principles for weed control at different stages through the cotton season.

Bayer strongly recommends that growers consult an agronomist when designing an IWM strategy for their property. For further resources and information see weedsmart.org.au.

Monitoring herbicide efficacy

All growers or agronomists should inspect fields between 14 and 28 days after spraying with glyphosate, dicamba or glufosinate to monitor the effectiveness of the herbicide application. During an inspection, any surviving weeds that are normally susceptible to the herbicide/s used should be identified. The outcomes of any inspection and any remedial application used should be recorded. Any case of suspected resistance should be reported immediately to Bayer (Nufarm for glufosinate) for further investigation.

Growing Roundup Ready Flex® Cotton?

If you are planning to grow Roundup Ready Flex® cotton in the 2024/25 cotton season, please refer to the Roundup Ready Flex® Weed Resistance Management Plan
crop.bayer.com.au/-/media/bcs-inter/ws_australia/use-our-products/product-resources/cotton-traits/rrflex-cotton-weed-rmp-m0181.pdf
or refer to the 2024/25 Bayer Technology User Agreement document.

XtendFlex®, Roundup Ready®, XtendiMax®, PLANTSHIELD® and VapourGrip® are Registered Trademarks of the Bayer Group; BIFFO® is a Registered Trademark of Nufarm Australia Ltd.

USEFUL RESOURCES:

Stewardship and resistance management regarding their technology traits and related products.
crop.bayer.com.au

XtendFlex® guides are downloadable
crop.bayer.com.au/products/biotechnology-traits/xtendflex-cotton

Resources on weed management and minimising the risk of resistance can be found at
weedsmart.org.au

STEER | PLANT | SPRAY | SPREAD | HARVEST | SHARE | ANALYSE

YOUR NOZZLE-BY-NOZZLE ADVANTAGE

CONSISTENT DROPLET SIZE

INDIVIDUAL NOZZLE CONTROL

WIDE SPEED RANGE

AUTOMATIC TURN COMPENSATION

HIGH VISIBILITY TOUCHSCREEN

Take your spraying program to the next level of accuracy and performance with RightSpot™ precision technology from Ag Leader. Suitable for retrofitting to most self-propelled or trailed sprayers, RightSpot utilises blended pulse technology to maintain consistent droplet size and coverage at all operating speeds. With independent control of up to 144 nozzles, automatic turn compensation and automatic reticulation, priming and flushing, RightSpot significantly reduces input costs and the potential for spray drift. Contact your local Ag Leader dealer and find out how RightSpot can optimise the efficacy of your spraying program.

MAKING FARMING EASIER

Ag Leader®

TABLE 29: Key principles for weed control in XtendFlex® cotton crops	
PRE-PLANT KNOCKDOWN	• Always start clean by planting into a weed-free field using either tillage or an effective herbicide application. • Know your field history in order to identify whether any volunteer cotton present is XtendFlex® cotton. • Consider using approved tank mixes when applying any of the OTT registered products in XtendFlex® cotton (do not mix any ammonium containing products e.g. ammonium sulfate (AMS) with dicamba).
RESIDUAL HERBICIDES	• Residual herbicides should be used where appropriate in an XtendFlex® cotton system • Consider using residual herbicides where weed pressure is high, or weeds will not be adequately controlled by the OTT products registered for use in XtendFlex® cotton. • The residual herbicide can be applied as a pre-emergence application (either a pre-plant incorporated application, or at planting application). • Use the recommended label rate and timing of the residual herbicide.
IN-CROP WEED CONTROL	• Refer to the product label to ensure target weeds are at the appropriate growth stage for all OTT products registered for use in XtendFlex® cotton. • Select the timing and application rate of sprays based on the most difficult to control weed species in each field in accordance with the label. • Post-directed sprays should be used to achieve more thorough coverage on weeds. • Refer to the 'Weeds Controlled' table on the label for the rate recommendations on specific weeds for products registered for OTT use in XtendFlex® cotton. • Aim for 100% control of weeds. Monitor and where required implement additional tactics such as inter row cultivation, and/or alternative modes of action to control survivors. • Be aware of any potential contamination of spray application equipment (including mixing stations). • Ensure all equipment is thoroughly cleaned and free of residues. • Only tank mix with products that are approved according to the label. • Do not mix products containing ammonium ions with dicamba, including ammonium sulfate (AMS), glufosinate-ammonium and ammonium salts of glyphosate. • Ensure all applications are made according to label guidelines on water volume, droplet size and environmental conditions and appropriate boom heights and application speeds are maintained. • Be aware of off-target drift to susceptible crops and fields with both aerial and ground applications. Do not apply herbicides by aircraft unless approved on label. • Monitor predicted conditions to manage the possibility of dicamba volatility and drift up to 72 hours post application (refer label). • Growers should use registered herbicides other than glyphosate, glufosinate or dicamba where required to increase diversity of weed control tactics.
LAY-BY APPLICATIONS	• If you currently use lay-by herbicides, then consider maintaining this program. • A robust lay-by program can provide residual control of weeds not controlled by glyphosate, dicamba or glufosinate. • Use the recommended label rate and timing of the residual herbicide.
PRE- HARVEST APPLICATION	• An over-the-top application of a Roundup Ready® Herbicide is possible, if required, before harvest and after cotton reaches 60% open bolls, as one of the 4 glyphosate applications. Rate: 1.5 kg/ha for Roundup Ready® Herbicide with PLANTSHIELD® or 1.9 L/ha for Roundup Ready® PL Herbicide with PLANTSHIELD® Technology. • This application can be used to control late season weeds and improve harvest efficiency. • Compatible with commonly used defoliants (see Roundup Ready® Herbicide with PLANTSHIELD® and Roundup Ready® PL with PLANTSHIELD® Technology labels). • Do not use on crops intended for planting seed production.

Management of volunteer and ratoon cotton

Controlling unwanted cotton is an essential part of good integrated pest and disease management and general farm hygiene. Volunteer (established unintentionally) and ratoon (regrown from surviving root stock) cotton plants can:

- create problems for Bt resistance management
- physically block row access
- act as a 'green bridge' or as early hosts for pests such as spider mites, aphids and cotton bunchy top
- interfere with disease management strategies
- reduce seed purity.

Unwanted cotton can occur in fields that have previously grown cotton, elsewhere on the farm, or even further afield (e.g. along irrigation channel or road corridors). Questions to ask when planning your IWM strategy include:

1. Are the volunteers/ratoons likely to be varieties that possess herbicide tolerance genes?
2. If a rotation or cover crop is planned, will there be problems managing unwanted cotton within it?

Do not allow established volunteers or ratoons to set seed as this will potentially create additional volunteers.

Mealybug hotspots are often associated with ratoon cotton plants.

Volunteers

The majority of volunteers come from seed cotton that falls out of the boll early, or is lost during picking or module assembly/transport, although plastic-wrapped round modules tend to have lower losses than tarped rectangular modules. Plants can also establish directly from fuzzy seed escapes while being transported to crushing plants or stock feed areas, or from planting seed accidently spilled on route to or within fields.

Do not ignore volunteers that emerge prior to planting as they may allow the early establishment of in-field pests populations and promote disease incidence. Also, having been more likely to be impacted by seedling diseases and cool conditions, volunteers rarely contribute to the crop yield.

Best practice...

- Control volunteer and ratoon cotton plants in crop and non-cropping areas as part of an integrated weed management strategy.
- Target plants when small, using physical methods or an appropriate herbicide.
- Read and follow all label directions before use to confirm timing and rates and use sufficient spray volume to achieve good coverage.
- Undertake crop destruction operations as soon as practical after picking to prevent ratoon cotton.
- Ensure implements are set up to cultivate both hill and furrow; avoid leaving uncultivated strips.
- Manual removal (i.e. chipping) may be necessary where isolated plants remain in non-field areas.

Volunteer cotton plants enable pests to survive between seasons.
Lewis Wilson

Inadequate end of season crop destruction can lead to ratoon cotton.
Murray Sharman, Qld DAF

Reducing the amount of viable cotton seed left in fields (through clean pick and stubble management) and around farm (cleaning up after module removal and spillages) will reduce the number of volunteers.

Cultivation and herbicides are the two most common methods of volunteer cotton control. Both require the cotton plants to have germinated and emerged (following pre-irrigation or sufficient rainfall). Cultivating for volunteer control readily controls seedlings, and also manages other weeds, making it an excellent non-chemical option to include within an IWM program, unless the germination is too close to planting. However, it is only fully effective when applied across the entire field (both furrow and hill). It is also relatively slow, can lead to soil damage (if conducted at an inappropriate time) or erosion, and increases soil moisture losses (a problem in rainfed farming systems).

Seedling volunteers can also be controlled reasonably well with less invasive physical removal such as Kelly chains, which break the young stems and can be used relatively close to planting. In-crop cultivation with sweeps is also effective on small volunteer cotton plants.

Most herbicides work best on young cotton seedlings (up to 4 nodes). Larger plants are usually much harder to kill, even when using double knocks.

Tables 30 and 31 provide a list of herbicide actives registered for volunteer control, including established plants. Note that glufosinate will not be effective in controlling XtendFlex® cotton volunteers.

Refer to product labels for specific use information as not all products containing these actives have volunteer cotton on the label. Use different modes of action than utilised in-crop where possible, to help prevent resistance in other weed species that may be present, ensure any plant-back intervals fit with your proposed planting schedule, and take precautions to minimise drift.

Excellent spray coverage is essential when using contact herbicides. Use sufficient volumes and appropriate speeds and note that shadowing from nearby stubble, lint or other weeds can adversely affect spray outcomes.

Crop rotation enables the use of alternate and residual herbicides. Ensure good control is achieved as cotton plants hidden within subsequent crops can continue to host pests and diseases.

Occasionally, cotton plants become well established before there is opportunity to control them due to unforeseen circumstances (often weather-related). Fluroxypyr (Comet®) can be used on larger (15-30 nodes) plants (see Table 31). Where isolated plants establish in fallows or non-field areas such as along roadsides and fences, physical removal by chipping can be very effective.

Ratoon cotton

In theory, ratoons (sometimes referred to as regrowth or stub cotton) should not occur after Bt crops as harvested plants are required to be controlled as soon as practical after picking (usually by mulching and/or root cutting followed by cultivation to destroy the root system) in the Technology User Agreement. Thorough crop destruction can be particularly challenging in a minimum-till situation, where usually the only soil disturbance is a single round of pupae busting, and care must be taken to ensure regrowth is prevented.

Ratoon cotton is normally the result of ineffective crop destruction where either the stems have not been fully severed or have not been cut below the cotyledons. Ratoons are more likely to occur from volunteer plants or if planted seed grew outside the row line targeted by root cutting.

Crop destruction provides an addition opportunity to destroy overwintering helicoverpa pupae. Pupal control is a strategy in managing insecticide resistance for the cotton industry and is mandatory for Bollgard 3 crops where the first defoliation occurs after March 31.

Ratoon cotton plants that have survived crop destruction can be difficult to control, having developed a large root system and small leaf surface area. Three herbicide options, registered for both optical booms and broadacre application, are available for the control of large volunteer cotton or ratoon cotton amongst stubble or in fallow (see Table 31), and are registered.

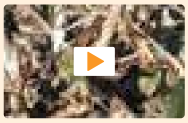
ALWAYS FOLLOW LABEL DIRECTIONS.

USEFUL RESOURCES:

Useful publications found at
cottoninfo.com.au/publications-and-media

WEEDpak
cottoninfo.com.au/publications/weedpak

Australian Cotton Production Manual: Chapter 23, Post-harvest pest and stubble management
cottoninfo.com.au/publications/2024-australian-cotton-production-manual



Effective end of season crop destruction
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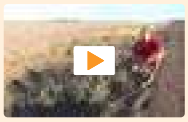


Rogue cotton plants in the farming community
youtu.be/CJP14_swggE

TABLE 30: Herbicides for control of volunteer cotton

Active ingredient	MoA group	Comments (always refer to product labels)
Amitrole + paraquat	34(Q) + 22(L)	Can be applied after an initial spray of glyphosate (double knockdown). Refer to label for spot spray rates.
Bromoxynil	5(C)	Apply in minimum of 80 L/ha water for Roundup Ready cotton. Refer to label for rain-fastness and restrictions on spray quality & condition.
Carfentrazone-ethyl	14(G)	Apply minimum spray volume of 80 L/ha to ensure effective coverage. To broaden weed spectrum may be tank mixed with the recommended rate of a knockdown herbicide. Refer to label for adjuvant recommendation.
Paraquat + diquat	22(L)	Apply in 50-100 L water/ha. Avoid spraying under hot dry conditions. For best results, spray in the evenings or in humid conditions.
Flumetsulam	2(B)	May be banded (>40%) over the row or broadcast. Minimum spray volume 150 L/ha for optimum results.
Flumioxazin	14(G)	Do not apply post-sowing pre-emergent. Do not sow crops for at least one hour after application. Can be tank mixed with glyphosate to control other weeds that may be present. Refer to label for adjuvant details.
Glufosinate-ammonium*	10(N)	Good coverage is essential. Do not apply more than three applications per season. Best results are achieved when applied under warm humid conditions.
Metribuzin	5(C)	Registered for control of volunteer cotton in pigeon pea. Refer to label for critical comments.
Fluroxypyr	4(I)	Summer fallow.
Saflufenacil	14(G)	Do not apply post-sowing pre-emergent. Always apply with adjuvant or high quality methylated seed oil. See label for mandatory no-spray zone and spraying rates.
Pyraflufen-ethyl	14(G)	Prior to sowing summer crop or starting a summer fallow. Apply by ground rig only. Good spray coverage is essential. Do not sow crops for at least 1 hour after application.

*Note that volunteers with XtendFlex® traits will be tolerant to glufosinate-ammonium; adjust your IWM plan accordingly.
For the latest registration details, refer to portal.apvma.gov.au/pubcris

TABLE 31: Herbicides for control of large (15 to 30 node) volunteer cotton and ratoon cotton in fallow

Active ingredient	Rates	Comments
Fluroxypyr 4(I)	1 L/ha followed by 1 L/ha OR	For control of large cotton plants or ratoon cotton a sequential application of Comet followed by Comet is required for maximum control. Ensure sufficient leaf regrowth has occurred on the ratoon cotton to maximise chemical uptake.
	1 L/ha followed by Shirquat® (22/L) 2 L/ha OR	For control of large cotton plants or ratoon cotton a sequential application of Comet followed by Shirquat is required for maximum control. The sequential application interval should be 7-14 days. Ensure sufficient leaf regrowth has occurred on the ratoon cotton to maximise chemical uptake.
	1 L/ha + 1 L/ha Amicide Advance® (4/I) 700/ha	For a single pass operation apply Comet + Amicide Advance 700. Ensure sufficient leaf regrowth has occurred on the ratoon cotton to maximise chemical uptake.

Refer to the Comet® 400 registration label for further details on control rates for optical spot spray technologies.
Note that control rates are based on L/ha for broadacre application and L/100L (spot spraying rate) for optical sprayers.
For the latest registration details, refer to portal.apvma.gov.au/pubcris

Integrated Disease Management (IDM)

Developing an IDM strategy

A plant disease occurs when there is an interaction between a plant host, a pathogen, and the environment. Effective IDM involves a range of control strategies which should be implemented regardless of whether a disease problem is evident, as the absence of visible symptoms does not necessarily indicate an absence of disease. Effective management can also delay the establishment of diseases in a cropping system.

Effective disease management does not always mean complete control of the disease through eradication of the pathogen, but rather aims at improving the resilience of the farming system. Many strategies may help to reduce the disease burden for subsequent crops and minimise the risk of diseases spreading within and between farms and regions.

IDM at planting

Optimal seed bed conditions

- Check field history for disease problems and avoid back-to-back cotton and rotations that promote cotton diseases.
- Prepare firm, high beds to optimise establishment and seedling vigour.
- To avoid root damage, do not position fertiliser and herbicides under the plant line.
- Ensure fields have good drainage to avoid waterlogging.

Sowing date/temperature

Sowing in cool and/or wet conditions slows plant growth and favours disease development, so aim to plant when soil temperatures are at least 16°C where possible and no cold shocks are forecast. The *Australian Cotton Production Manual* (ACPM) includes information on crop establishment.

Soil temperatures are available from the CSD Faststart Cotton Soil Temperature Network (membership required)
csd.net.au/soil-temperature

Variety selection

A number of varieties have some resistance to Verticillium wilt or Fusarium wilt (indicated by higher V rank and F rank respectively). Consider the disease status of each field when selecting varieties. Also consider the variety's seedling vigour, particularly when pre-irrigating or planting early. Refer to CSD's variety notes for more information csd.net.au/disease-ranks.

When black root rot is present, use the more indeterminate varieties that have the capacity to catch up later in the season.

Different seed treatment options are also available and must be chosen when seed is ordered. Contact CSD for more information.

Replanting

Make replant decisions early, based on stand losses, not on seedling size. Refer to the ACPM's *Crop establishment* chapter for more information.

IDM in crop

Fungicides

All cotton seed sold in Australia for planting is treated with a standard fungicide for broad-spectrum disease control. See Table 33 (page 122) for a list of fungicides registered in cotton or available under permit. Where possible rotate fungicide mode of action groups.

Irrigation scheduling

Early season, the temperature of irrigation water is considerably lower than soil temperatures, so pre-irrigating fields before planting can avoid cold shock and provide better conditions for seedling emergence, provided the hills or beds sub-up adequately. Irrigations late in the season to extend plant maturity can result in a higher incidence of verticillium wilt.

Irrigate as required if disease has weakened the root systems and there are signs of water stress, but avoid waterlogging, particularly when temperatures are cool. Manage tail water to minimise the risk of spreading pathogens; if possible water the least infected fields first. General traffic, sprays, and picking should also follow the same order.

Agronomic management

High planting rates can compensate for seedling mortality, but a dense canopy favours development of a range of leaf spots and boll rots. Optimise nutrition and irrigations and consider the use of growth regulators when required.

If black root rot is present, either manage for earliness to get the crop in on time (short season areas) or manage for delayed harvest to allow catch up (longer season areas).

Best practice...

- Monitor in-crop and over time for disease symptoms. Identify areas with a history of disease.
- Select disease resistant varieties where possible.
- Practice IDM at planting, in-crop and post-harvest.
- Report unusual symptoms and collect a sample to send for diagnosis.
- Be aware of and control insect vectors according to industry thresholds.
- Implement good farm hygiene and biosecurity practices.


Aerial photo of Fusarium wilt damage.

Balanced crop nutrition

A healthy crop is more able to express its natural resistance to disease. Excessive nitrogen will favour fusarium and verticillium wilts, and will also greatly increase the risk of boll rot, particularly in fully irrigated situations. Potassium is important for natural plant defences and a deficiency can lead to the expression of more severe disease symptoms. Refer to NUTRIpak, the CottonInfo website or the ACPM for more information on cotton nutrition.

Conduct your own in-field disease survey

Monitoring and recording the incidence and severity of each disease allows you to make a comparison over time and adjust your management strategies accordingly. The following section includes examples of the key diseases in cotton and their common symptoms.

If disease is suspected, sample healthy plants as well for submission to cotton pathologists. Occasionally, symptoms of nutrient deficiency can be misinterpreted for disease, so if the disease diagnostics turn out to be negative, consider a nutritional analysis.

Early season: Start monitoring when seedlings reach the 2 true leaf stage. Look for plants with signs of poor vigour or unusual symptoms. Examine roots by digging up the seedlings – DO NOT pull seedlings as this may damage the root system or remove characteristic symptoms or infected parts of the roots. Examine multiple plants at multiple locations as diseases are often unevenly distributed.

Compare number of plants established per metre with number of seeds planted. Refer to the ACPM for replanting considerations.

During the season conduct disease surveys as frequently as possible. Look for plants that show unusual symptoms, have poor vigour, or have died.

Cut both diseased and healthy-looking plants in several places along the stem and look for discolouration. Plants infected with verticillium or fusarium wilt may display minimal or no external symptoms, particularly in varieties with high disease rankings.

Perform a **late season** check after the final irrigation but before defoliation to give an indication of the disease burden that field has been under and assess disease risk in the following years.

If a suspect plant is located, please contact your nearest CottonInfo REO (see inside back cover) for more information or to determine the appropriate pathologist and process for submitting a sample.

Cotton trash bleached grey by 140 days of UV solarisation.
Scott Brimblecombe

IDM post harvest

Control alternative hosts and volunteers

Having a host free period prevents build-up of pathogen inoculum and carryover of disease from one season to the next. The pathogens that cause verticillium wilt, fusarium wilt, tobacco streak virus, alternaria leaf spot, some rots, and cotton bunchy top can also infect common weeds found in cotton growing areas (Table 32).

It is particularly important to have a host-free period as some diseases, such as cotton bunchy top, can only survive on living plants. Controlling alternative hosts, especially cotton volunteers and ratoons, will help reduce the risk of quality downgrades and yield loss. Utilise the off-season to rotate herbicide chemistries and explore alternate mechanical means of weed control. See the *Weeds* chapter and for more information.

Checking for volunteer plants youtu.be/9C2Utf5mUxkk

Manage crop residues

The pathogens that cause verticillium wilt, fusarium wilt, black root rot, boll rots, seedling disease and Alternaria leaf spot can all survive in cotton and some rotation crop residues. Carefully manage crop residues to minimise carryover of pathogens into subsequent crops.

If fusarium wilt is known to be present in a field, slash residues and retain on the surface for 60-120 days if possible (or at least one month) prior to incorporating, in order to disinfect the stalks through exposure to the UV component of sunlight. A good indication of adequate UV exposure is the bleaching of stems from pale brown to grey.

In all other circumstances (including the presence of verticillium wilt and other diseases), incorporate crop residues as soon as possible after harvest to promote faster decomposition.

Use crop rotations to help manage disease

Successive crops of cotton (or other host species) can contribute to a rapid increase in disease incidence, particularly if susceptible varieties are used. Employ a sound crop rotation strategy using crops that are not hosts for the pathogens present.

The pathogen that causes verticillium wilt has a large host range (see Table 32), and most legume crops host the black root rot and fusarium wilt pathogens. Some alternative crops such as vetch, canola and mustards can provide a biofumigation effect against black root rot under specific management regimes. Consider all pathogens present when planning crop rotations.

Australian trial work with cotton has shown crop rotations influence the abundance and diversity of soil microbial populations. After two years of rotation, verticillium wilt disease levels were lowest in cotton following bare fallow compared to maize, sorghum or continuous cotton. However, soil analysis indicated the fallow also had the lowest diversity of soil microbial communities which is not good for long term soil health. Disease incidence was significantly lower following maize and sorghum compared to continuous cotton, and these crops are a good rotation option.

Cotton is highly dependent on arbuscular mycorrhizal fungi (AMF) which form beneficial associations with plant roots and can act as agents in nutrient exchange. Bare fallow for more than 3 to 4 seasons or removal of topsoil (especially more than 40 cm), such as in the development of a bankless channel system or laser level cuts, may result in a severe lack of AMF. A cereal or green-manure crop may restore sufficient mycorrhizal fungi.

TABLE 32: Weeds as hosts of cotton pathogens

Family	Scientific Name	Common Name	Cotton disease					
			Alternaria leaf spot	Black root rot	Cotton bunchy top	Fusarium wilt	Tobacco streak virus	Verticillium wilt
Malvaceae	*Abutilon theophrasti*	Velvetleaf		✔	✔			✔
	Anoda cristata	Anoda weed	✔		✔			✔
	Gossypium hirsutum	Cotton volunteers/ratoons	✔	✔	✔	✔	✔	✔
	Hibiscus trionum	Bladder ketmia	✔		✔	✔		✔
	Malva parviflora	Small flowered mallow			✔			✔
	Malvastrum americanum	Spiked malvastrum			✔			
	Sida rhombifolia	Paddy's lucerne			✔			
Aizoaceae	*Trianthema portulacastrum*	Black pigweed			✔			
Amaranthaceae	*Alternanthera nodiflora*	Common joyweed						*
	Amaranthus macrocarpus	Dwarf amaranth				✔		✔
	Amaranthus retroflexus	Redroot amaranth		✔				✔
	Gomphrena celosioides	Gomphrena weed						✔
Asteraceae	*Bidens pilosa*	Cobler's pegs					✔	*
	Carthamus lanatus	Saffron thistle						✔
	Centaurea solstitialis	St Barnaby's thistle						✔
	Helianthis annuus	Sunflower volunteers					✔	✔
	Parthenium hysterophorus	Parthenium weed					✔	
	Silybum marianum	Variegated thistle						✔
	Sonchus oleraceus	Common sowthistle		✔			✔	✔
	Verbesina encelioides	Golden crownbeard		✔			✔	✔
	Xanthium spinosum	Bathurst burr						✔
	Xanthium occidentale	Noogoora burr					✔	✔
Brassicaceae	*Brassica* spp.	Wild turnip						✔
	Capsella bursa-pastoris	Shepherd's purse		✔				✔
	Rapistrum rugosum	Turnip weed						✔
Chenopodiaceae	*Rhagodia nutans*	Climbing saltbush						✔
Convolvulaceae	*Convolvulus erubescens*	Australian bindweed						✔
	Ipomoea lonchophylla	Cowvine, peach vine						✔
	Ipomoea plebeia	Bellvine		✔		✔		✔
Cucurbitaceae	*Citrullus lanatus*	Wild melon				✔		
Euphorbiaceae	*Chamaesyce hirta*	Asthma plant			✔			
	Euphorbia drummondii	Caper spurge						✔
Fabaceae	*Medicago polymorpha*	Burr medic		✔	✔			✔
	Medicago sativa	Lucerne volunteers		✔				✔
	Medicago spp.	Medic		✔				✔
	Neptunia gracilis	Native sensitive weed						✔
	Sesbania cannabina	Sesbania pea				✔		
Lamiaceae	*Lamium amplexicaule*	Dead nettle		✔	✔			✔
	Salvia reflexa	Mintweed						✔
Martyniaceae	*Proboscidea louisianica*	Devil's claw						✔
Polygonaceae	*Fallopia convolvulus*	Black bindweed						✔
	Rumex crispus	Curled dock						✔
Portualacaceae	*Portulaca oleracea*	Red pigweed						✔
Solanaceae	*Datura ferox*	Fierce thornapple		✔			✔	✔
	Datura stramonium	Common thornapple		✔			✔	✔
	Nicotiana glauca	Wild tobacco		✔				✔
	Physalis ixocarpa	Groundcherry						✔
	Physalis minima	Chinese lantern					✔	*
	Physalis virginiana	Perennial groundcherry						*
	Solanum nigrum	Blackberry nightshade					✔	✔
Verbenaceae	*Verbena bonariensis*	Purpletop						✔
	Verbena officinalis	Common verbena						✔

* other species of the same genera are a host
blank = unknown

IDM all year round

Manage insect vectors

The risk and severity of diseases caused by viruses can be minimised by managing the vector that carries the pathogen. Cotton bunchy top can be transmitted by aphids feeding on infected plants before migrating to healthy plants. Transmission of tobaccvo streak virus to plants relies on the virus from infected pollen entering plant cells through the feeding injury caused by thrips. Several exotic diseases also have insect vectors (see the *Biosecurity* chapter for more details). Consider integrated pest management principles and resistance risks when managing vectors.

Viruses can only survive in living plants. Control of cotton ratoons and volunteers throughout winter will reduce pathogen levels and also lower vector insect populations, drastically reducing disease risk.

On-farm biosecurity and hygiene

Minimise the risk of moving pathogens on or off your farm, from field to field or farm to farm by considering vehicle and machinery movements within the farm. Have a strategy for ensuring clean movement of vehicles and machinery onto and around the farm. Ensure contractor equipment has been thoroughly cleaned before entering your fields. Minimise spillage and loss when transporting modules, hulls, cotton seed or gin trash.

Ensure all staff, contractors and visitors are aware of the requirements and your commitment to 'Come Clean. Go Clean.' before entering the farm.

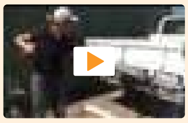
A documented biosecurity plan for each cotton producing farm is highly recommended to identify biosecurity risks and management options for disease outbreaks.

Volunteer and ratoon cotton can allow diseases such as cotton bunchy top to persist between seasons. Linda Scheikowski, Qld DAF

USEFUL RESOURCES:

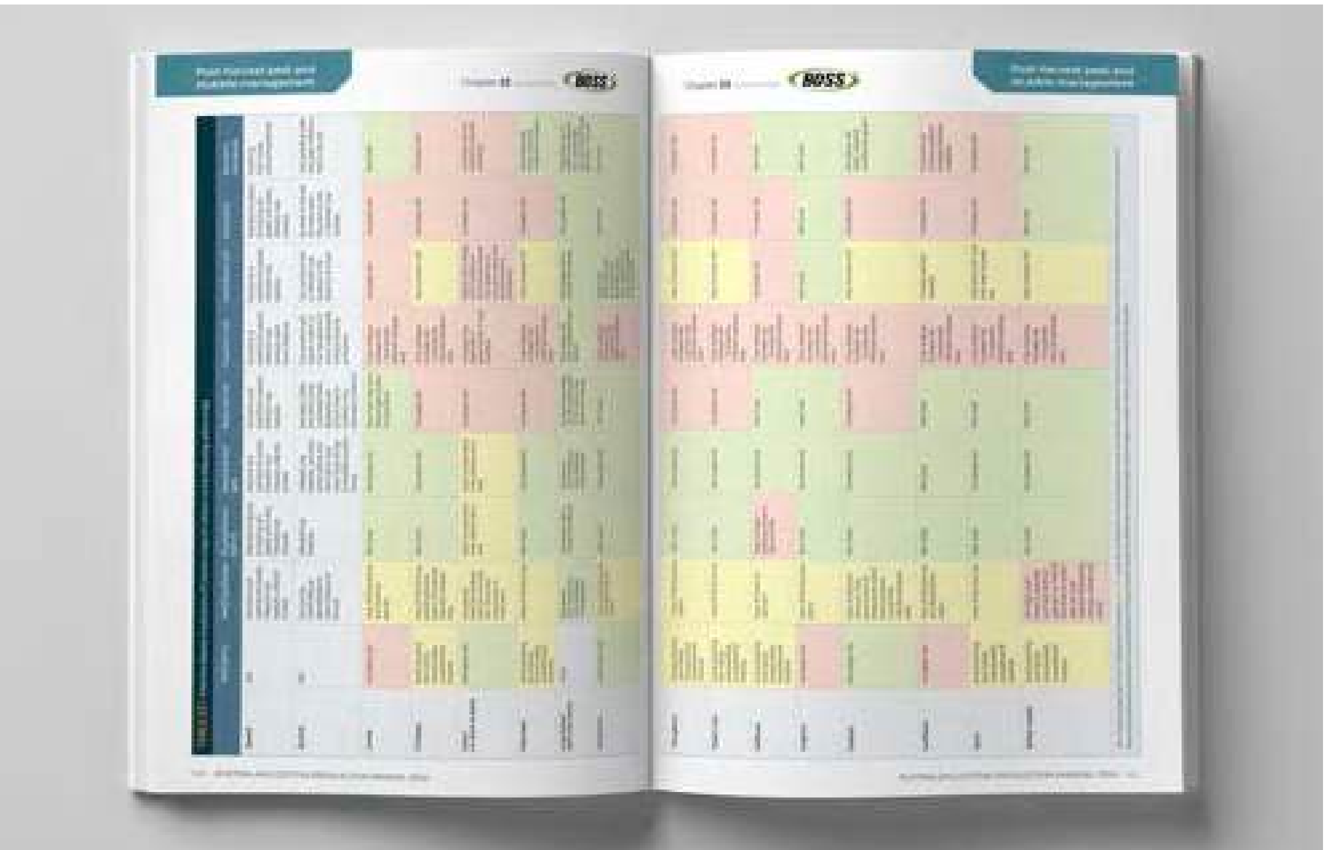
Useful publications can be found at
cottoninfo.com.au/publications-and-media

Useful information can be found at
mybmp.com.au



Come Clean. Go Clean.
youtu.be/gR8hf8-hYOA

Collecting samples for disease testing
youtu.be/4mCk2883IO0



The Australian Cotton Production Manual's Post-harvest pest management chapter includes a table detailing the potential disease implications for cotton when rotating crops that can assist in developing a rotation strategy.)

Key diseases

Cotton production covers a diverse range of environmental conditions, planting dates and agronomic strategies. If pathogens are present, the relative severity and impact of disease can vary greatly with region, season, field history and farm management. Visual symptoms may be highly variable - the photos provided here are examples only. Abiotic factors (including water stress and nutritional deficiencies or toxicities) may produce similar symptoms to some diseases. If you are unsure, collect samples for testing (more information on page 120).

Black root rot (BRR)

Pathogen: *Berkeleyomyces rouxiae*

Black root rot (formerly classified as *Thielaviopsis basicola*) is more common in southern cooler growing regions and can significantly impact crops, particularly where growing seasons are short.

Symptoms

Affected crops may be slow growing or stunted, especially early season. The disease causes destruction of the root cortex (outer layer), seen as blackening of the roots. Some roots may die but the fungus does not kill seedlings by itself. Severe black root rot can increase the susceptibility of plants to *Pythium* or *Rhizoctonia* spp. Badly affected plants early in the season may not show symptoms later on as the dead cells in the root cortex are sloughed off when growth resumes in warmer weather.

Favoured by

- Cool wet conditions – soil temperatures below 20°C are most favourable, but infection will still progress at temperatures up to 25°C.
- Medium to heavy clay soils.
- Back-to-back cotton or following susceptible crops including most legumes.

Host range

All cotton varieties are susceptible, as are most legumes, including faba bean, soybean, cowpea, field pea, chickpea, mungbean, lablab and lucerne. Datura weeds (thornapple, castor oil) are also hosts. Non-hosts include cereals, sunflower, brassicas such as canola and broccoli, and onions.

IDM tactics

- Choose more indeterminate varieties that have the capacity to 'catch up' later in the season.
- Use Bion® Plant Activator seed treatment to assist the plant's natural resistance mechanisms.
- Plant into well prepared, high, firm beds.
- Pre-irrigate/plant into moisture in preference to 'watering up' to avoid a cold shock.
- Time sowing to avoid cool soil temperatures (<18°C) if possible.
- Make replanting decisions based on stand losses, not the size of the seedlings. Watch for early onset of water stress and irrigate accordingly, but avoid waterlogging.
- Anticipate delayed growth and later maturity and manage the crop accordingly (black root rot 'steals' time from your crop).
- Minimise tailwater.
- Practice good farm hygiene – Come Clean. Go Clean.
- Crop rotations have many benefits and increase microbial diversity in the soil, but will not reduce black root rot inoculum levels (apart from a rice rotation, where prolonged flooding can reduce inoculum levels).
- Rotate with biofumigation crops such as vetch or mustard between consecutive cotton crops or after a wheat fallow. Success depends upon the growth of the biofumigation crop and good incorporation (at least four weeks before planting cotton). Check that the biofumigant is not a host of other cotton diseases.
- Avoid legumes.
- Control weeds, cotton volunteers, and cotton ratoons.
- Flooding of fields for 30 days when maximum temperatures are above 30°C significantly reduces the population of *B. rouxiae*. Even better results will be seen if fields are flooded for 60 days.

Severe black root rot infection on a mid-November planted crop in a Murrumbidgee field. Duy Le, NSW DPI

Boll rot, tight lock and seed rot

Boll rots are caused by a number of pathogens, including fungi (*Fusarium* spp., *Phytophthora* spp., *Diplodia* spp., *Rhizoctonia* spp., *Alternaria* spp., *Colletotrichum gossypii*) and bacteria (*Xanthomonas citri* pv. *malvacearum*).

Tight lock refers to a type of boll rot, where the lock remains hard and fails to fluff out. Seed rot describes a boll rot that begins in the seed.

Phytophthora boll rot

Phytophthora boll rot (caused by *Phytophthora nicotianae* var. *parasitica*) usually occurs when soil is splashed up onto low bolls that are beginning to crack open or when low bolls are subject to inundation by backed-up tail water or flooding. Infected bolls quickly turn brown and become blackened and tight locked (sometimes with areas of white mould on the surface before opening prematurely).

Sclerotinia boll rot

Sclerotinia can cause both boll and stem rots and characteristically has black fungal structures within and/or on the surface of the rotted bolls. A white fluffy fungal growth may be present and the branch adjacent to the boll may also be affected. For more information, see the section on scletotinia rots in this chapter.

Fusarium boll rot

Not to be confused with Fusarium wilt, Fusarium boll rot causes similar boll rots to Phytophthora, with mould often appearing as a covering of orange or pink spore masses.

Diplodia boll rot

Diplodia boll rot starts as dark brown lesions that rapidly expand to cover the whole boll as the rot progresses. In the later stages of development, bolls become covered with a black smut-like fungal growth which can easily be rubbed off the boll surface.

Several other fungi can cause secondary boll rots in cotton, taking advantage of injury or wounds in the boll wall, often caused by insect pests.

Bolls affected by Diplodia are covered in 'sooty' black spores.
Linda Smith, Qld DAF

Anthracnose boll rot

Occasionally seen in Queensland crops, anthracnose boll rot (caused by *Colletotrichum truncatum*) is characterised by large spreading lesions on bolls, often with a pink spore mass in the centre. The pathogen is able to infect all parts of the cotton plant and at any stage of growth, although it is more commonly found on higher bolls. Seedling stems may be girdled at or near the base of the stem.

Alternaria spp.

This fungus causes leaf spot in cotton as well as grasses and weeds. It is abundant on decaying debris in and around cotton fields. Released spores can penetrate bolls through the sutures of opening bolls. In regions with frequent dews and high humidity, the bolls in the lower portion of the plant are susceptible to this fungus. If moisture remains high, the entire boll may become infested and destroyed. If dry conditions return, the infected boll may not open properly. Infected bolls are usually dull to dark brown when dried.

Advanced infestation of fusarium boll rot.
Linda Scheikowski, Qld DAF

Anthracnose boll rot (left) showing orange spore masses.
Duy Le, NSW DPI

Tight lock

Tight locked bolls are able to open normally but one or more locks remain compact and fail to fluff out due to fungal or bacterial infection. Flower thrips may also have a role in the development of tight lock. Due to the tight consistency of the seed cotton mass, harvesting equipment is either not able to extract the fibre from the locules or locks are knocked to the ground, giving the appearance of poor harvesting procedures.

Seed rots

Seed rot refers to boll rot that begins in the seed. Pathogens gain entry to the unopened boll when sucking insects (such as green vegetable bug, mirids or pale cotton stainers) feed on the developing seeds through the boll wall, as indicated by small black spots (1-2 mm diameter) on the surface of the boll. Seeds within the maturing green bolls are swollen and discoloured yellow or brown. When the affected bolls open, the locks with infected seed fail to fluff out and remain compact and discoloured. Seed rots do not necessarily affect the whole boll, rather they may be limited to one or two locks.

Favoured by

- Wet and humid conditions, especially from a thick rank canopy and high moisture from rains and dews.
- Rainfall on exposed soil that splashes soil up onto the plant. Low mature bolls and lodged plants are at higher risk of infection.
- High numbers of sucking pests soon after flowering (seed rots).
- Boll rots and tight locks can also develop when bolls that are opening are exposed to wet weather.

Bolls with seed rot caused by pale cotton stainers.
Stephen Allen

Tight locked boll (top). Healthy, fluffy locules (left) and fully affected, severe tight lock locules (right). Linda Smith, Qld DAF

Host range

A broad range of fungal and bacterial species are associated with boll rots and their host ranges vary. For example, Phytophthora hosts include safflower, pineapple, tomato and citrus as well as a large number of ornamental plants derived from Australian native flora. Sclerotinia hosts include sunflower, safflower, soybeans and most pasture legumes.

IDM tactics

- Do not allow water to back-up into the field and inundate low bolls on plants near the tail drain.
- Avoid very low plant populations leading to exposed soil that can be splashed up onto low bolls at the end of the season.
- Avoid rank growth and a dense crop canopy if possible, especially in wet seasons.
- Assess incidence prior to or after defoliation by counting all of the bolls on ten plants from each of ten randomly selected sites across the field. Note that plants near the tail drain may bias the result.
- Thoroughly incorporate crop residues as soon as possible.
- Consider the potential for insect damage to provide infection pathways when making management decisions.
- Practice good farm hygiene and Come Clean. Go Clean.

Collar rot

*Agroathelia rolfsii (*formerly *Sclerotium rolfsii)* is a soil-borne fungal pathogen that causes southern blight, southern stem blight, and southern stem rot in a range of crops.

The reproductive phase of the fungus (sclerotia) germinate to produce hyphae that colonise plant stems and root tissue, causing wilting and rotting. Sclerotia form on the infected site and can survive on the soil for several years, making it a difficult pathogen to manage.

Symptoms

This pathogen causes collar rot in cotton, characterised by girdling of the stem near or just below the soil surface and eventual plant death. This pathogen is also associated with boll rot, as it may infect the bolls close to ground level. White fungal hyphae are visible at the infection site, and a white and brown spherical resting structure known as sclerotia the size of a mustard seed (0.5-2.0 mm) is present around the infection site.

Favoured by

A. rolfsii is commonly found in the tropics and subtropics during warm (27-35°C) and wet weather. Some antagonistic microbes, such as *Trichoderma* spp., *Bacillus subtilis*, and *Gliocladium virens*, are known to suppress the growth of *A. rolfsii.*

Host range

Other crop hosts include French bean, capsicum, carrot, cucurbits, peanut, potato, soybean, sunflower and tomato.

IDM tactics

- Regularly monitor fields for any signs of disease symptoms
- Remove infected plant debris and weeds to reduce the inoculum levels in the soil.
- Rotate cotton with non-host crops such as maize and sorghum to help reduce the soil inoculum. In general, it is recommended that cotton be planted after a gap of 2 to 3 years of growing non-host crops.
- Deep tillage helps to bury sclerotia deeper in the soil profile, making them less viable and less likely to have quick access to crop roots.
- Promote good drainage and avoid excessive soil moisture to minimise favourable conditions for fungal growth.
- Use compost to promote beneficial microbial communities and improve soil health.
- While no fungicides are currently registered for use against this disease in cotton, there may be incidental impact on *A. rolfsii* if products such as azoxystrobin, propiconazole, or tebuconazole are used on rotation crops.


Hyphal growth on cotton stems Dinesh Kafle, Qld DAF


Girdling of cotton stem Dinesh Kafle, Qld DAF


Sclerotia and hyphae Tegan Brownie, Nutrien Ag Solutions


Sclerotia on Agar media Dinesh Kafle, Qld DAF

Cotton bunchy top (CBT)

A viral disease spread by cotton aphids, CBT can only survive in living plants.

Ratoon plants that were affected by CBT and survived from the previous season often harbour aphids which can then move to adjacent plants, creating patches of infected plants.

Symptoms

Leaves usually have pale green angular patterns around the margins and darker green centres, and can be leathery and brittle compared to the leaves on healthy plants. After infection, subsequent plant growth is characterised by small leaves, short internodes and small bolls.

When plants are affected at a very early stage (e.g. as seedlings) the whole plant has a compact, severely stunted appearance. Roots appear hairy and dark brown compared to the light yellow-brown colour of healthy roots, and small knots form on the secondary root branches.

Symptoms are difficult to distinguish in perennial volunteer cotton and late crops (post cut-out) where there has been insufficient new growth. It usually takes 3-8 weeks from infection until symptoms become obvious.

Favoured by

- High aphid populations, in close proximity to ratoon cotton. Ratoons act as both a preferred host for the aphids and a reservoir for the disease, creating a source of infection in the new season.
- Climatic conditions suitable for aphid reproduction, feeding and spread.
- Wet or mild winters that enable more volunteer and ratoon cotton and aphids to survive between season and cropping cycles.

Cotton aphid has a broad host range, including many weeds. The presence of weed hosts allow cotton aphid populations to persist over winter, increasing the likelihood of aphids moving into cotton early in the season.

Host range

The most critical alternative host plant is ratoon or volunteer cotton that survives between seasons, retaining leaves through winter and supporting infected aphid populations from one season to the next. The importance of other host plants is not well understood but in some situations marshmallow weed (*Malva parviflora*) may be an important overwintering host for virus and aphids.

Pale green angular patterns around the margins and darker green centres is typical of cotton bunchy top.
Linda Smith, Qld DAF

CBT infection leads to a distinctive leaf mottling. Stephen Allen

Other natural field hosts of CBT include: velvetleaf, spurred anoda, asthma plant, Sturt's desert rose, rosella, bladder ketmia, deadnettle, marshmallow weed, prickly malvastrum, burr medic, Paddy's lucerne, and black pigweed (see Table 32). Rose cotton bush (*Gossypium australe*) and chickpea were also hosts in field or pot experiments, and the virus may have an even wider host range, including other non-Malvaceae species.

IDM tactics

Step 1. Avoid the problem – eliminating hosts, particularly over winter, is the most effective way to minimise the risk of CBT. Break the green bridge and Step 2 should not be required.

- CBT virus can only survive in living plants. A break in the presence of hosts between cotton seasons will reduce the risk of CBT surviving on-farm through winter. Cotton volunteers, regrowth and ratoons are important hosts so effective crop destruction and control of ratoons and volunteers is critical for CBT control. This also removes an important overwinter host for cotton aphid.
- Good on-farm management of broadleaf weeds is important as they can also host aphids and some may be hosts for CBT.
- Control volunteers/ratoons before cotton emerges to reduce the risk of winged aphids moving into nearby crops.

Step 2. Manage the risk – aphid control should not be the primary means of preventing infection.

- Sample young cotton regularly for aphids and assess aphid spread within the field, but don't over-react to aphids. Excessive use of aphicides will select for resistance and restrict control options.
- Maintain the beneficial complex (many beneficials present, high aphid mortality and little population spread) and keep monitoring. If aphids are healthy then consider selective control so that beneficials can provide ongoing mortality.
- If experiencing a high influx of aphids, consider a quick selective control to reduce the risk of CBT infection.
- Cotton varieties with CBT-resistance are now included in the range of varieties commercially available, and should be considered as part of an IPM plan, particularly in areas that have a history of high CBT pressure

Identifying CBT disease youtu.be/xrp1420cjlk

CBT management youtu.be/3DOS61-wqqA

Fusarium wilt

Pathogen: *Fusarium oxysporum* f. sp. *vasinfectum* (Fov)

Symptoms

External symptoms include stunted growth and dull and wilted leaves followed by leaf yellowing or browning and eventual death from the top of the plant. Some affected plants may reshoot from the base of the stem. These symptoms most commonly become apparent in the seedling phase when plants are beginning to develop true leaves, or after flowering during boll fill. Symptoms can appear as individual plants or as a small patch, often near the tail drain or low-lying areas of the field.

Internal symptoms can be checked by cutting the stem. Infected plants will reveal continuous brown discolouration of the stem tissues from the main root up into the stem. The discolouration is similar to Verticillium wilt but usually appears as continuous browning rather than flecking.

Favoured by

- Susceptible varieties.
- Stresses in the crop – e.g. waterlogging, root damage through cultivation, cool and wet growing conditions.
- Poor farm hygiene on and between farms and districts.

Host range

The Fov pathogen is specific to cotton but can also live in the residues of most non-host crops. Bladder ketmia, sesbania pea, dwarf amaranth, bellvine and wild melon are alternative weed hosts that show no external symptoms. These weeds may act as an on-farm reservoir for the disease and need to be constantly managed.

IDM tactics

- If your farm is free from this disease, keep it that way! Ensure all staff and contractors practice good farm hygiene and Come Clean. Go Clean.
- Select varieties with a high F rank and use Bion® Plant Activator.
- If possible, delay planting until soil temperatures are 16°C and rising.
- Manage the crop to avoid stresses such as waterlogging, over-fertilisation and root damage.
- Avoid mechanical inter-row cultivations if possible, as this can cause root damage that provides an entry point for the pathogen.

Fusarium wilt: Wilting and dying plants are often observed at the tail drain. Linda Smith, Qld DAF

- Regularly inspect fields for early detection and containment of isolated outbreaks. Send any suspect samples to Dr Linda Smith (Qld DAF). See page 120 for an example sample sheet to include with the specimens.
- GPS mark field locations that are of concern.
- Isolate affected areas from irrigation flows and traffic.
- Minimise tail water from affected fields.
- After harvest, root pull and retain crop residues on the surface for 60-120 days if possible (until they turn grey; see photo on page 103) prior to incorporation.
- Fusarium can survive on non-host crop residues. Avoid green manure crops as this returns organic matter to the field which Fusarium can survive on as a saprophyte.
- Rotate with non-hosts for up to 3 years. Hosts such as legumes can potentially increase disease. A summer sorghum/maize-fallow-cotton rotation can increase cotton plant survival, reduce disease incidence and increase yield in the third year compared to continuous cotton.

Managing Fusarium wilt youtu.be/Cygy6XiRDcw

Post-harvest management of Fusarium wilt youtu.be/NGeQ4FTH7IM

Dark brown discolouration observed in cross sections of cotton stems infected with Fov. Janelle Montgomery, CottonInfo

Sponsored by

Leaf spots

Alternaria leaf spot (ALS): *Alternaria alternata* and other minor spp.
Cercospora leaf spot: *Cercospora spp.*
Target spot: *Corynespora spp.*
Stemphylium leaf spot: *Stemphylium spp.*
Ramularia leaf spot: *Ramulariopsis spp.*

ALS is the most common cause of leaf spots in cotton in cooler regions. As you move further north other leaf spot fungi and disease complexes occur due to the warmer and/or more humid climate.

Ramularia leaf spot of cotton is a foliar disorder caused by *Ramulariopsis* sp. (including *R. gossypii* and *R. pseudoglycines*) that may be referred to in overseas literature as grey mildew, frosty blight, false mildew or areolate mildew. Preferring tropical conditions, it was recently found in the Northern Territory and Western Australia, although according to historical records, it had previously been present in Queensland also.

Symptoms

Cotton plants are prone to leaf spot infections at all growing stages, but are most susceptible as seedlings and late in the season as the crop begins cut-out. Symptoms start as pinhead spots that develop into necrotic lesions surrounded by a purple halo. They can be seen on cotyledons, young to mature leaves, squares and bolls. Under favourable conditions, lesions continue to enlarge and join to form irregular shapes. Severe infection may result in leaf desiccation.

Typical lesions associated with leaf spot of cotton.
Linda Scheikowski, Qld DAF

Alternaria leaf spot of seedlings. Cotton trash is a common source of inoculum.

While ramularia leaf spot also begins as spots, it produces distinctive fungal 'mildew' growth and can be easily identified by the presence of white to greyish coloured spores on the underside of the leaf (powdery growth may also occur on the upper surface). No other commonly found cotton disease produces white, powdery growth on the underside of the leaf. Ramularia infections generally start in the more humid lower canopy before spreading to upper leaves and potentially affecting the entire plant. Infected leaves dry up from margin and cup inward before turning yellowish brown and falling off prematurely. This disease can have ongoing cycles throughout a season.

Favoured by

Alternaria spores can only germinate when there is several hours of free moisture on the leaf surface. Epidemic development is therefore favoured by either repeated heavy dews or extended periods of wet weather.

- Symptom development is suppressed by periods of very hot weather.
- Symptom development is favoured by physiological or nutritional stress e.g. heavy fruit load or premature senescence.
- Back-to-back fields are at greater risk of developing the disease.

Ramularia sp. requires temperatures of 20–30°C with prolonged high humidity (>80%) and frequent rain for infection and disease development. However, cool weather and prolonged dewy periods are also a trigger. Close planting or excessive nitrogen applications can increase disease severity.

Host range

Leaf spots are widely distributed and while they generally have a wide host range, some strains show host specificity.

Perennial and self-sown cotton plants can harbour these pathogens. The primary method of infection is through spores from infected debris or volunteer and ratoon cotton. Spread may occur from infected leaves, but the fungi can also be moved by wind, rain splash, irrigation water and farm equipment.

Unlike other mildews such as powdery mildew of cucurbits, *Ramulariopsis* sp. can grow without the presence of a living host. Because of this ability to live on non-living organic residues, the pathogen can persist on decomposing plant material between seasons.

IDM tactics

- Avoid back-to-back cotton (plant a break crop).
- Avoid planting into fields containing unincorporated infected residues from a previous crop.
- Provide balanced crop nutrition (especially potassium) and avoid excessive application of nitrogen.
- Consider planting densities and spacings that encourage air flow and manage crop to avoid extremely rank growth.
- Apply registered or permitted foliar fungicides according to label.
- Ensure complete crop destruction at season's end – incorporate crop residues as soon as possible after harvest.
- Control alternative weed hosts, volunteer and ratoon cotton plants before, during and post season.

Initial symptoms include whitish grey powdery fungal growth on the underside of the leaf. Murray Sharman, Qld DAF

Ramularia leaf spot spreads across the leaf causing premature defoliation. Olivia Borden, E.E Muir & Sons

Nematodes

Reniform nematode: *Rotylenchulus reniformis*

Root-knot nematodes: *Meloidogyne* spp.

Plant-parasitic nematodes feed on plant roots using a retractable mouth spear (like a hypodermic needle) called a stylet. Root-knot and reniform nematodes are distributed worldwide within tropical and subtropical regions with a wide range of both crop and weed species as hosts. In Australia, on cotton, reniform has only been detected in Central Queensland. Root-knot nematode (*M. incognita*) has only been reported in one field each in Northern and Central Queensland. Guava root-knot nematode (*M. enterolobii*) has been recently detected in Queensland and the Northern Territory.

Several other plant-parasitic nematodes, including lesion nematode (*Pratylenchus* sp.), spiral nematode (*Helicotylenchus dihystera*), and stubby-root nematode (*Paratrichodorus minor*) have been detected in very low populations in cotton fields across Queensland and New South Wales, however they do not currently pose any significant threat as high numbers are required to cause substantial harm.

Symptoms

Reniform nematodes produce minimal symptoms on the roots, while root-knot nematodes typically cause galling. Above ground symptoms of nematodes (including stunted growth, wilting, and leaf yellowing) may resemble water and nutrient stress. Nematodes typically reduce crop productivity rather than causing complete plant death. Populations can be quite uniform in their distribution across a field, making detection of early plant symptoms difficult.

Favoured by

These nematodes prefer warm climates (tropical and subtropical regions), although they can be found in warm temperate regions as well.

Damage potential differs widely according to soil type. Sandy soils tend to promote the greatest level of damage, while nematode survival and reproductive success is favoured by soils with higher (20-40%) silt or clay.

Root-knot nematodes thrive in sandy and sandy loam soils and causes little damage in soils with clay content greater than about 15%. However, the reniform nematode has been associated with soil types having higher silt and (or) clay contents compared with most plant-parasitic nematodes

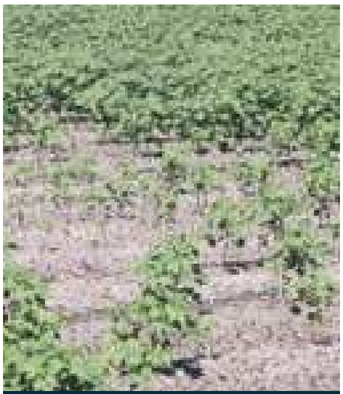
Host range

Reniform nematodes have a very wide host range, including chickpea, mungbean, pigeon pea, sunflower and vetch. Certain crops are considered to be non-hosts, including maize, canola, faba beans, safflower, sorghum, soybean, wheat, barley, triticale and oats. Hosts of southern root-knot nematode include field crops such as maize, soybean, grain sorghum, wheat, rye, oats, barley, and many vegetables, fruit including banana, weeds and ornamentals. Guava root-knot nematode hosts include soybean, banana, many vegetable crops and some weed species.

IDM tactics

- Come Clean. Go Clean. Good farm hygiene is the key to minimising the spread.
- Rotating with non-host crops to reduce base populations. Long fallows can also help to break the life cycle; however all weeds, cotton volunteers and ratoons must be controlled.

Large galls on cotton roots caused by guava root-knot nematode. Deltapine



Stunted plants caused by reniform nematodes. Linda Smith, Qld DAF

- Plant into good conditions, including optimum soil temperature, no water stress and well-formed beds.
- Monitor crops for patches of stunted plants and submit suspicious root samples for testing to Dr Linda Smith or Dr Dinesh Kafle (Qld DAF) phone 13 25 23.
- Manage cotton stubble. Cut cotton stalks and till soil through the stubble zone as soon as possible after harvest to destroy breeding sites. Ensure root cutting is successful and there is no re-growth.

Assessment

Monitor for patches of unexplained unthrifty or stunted plants and send a sample of soil if concerned. Nematodes cannot be seen with the naked eye, but affected roots may have small nodules (which are the egg masses).

- Mark patches with a GPS or on a map so you can re-monitor next season.
- Scrape off the dry top soil and sample 10-15 cm deep using a small trowel or soil corer.
- If there is more than one patch in a field, collect multiple samples from these areas in a bucket, and mix through.
- Place approximately 400 g of the soil in a clearly labelled plastic bag.
- The extraction process relies on live nematodes so please keep cool in an esky without an ice brick, DO NOT STORE SAMPLES IN THE FRIDGE.
- Include information about the sample sheet (see page 120 for a form and checklist on sending plant samples for diagnosis).

Reniform nematode in cotton youtu.be/QgBn4vfkOzI

Reniform egg masses on cotton root. Damien Erbacher

Reniform nematode in cotton root. Linda Scheikowski, Qld DAF

Reoccurring wilt

Pathogen: Novel *Eutypella* species

Reoccurring wilt, caused by novel species of *Eutypella* was first observed in the 2017/18 season and is the first known detection of this fungus causing disease on cotton.

Symptoms

The disease typically presents as wilting and sudden death of plants, either as single plants or in a patch similar to a lightning strike, but some plants within the patch may not be affected. Leaves turn bronze-brown, die and remain attached to the plant. A section of bark on affected plants will become blackened.

Internal symptoms can be observed by cutting the stem. A reddish-grey vascular discolouration can be seen and may not appear evenly through the cross-section, often appearing in a 'V' shaped sector of the stem.

Favoured by

The etiology is still being established. At this stage it is unclear what factors are contributing to the disease. Anecdotally, reoccurring wilt has been observed in plants suffering stress from water deficiency. The disease has also been observed in cotton grown in field areas that typically have poor growth.

Host range

It is still too early to make assumptions on the host range of the pathogen that causes reoccurring wilt.

Single dead plant amongst healthy plants.
Linda Smith, Qld DAF)

In cross-section the infected tissue may be V-shaped with reddish-grey discolouration. Duy Le, NSW DPI

IDM tactics

Glasshouse trials support the theory that Eutypella-infected cotton residues are a source of pathogen inoculum. When infected stem residues were buried just under the soil surface next to the stem of cotton seedlings, plants became infected with Eutypella and died, expressing typical symptoms of the disease. IDM tactics include burying infected crop residues after harvest and avoiding back-to-back cotton, to ensure infected residues are broken down before planting back to cotton.

Monitor fields for symptoms as described and send samples for pathogen confirmation. Provision of samples also enables the genetic diversity of this pathogen to be understood.

Come Clean, Go Clean. Implement and maintain good farm biosecurity practices between fields and farms to help prevent the spread of all pathogens.

USEFUL RESOURCES:

Contact your nearest REO or one of the pathologists if you suspect the disease on your farm. Please send any suspicious plants to one of the cotton pathologists:

Qld DAF
Linda Smith 0457 547 617

NSW DPI
Duy Le 0439 941 542
(please do not send suspected Fusarium samples to Duy)

Identifying reoccurring wilt
link.springer.com/article/10.1007/s13313-021-00843-8

Blackening of the stem. Linda Smith, Qld DAF

Sclerotinia boll rot and stem blight

Sclerotinia boll rot and stem blight is caused by the soil-borne fungus *Sclerotinia sclerotiorum*.

The disease primarily impacts yield, although cotton stand establishment and seed quality may also be affected by this disease.

Symptoms

Infections can be found on stems, branches, bolls, and leaves. Tips of infected limbs remain green and healthy for several days before wilting becomes evident. When the canopy is pulled back, bleached stems and white cottony growth can be seen. Diseased bolls appear soft and rotten, covered with white mycelium and large black irregularly shaped resting structures (sclerotia). These large sclerotia (2 to 10 mm diameter) produced within and/or on the surface of the rotted bolls and the white cottony fungal growth are key characteristics of the disease.

The sclerotia germinate to produce apothecia (small cream coloured 'golf tees') that release clouds of microscopic spores. Infection occurs thorough dead or dying tissue (e.g. flower petals). The fungus then grows into healthy plant tissue such as the developing boll and down the fruiting branch towards the main stem. Limbs near the soil surface die first and the infection progresses rapidly towards the upper plant.

Sclerotinia boll rot characteristically has black irregularly shaped sclerotia within and/or on the surface of the rotted bolls (L) and a white cottony fungal growth. Linda Smith

In vitro production of apothecia on sterile sand and ascospore discharge of *Sclerotinia sclerotiorum*.
H.R. Dillard, Cornell University

Favoured by

The disease is favoured by cool temperatures (between 15 and 24 °C) and moist conditions under a closed plant canopy. It is often severe in varieties that are selected for high-yield environments or when cultural practices result in a dense, early closing canopy (e.g. high plant population).

Host range

This pathogen can attack hundreds of plant species including sunflower, safflower, soybean, most pasture legumes and many weeds.

IDM tactics

Disease control measures include farm hygiene, crop rotation, weed control and chemical control.

- Since sclerotia can be transferred between fields through harvest equipment or contaminated seeds, it is important to harvest infected fields last and clean the harvest equipment thoroughly to prevent spreading sclerotia to other fields.
- Weed control is necessary because ragweed, pigweed and other weeds are alternate hosts for this fungus. Weeds can also increase canopy density and trap moisture that accelerates disease spread.
- Five year or more rotations with non-host crops such as small grains, cereals, and maize reduce the number of sclerotia in the soil by loss of viability over time, but one-to-three-year rotations may not have a significant impact on incidence of disease because the sclerotia can survive in the soil for up to 10 years.

Sclerotinia in cotton youtu.be/yt_542Kj3_0

Seedling diseases

Seedling diseases are caused by numerous pathogens either acting alone or in combination that commonly cause 'damping off' (death of seedlings) and reduced plant stands. The main pathogens infecting cotton seedlings are *Rhizoctonia solani, Pythium ultimum*, *Fusarium* spp. (not the Fusarium wilt pathogen) and black root rot (see page 106).

Symptoms

- Pre-emergent seed rots.
- Post-emergent damping off (wilting, collapse and death of seedlings).
- Slow early season growth, small cotyledons and reddened hypocotyls.
- Lesions on roots.

Affected plants may be scattered across the field or concentrated in poorly drained areas. In some situations seedling disease may be particularly evident in rows where other factors such as fertiliser placement, herbicide application, planting depth etc have had an effect.

Favoured by

Anything that slows down germination and seedling growth, including cool and/or wet weather, poorly formed beds, compaction, waterlogging, incorrect planting depth, poor placement of fertiliser, excessive rates of herbicide at planting, movement of herbicide into the root zone (i.e. by rain) and infection by other pathogens.

Host range

Seedling disease pathogens have a wide host range and can survive on the residues of many crops and weeds. International research has determined that winter legume crops do not appear to increase the risk of cotton seedling diseases sufficiently to deter their use in reducing soil erosion and providing nitrogen to the following crop.

Rhizoctonia lesions on cotton seedlings. Duy Le, NSW DPI

The pathogens can survive on plant residues, so incorporation early enough to allow breakdown is important.

IDM tactics

- Use a variety with good seedling vigour.
- Use effective seed treatment fungicides.
- Plant into well prepared, high, firm beds.
- Carefully position fertiliser in the bed (not under the plant line).
- Plant into moisture rather than planting dry and watering-up.
- Delay planting until temperature and moisture conditions are optimum.
- Be careful with the use of herbicides at planting.
- Incorporate rotation crop residues as soon as possible after harvest.

Rhizoctonia seedling disease is favoured by cool, wet weather. Alison Seyb, formerly NSW DPI

Verticillium wilt

Pathogen: *Verticillium dahliae*

Verticillium wilt is caused by the soil-borne fungal pathogen *Verticillium dahliae*. In Australian cotton there are currently four strains of *V. dahliae* (one was recently detected in Noogoora burr), however virulence varies greatly within all strains. All incidences of Verticillium wilt should be taken seriously regardless of the strain as yield losses can still be severe without defoliation occurring.

Symptoms

Symptoms of Verticillium wilt and Fusarium wilt are similar. Verticillium wilt has dark brown to black streaks through the centre of the stem when cut diagonally. When cut lengthways, stems show brown flecking of the inner tissues. As Verticillium wilt and Fusarium wilt can be difficult to tell apart, plant/s suspected of being infected with *F. oxysporum* f. sp. *vasinfectum* or *V. dahliae* need to be diagnosed by a pathologist. In some instances there are fields with both Verticillium and Fusarium wilt present, so send multiple stems in the sample.

V. dahliae can also cause a characteristic yellow mottle between the veins and around the leaf margins. Lower leaves are usually affected first. Dead tissue develops at the leaf edges and may replace the mottled areas.

Favoured by

- Cooler temperatures (cotton varieties that are resistant at 25-27°C are susceptible at 20-22°C).
- Extended wet and overcast weather.
- Waterlogging or over-irrigating (particularly in late-maturing crops).
- Nutritional imbalance such as potassium deficiency or excess nitrogen.

Extended crop growth late in the season, including through the use of excessive nitrogen, increases the risk of this disease.

Host range

V. dahliae has a large host range and causes vascular wilt on more than 250 plant species including volunteer cotton, ratoon cotton, soybean, canola, safflower, sunflower, mungbean, chickpea, cowpea, peanut and faba bean. International literature and pot trials with Australian strains also suggest that wheat, barley, oats, triticale, canary grass, lablab, black gram, vetch and maize may be hosts. Weed hosts include Noogoora and Bathurst burr, saffron thistle, thornapple, caustic weed, bladder ketmia, burr medic, black bindweed, red pigweed, devils claw, turnip weed, mintweed and blackberry nightshade. There is some host specificity between strains.

Characteristic symptoms of Verticillium wilt include wilted plants, leaf mottle and necrosis. As disease progresses, defoliation and plant death may occur. Linda Smith, Qld DAF

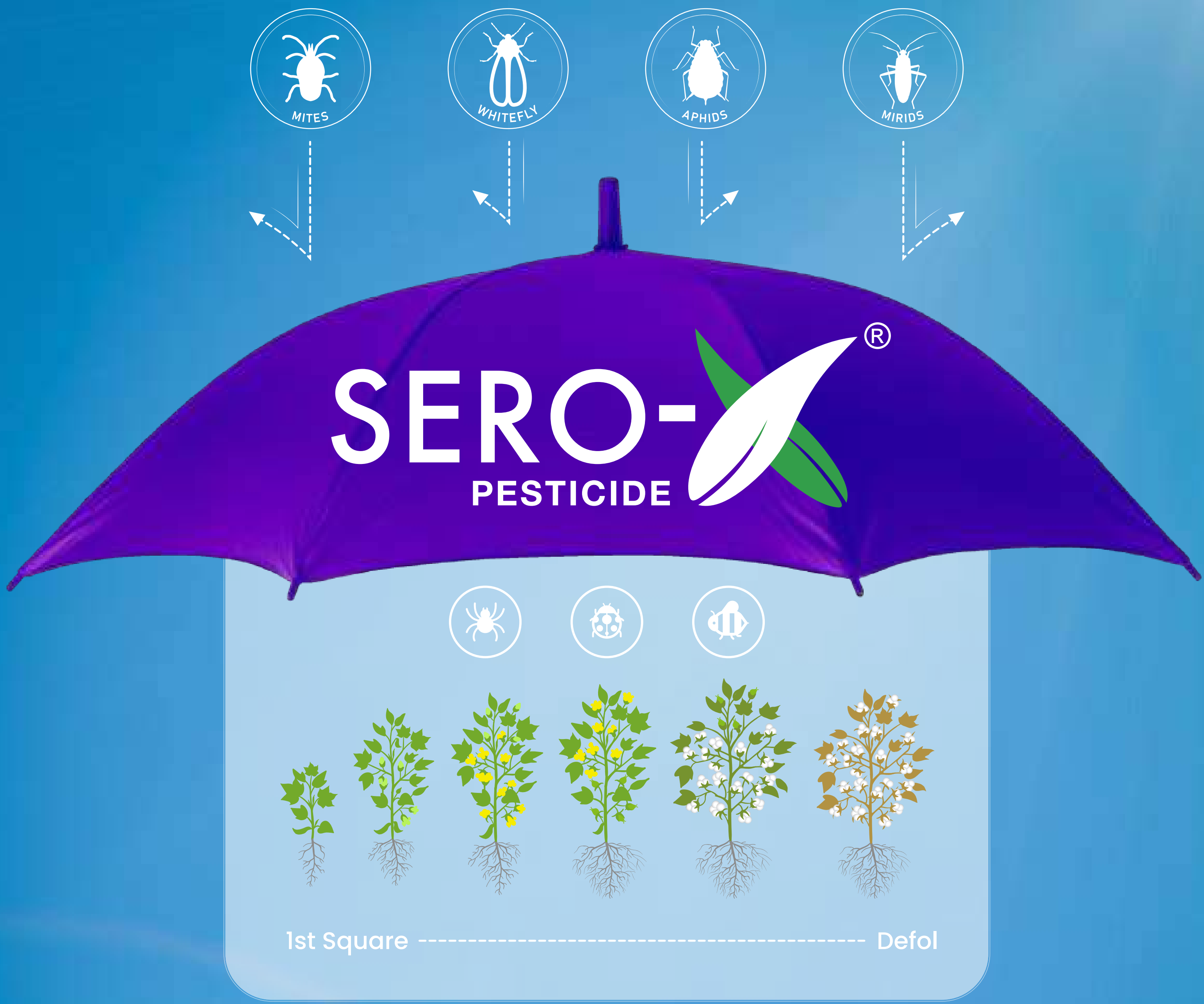
IDM tactics

- Select varieties with a high V rank.
- Manage for earliness, including optimising nutrition and water inputs.
- Avoid over-watering, waterlogging and late season irrigations that extend maturity.
- Minimise tailwater to reduce risk of spread.
- Avoid inter-row cultivation with knives if possible. This causes root damage and provides an entry point for the pathogen.
- Ensure that crop destruction and incorporation occurs soon after picking to reduce the build-up of inoculum.
- Rotate with non-host crops (i.e. sorghum or maize).
- Avoid frequent fallows to maintain microbial diversity and populations of beneficial bacteria and fungi.
- Avoid/control alternative hosts, including volunteer and ratoon cotton.
- Send any suspicious plant samples to your state pathologist for correct identification of pathogen.
- If your farm is free of *V. dahliae*, try to keep your farm that way. Ensure all farm staff and contractors practice good farm hygiene and Come Clean. Go Clean.

Verticillium wilt youtu.be/hgiatA52nNw

Typical leaf symptoms of Verticillium wilt. Stephen Allen

Dark grey peppery discolouration observed in cross sections of cotton stems infected with *V. dahliae*. Duy Le, NSW DPI



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Other diseases

Other diseases that can affect cotton include bacterial blight, bacterial stunt, post-harvest rot, sudden wilt, tobacco streak virus (TSV) and tropical rust. These diseases are much less common than the others mentioned in this chapter, largely thanks to cotton breeding programs and biosecurity measures.

Not all unusual plant symptoms are a sign of disease. Some herbicides, insects, soil constraints and environmental factors can also contribute to abnormal plant growth.

More detailed information on cotton diseases and other symptoms can be found at the CottonInfo website (www.cottoninfo.com.au/disease-management) with links to the Cotton Symptoms Guide and various disease factsheets, along with information on how to send a sample in for disease diagnostics.

Collecting stem and leaf samples for disease testing
youtu.be/4mCk2883IO0

Foliar symptoms of TSV may include purplish or brownish-black patches that can be circular or irregular.

Bacterial blight symptoms include dark water-soaked lesions on leaves, stems or bolls.

SENDING SAMPLES FOR DIAGNOSIS BY A PATHOLOGIST* – Attach a completed form to each sample

Collected/Submitted by:	Address/Email/Fax/Telephone:
Property name and field number:	Date collected:
Grower/Agronomist:	Grower's address or area/locality:

Mark (X) as appropriate

SYMPTOMS	DISTRIBUTION	INCIDENCE/SEVERITY	CROP GROWTH STAGE
☐ Poor emergence or seedling depth	☐ One field only	☐ All plants	☐ Irrigated
☐ Leaves: spots, dead areas or mildew	☐ In several fields	☐ Scattered single plants	☐ Dryland
☐ Leaves: discoloured	☐ In all fields	☐ Scattered patches of plants	☐ Seedling stage
☐ Leaves: mottled	☐ One variety only	☐ In a large patch (>5 m)	☐ Setting squares
☐ Leaves or shoots: distorted or curled	☐ Several varieties affected	☐ In a small patch (1-5 m)	☐ Early flowering
☐ Plants stunted	☐ Some rows more affected	☐ In a small patch (<1 m)	☐ Peak flowering
☐ Plants wilting	☐ On lighter soil types	☐ Plants dead	☐ First bolls open
☐ Premature plant death	☐ On heavier soil types	☐ Plants defoliating	☐ Defoliated
☐ Bolls: spots or dead areas	☐ In poorly drained area(s)	☐ One to a few plants only	☐ Ready to pick
☐ Roots: discoloured, bent, pruned, etc.	☐ Other: (please specify)		

OTHER INFORMATION
- Cultivar ....
- Paddock History ....
- Nearby crops ....
- Rainfall in last 10 days ....
- Average temperature range over the last 10 years ....
- Date of last irrigation ....
- Date of last cultivation ....

Please contact your nearest CottonInfo REO to determine the appropriate pathologist and address for submitting sample

***IF FUSARIUM WILT IS SUSPECTED,DO NOT SEND SAMPLES TO ACRI**

When sending samples:
- Send multiple samples (e.g. more than 1 leaf, stem or plant).
- If possible include a healthy plant as well as the diseased plant material.
- It is better to despatch samples early in the week rather than just before the weekend.
- Never wrap samples in plastic. Dry or slightly dampened newspaper is better.
- When collecting seedlings – dig them up rather than pull them out. Include some soil.
- Several sections of stem (10-15 cm long) are usually adequate for wilt diseases.
- Keep the sample cool and send as soon as possible.

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TABLE 33: Fungicides registered or under permit for use in cotton

	Active ingredient	Trade name		MoA group	Targets	Comments
Seed treatments	Azoxystrobin 75 g/L + Metalaxyl-M 75 g/L + Sedaxane 35 g/L + Fludioxonil 12.5 g/L	Vibrance® CST	Vibrance® Complete	4, 7, 11, 12	Damping-off caused by *Pythium* spp. and *Rhizoctonia solani*	Seed treatment available through CSD when ordering seed.
Seed treatments	Acibenzolar-S-methyl 500 g/L	Bion®	Vibrance® Complete	No group	Fusarium wilt, black root rot	Seed treatment available through CSD when ordering seed. Suppression only. Activates the plant's natural resistance mechanisms.
Seed treatments	Metalaxyl-M 350 g/L	Various		4	Damping-off caused by Pythium and Phytophthora. Fusarium wilt disinfection on seed	Seed dressing. Qld & NSW only. Does not protect against damping off by Rhizoctonia, Fusarium or other fungi. 97% R-enantiomer. Much more effective in controlling diseases. Lower rates can be used.
At planting	Quintozene 750 g/kg	Terraclor®		14	Damping-off caused by *Rhizoctonia* spp.	Qld, NSW & WA only. Soil fungicide. Spray over seed and surrounding soil at planting.
At planting	Tolclofos-methyl 500 g/L	Tolex® Rhizolex® In Furrow		14	*Rhizoctonia solani*	Qld & NSW only. Mix with seed immediately before planting. Applied as an in-furrow spray or water injection at planting.
Foliar fungicides	*Clitoria ternatea* extract 400 g/L	Sero-X®		UNE	Verticillium wilt microsclerotia	Will reduce the amount of microsclerotia (inoculum) returning to the soil. Qld, NSW & WA only. Three applications are required: 1. When majority of plants are between first square and first flower. 2. When majority of plants are between mid to peak flowering. 3. With the first defoliation. Foliar application only. Will not reduce the severity of the disease in the season it is applied.
Foliar fungicides	Metentrifluconazole 75 g/L	Belanty®		3	Ramularia leaf spot	PER94282. Expires 28 February 2026. NT, QLD and WA only. Do not apply by a vertical sprayer. Release height restrictions and buffer zones may apply. Maximum 3 applications per crop, 15 days apart.
Foliar fungicides	Prothioconazole 100 g/L + Azoxystrobin 133 g/L	Maxentis®		3, 11	Ramularia leaf spot	PER92749. Expires 30 September 2025. WA, NT and QLD only (locations above the 26 parallel). Maximum 2 applications per crop. Note: If you are growing produce for export, please check latest with the permit holder for the latest MRL information.
Foliar fungicides	Tebuconazole 430 g/kg	Various		3	Alternaria leaf spot	PER82660. Expires 30 November 2024. Southern cotton growing valleys: Bourke, Gwydir, Lachlan, Macquarie, Murrumbidgee, Murray and Namoi Valleys and north Queensland (tropical) region primarily around the Mareeba region on the Atherton tablelands only. WHP: 6 weeks. Maximum of 2 applications per season, 14 days apart.
Seed export	Carboxin 200 g/L + Thiram 200 g/L	Vitavax® 200FF		7, M3	Seedborne disease control	Cotton seed destined for export to countries that specify such treatment only – not registered for seed used in Australia.

Industry pathology team leaders:
Qld DAF pathologist, Linda Smith 0457 547 617
NSW DPI pathologist, Duy Le 0439 941 542
cottoninfo.com.au/publications/cotton-symptoms-guide

Regional disease update 2023-24

Commercial cotton crops were assessed at both the seedling stage and late season (in the 22^{nd} and 41^{st} consecutive disease surveys in Queensland and New South Wales respectively) for disease incidence (% of surveyed plants) and severity (extent of symptoms). Fields were also monitored for anything unusual, including the presence of exotic diseases such as blue disease, cotton leaf curl disease, phymatotrichopsis (Texas) root rot, hypervirulent strains of bacterial blight and exotic strains of both verticillium and fusarium wilts. None of these exotic diseases were observed.

Regional surveys were conducted by Linda Scheikowski and Dinesh Kafle (Qld DAF), Duy Le and Chi Nguyen (NSW DPI), and CottonInfo Regional Extension Officers. Thank you also to regional consultants who assisted with collection of disease incidence data. Note that these surveys were undertaken within different projects, so the focus and approach differed between organisations.

Queensland

Queensland targeted surveys were undertaken as part of the CRDC project DAQ2302: *Tactical management and surveillance of Verticillium, Fusarium and reoccurring wilts.*

Early season

A total of 15 farms and 26 fields were surveyed between 18 October and 7 December 2023 at Theodore, Emerald, St George and the Darling Downs. For black root rot, roots were examined microscopically to confirm the presence of spores (see photo below). Soil collected was subjected to an extraction process for nematodes. Reniform nematode continues to be detected only in Central Queensland at this stage, and no root-knot nematodes were detected early season. Several other minor plant-parasitic nematodes such as lesion *Pratylenchus* sp., spiral *Helicotylenchus dihystera,* and stubby-root *Paratrichodorus minor* have been detected in cotton fields across Queensland (and New South Wales in 2020/21 and 2021/22 seasons), however they are usually only minor pests of cotton (needing high numbers to cause appreciable injury) and therefore do not pose any significant threat.

The importance of farm hygiene cannot be stressed enough to prevent the spread of reniform nematode into other cotton growing regions outside Central Queensland. Despite being regarded as a tropical/subtropical pest, it can survive and reproduce in more temperate regions.

Early season fusarium wilt (left) alongside a healthy plant.
Linda Scheikowski, Qld DAF

Central Queensland

Eight fields were surveyed in Emerald and Theodore with average plant stands of 6-11 seedlings. Black root rot was only detected in Theodore in four of six fields with disease incidence ranging from 0.5-16% (mean 4.4%) and severity between 0.05 and 6% (mean 1.7%) (Table 34A). Rhizoctonia was present in Theodore fields at an incidence of 2-12% (mean 5%). In some fields back-to-back planting resulted in a reasonable amount of cotton trash being still present.

St George

Plant stand for St George fields was 9-14 plants/m with an average of 11.4 plants/m. Fusarium was only detected in one of the four fields surveyed, and at very low incidence (0.2%), a substantial reduction from the 7.2% detected in the 2022-23 survey. Black root rot was present in three fields with an incicence between 7 and 53% (mean 22%) and severity of 14-17%. Rhizoctonia was present in all fields with disease incidence between 1.7 and 10% (mean 6.6%).

Darling Downs

Plant stand ranged between 8-13.2 plants/m, with an average of 10.5 plants/m. Ten of the fourteen fields surveyed had black root rot, with incidence ranging from a trace to 100% (mean 29.3%) and severity of blackened tap root from 0.2 to 74% (mean 17.9%). Fusarium was detected in eleven fields with an incidence of 0.3-5.7% (mean 1.8%) infected plants (compared to 6.6% in the 2022-23 season). Rhizoctonia incidence ranged from 0.3 to 29% (mean 8.9%). A trace of tobacco streak virus was observed as well as some mild alternaria in a few fields only.

Blackened tap roots caused by black root rot (left) and spores observed on roots (right). Linda Scheikowski, Qld DAF

TABLE 34A: Average disease incidence (% of infected plants) of common seedling diseases observed for each Queensland region during early season disease surveys, 2023-24, together with plant stand and presence/absence of reniform nematode in soil

Region	Plant stand/m	Average disease incidence (%)					Reniform nematode (Y/N)
		BRR (severity)	Fov	Rhizoctonia	Alternaria	TSV	
Emerald	8.1	0	0	0	0	0	N
Theodore	7.6	4.4 (1.7)	0	5	0	0	Y
St George	11.4	22 (12)	0.2	6.6	0	0	N
Darling Downs	10.5	29 (18)	1.8	8.9	7.2	0.2	N

BRR = Black root rot (severity in brackets is the % of blackened tap root). Fov = Fusarium wilt. TSV = tobacco streak virus.

TABLE 34B: Average disease incidence (% of infected plants) of common diseases detected during late season surveys in each Queensland region, 2023-24, together with mean percentage of open bolls

Region	% open bolls	Average disease incidence (%)						
		Leaf spots (severity)	Fov (severity)	Verticillium (severity)	Seed rot	Tight lock	Boll rot	Reoccurring wilt
Emerald	74	100 (0.1)	0	0	7.8	7.2	7.2	0
Theodore	67	93 (0.3)	7.8 (0.5)	0	6.1	6.2	8.8	1
St George	81	28 (0.1)	2.5 (1.0)	2.4 (0.3)	2.6	7.3	11.8	0
Darling Downs	21	39 (0.3)	3.9 (1.5)	3.8 (0.9)	0.3	2.9	1.4	0

Fov=Fusarium wilt (severity measured on a scale of 0-5, where 0 is no stem browning and 5 is complete vascular discolouration of stem when cut transversely). Verticillium severity is based on external leaf symptoms on a scale of 0-4, where 0 is no symptoms and 4 is plant death or defoliation. BR- boll rot.

Late season

Late season surveys were conducted between 27 February and 12 April 2024 with average disease incidence across the regions summarised in Table 34B.

Boll rots and leaf spots

Boll rots, tight lock, seed rot and leaf spots were detected in all regions late season. At the time of surveys, crops on the Darling Downs were not as advanced with less open bolls, so less boll rot and tight lock was observed compared to the other regions (Table 34B). Boll rots are caused by numerous pathogens, commonly species of *Phytophthora*, *Fusarium* and *Lasiodiplodia* species. This season, lasiodiplodia boll rot was only detected in Central Queensland (Theodore).

Various leaf spots were again showing up in late season across all regions under conducive weather conditions due to a combination of pathogens such as *Alternaria*, *Stemphylium*, *Cercospora* and *Corynespora* species. The first three are often associated with nutrient deficiency (commonly potassium), while *Corynespora* sp. (target spot) is typically found where canopy closure results in high humidity that is exacerbated by frequent rainfall, irrigation and/or cloudy weather. Excess available nitrogen may also support the disease development by promoting rank growth. In fields where the canopy was more open (due to shorter plants or planting configuration such as two in, one out), less boll rot, tight lock and leaf spots were observed.

Reoccurring wilt

Reoccurring wilt was only observed in Theodore in surveyed fields and at an incidence of 4% in one field. Outside of formal surveys however, reoccurring wilt was detected from another new field on the western Darling Downs, occurring in both patches and single plants with an average disease incidence of 11% across the field.

Fusarium and verticillium wilts

Central Queensland: Fusarium was only detected outside of survey transects in one Emerald field. Only one field had fusarium in Theodore (the field incidence was 46.5%). No verticillium was observed in Central Queensland.

Examples of boll rots observed during late season surveys in Queensland. Lasiodiplodia boll rot (far right) was only observed in Theodore this season. Linda Scheikowski, Qld DAF

Symptoms of verticillium wilt on the Darling Downs ranged from single plants with mild foliar symptoms to patches of more advanced disease. Linda Scheikowski, Qld DAF

St George: Fusarium was detected in three of the four fields in St George with incidence between 0.3-9.3%. The field with the highest fusarium incidence also contained verticillium at an incidence of 9.7%.

Darling Downs: Thirteen of the fourteen fields surveyed had either fusarium wilt, verticillium wilt or both. Seven fields were fusarium only with disease incidence ranging from 0.7 to 9% (mean 4.7%). External leaf symptoms were largely mild, while stem vascular severity averaged 1.5 (mild). Verticillium was detected in two fields for the first time at incidences of 1 and 3.5% (mean severity 2.3).

Four fields were mixed (containing both fusarium and verticillium wilt), with respective incidences of 11.7% & 7.3%; 1.3% & 24.7%; 0.7% & 2%; and 8% & 14.3%.

Other

Charcoal rot (caused by *Macrophomina phaseolina*) was reported from single fields in Emerald and Theodore. Cotton bunchy top (CBT), a viral disease spread by the cotton aphid, was observed outside survey transects in one field at Theodore and one field at the Darling Downs. Elimination of hosts, particularly over winter, is the most effective means of minimising the CBT risk.

New South Wales

The disease survey in NSW is a part of the CRDC project DAN2307: *Characterisation and management of Alternaria leaf spot and black root rot pathogens of cotton in NSW.*

Early season

In total, 55 fields were surveyed across the Border Rivers, Gwydir, Namoi, Macquarie, Murrumbidgee and Lachlan valleys. With a warm September, a significant number of fields benefited from early planting in the last week of September. Many fields in Macquarie established to the ideal 12-14 plants/m and disease pressure in those early planted crops also appeared mild during the first week of November. However, many other fields still experienced a significant black root rot infection.

Alternaria leaf spot was very minor this year, while fusarium wilt was prevalent in the Border Rivers and Gwydir valleys. Survey results are summarised in Table 35A.

Soil samples were collected early and late season and assessed for the presence of plant parasitic nematodes. Reniform nematode, which causes significant loss in Central Queensland, was not detected in NSW cotton growing regions. Other common nematode species such as spiral, lesion and stubby-root nematodes were detected at very low numbers. These nematode species are rarely of concern as very high numbers are required before crop damage occurs.

Lachlan

Nine fields wre surveyed around Forbes, Condobolin and Hillston. Crops established well, with average seedling stands of 9.9-14.3 plants/m. Black root rot incidence varied between 0 to 99.5% (mean 57.4%), with disease severity from 0 to 53.3% (mean 22.9%, which was half of that recorded in the 2022-23 season). Mild infection of rhizoctonia was detected with an incidence of 16-98% (mean 52.4%); the disease severity was from 1.8 to 15.9% (mean 4.8%). Alternaria leaf spot was not detected in the surveyed fields.

Murrumbidgee

Eleven fields were surveyed, with average seedling stands from 8-14.4 plants/m. Black root rot incidence varied between 6.5 to 93% (mean 32.2%), with a severity from 1.6 to 49.8% (mean 13.6%). Rhizoctonia rot incidence ranged from 7 to 96.5% (mean 45.9%), but only mild infection was detected. Alternaria leaf spot was detected in six fields; the incidence was 0-11.5% (mean 2.1%) and the severity mostly less than 0.5%.

Macquarie

Ten fields were surveyed, with average seedling stands from 6-17.3 plants/m. Black root rot was detected in all fields with an incidence of 1.5 to 100% (mean 27.1%) and severity from 0.2 to 66.9% (mean 11.4%). Rhizoctonia rot incidence varied from 55 to 100% (mean 85.1%) and severity of 1.7-18.9% (mean 7.7%). Alternaria leaf spot was minor in all surveyed fields, with an incidence of 0-52% (mean 6.2%) and severity was mostly less than 0.5%. Fusarium wilt on seedlings was detected in one field with the incidence up to 6%.

Classic seedling symptoms of black root rot (left). Infections can lead to profound black necroses of the pith and surrounding woody tissue in the collar area (right). Duy Le, NSW DPI

Namoi

Fifteen fields were surveyed, with average seedling stands from 7.7-13 plants/m. Black root rot was detected in all surveyed fields, with an incidence of 3.5 to 78% (mean 30.4%) and severity of 0.4 to 15.6% (mean 4.5%). Rhizoctonia rot incidence varied from 80 to 100% (mean 96.4%) and severity varied from 1 to 24.5% (mean 8.5%). Alternaria leaf spot was prevalent in all surveyed fields, with an incidence from 0 to 9.5% (mean 3.6%) and the severity was mostly less than 0.5%.

Gwydir

Twelve fields were surveyed, with average seedling stands from 6.9 to 11.6 plants/m. Black root rot incidence varied between 1 to 96% (mean 47.2%) with a severity from 0.9 to 27.5% (mean 8.9%). Rhizoctonia rot incidence varied from 33 to 100% (mean 81.4%) and severity from 3.2 to 14.2% (mean 6.3%). Alternaria leaf spot was prevalent in many surveyed fields, with an incidence of 1-25.5% (mean 16.1%) but only minor pinhead lesions were observed in most fields and the severity was below 0.5%. Fusarium wilt on seedlings was detected in seven fields with disease incidence from 0.5 to 26%. The mean incidence was 6%, three times higher than last season.

Border Rivers

Average seedling stands in the eleven fields surveyed ranged from 6.4 to 12.8 plants/m. Black root rot incidence varied between 2.5 to 96.5% (mean 20.1%) and disease severity from 0.3 to 59.1% (mean 7.2%). Rhizoctonia rot incidence varied from 57.9 to 100% (mean 86.5%) with a severity of 4.5 to 20.1% (mean 11.1%). Alternaria leaf spot was prevalent in all surveyed fields, with the incidence from 1.5 to 27.5% (mean 7.2%) and severity less than 0.5%. Fusarium wilt on seedlings was detected in three fields with the disease incidence lower than 1%.

Late season

A total of 67 fields were visited, and in most the late season disease pressure was relatively low and crops were performing well. Foliar symptoms associated with alternaria, fusarium and verticillium infection were mild. Cotton bunchy top disease was again detected many valleys, however the disease was highly sporadic. Black necroses of the pith and surrounding woody tissue associated with black root rot infection (see photo below) were also detected more often this season. Survey results are summarised in Table 35B.

Fusarium wilt caused seedling deaths in the Gwydir.
Duy Le, NSW DPI

Relatively mild foliar symptoms such as yellow mottling and necroses associated with verticilium wilt.
Duy Le, NSW DPI

Lachlan

Verticillium wilt was detected in four of the nine surveyed fields with the incidence below 2%. However, of concern was a field in Forbes when the disease continued to spread after four years without growing cotton. Fusarium wilt was detected in one field with the incidence below 10%. Alternaria leaf spot was evident on the top half of the canopy in all nine surveyed fields, but the severity was generally less than 1%. A low incidence of boll rot and tight lock was detected in the lower canopy. Evidence of black root rot-colonised woody tissue was detected in one field. Cotton bunchy top was detected in two fields. Reoccurring wilt was not detected in the surveyed fields.

Murrumbidgee

Similar to the Lachlan, late season disease pressure was milder than that of the previous season. Mean Alternaria leaf spot severity was only 0.7%, and a low incidence of boll rot was detected in the lower canopy of all surveyed fields. Verticillium wilt was only recorded in one surveyed field with an incidence of 1.5%. However, Verticillium wilt was also confirmed in a number of additional fields without previous history of Verticillium infection, indicating widespread distribution of the disease. Fusarium wilt was detected and confirmed in one field near Whitton. Cotton bunchy top and reoccurring wilt were not detected in the surveyed fields.

Macquarie

Verticillium was detected in five out of nine surveyed fields with an incidence between 3 to 47% (mean 5.4%). Fusarium wilt was detected in two fields, including one that did not have a previous history. The disease incidence was up to 58% (mean 6.4%). Reoccurring wilt was detected in one field where there was no previous history (Figure 10). Alternaria leaf spot was prevalent with a mean disease severity of 2.3%. Boll rot and tight lock were detected at a low level in all surveyed fields with a mean incidence of 2.2 and 0.75, respectively. Cotton bunchy top was detected outside of surveyed transects in four fields.

TABLE 35A: Summary of disease incidence (with severity % in brackets) recorded during the early season disease surveys in NSW during 2023-24

Valley	Average plant stand (plants/m)	Average percentage of disease incidence (and severity %)			
		Fov	Black root rot	Rhizoctonia rot	Alternaria leaf spot
Border Rivers	10.4	0.4	20.1 (7.2)	86.5 (11.1)	7.2 (0.05)
Gwydir	10.1	6.0	47.2 (8.9)	81.4 (6.3)	16.1 (0.07)
Namoi	10.3	0	30.4 (4.5)	96.4 (8.5)	3.6 (0.03)
Macquarie	12.8	0.6	27.1 (11.4)	85.1 (7.7)	6.2 (0.15)
Murrumbidgee	10.6	0	32.2 (13.6)	45.9 (3.2)	2.1 (0.02)
Lachlan	11.2	0	57.4 (22.9)	52.4 (4.8)	0 (0)

TABLE 35B: A summary of % disease incidence (boll rot, tight lock and bunchy top) and % severity (Alternaria leaf spot) recorded in the late season disease surveys

Valley	2023-24 season [previous season in square brackets]			
	Alternaria	Boll rot	Tight lock	Bunchy top
Border Rivers	0.5 [0.6]	5.3 [1.6]	1.9 [0.8]	Detected [Detected]
Gwydir	0.1 [0.8]	0.9 [1.8]	2.2 [1.0]	Detected [0.2]
Namoi	0.6 [0.2]	0.6 [2.0]	0.6 [0.1]	0.1 [0.2]
Macquarie	2.3 [1.2]	2.2 [1.4]	0.7 [0.8]	Detected [0.3]
Murrumbidgee	1.5 [0.7]	0 [0.2]	0 [0]	0 [0]
Lachlan	1.0 [0.2]	0.1 [0.2]	0.4 [0]	0.1 [0]

Namoi

No Fusarium wilt was detected, but verticillium wilt was detected in all surveyed fields. Verticillium wilt incidence was higher than that of the 2022/23 season, however most crops performed well and the verticillium wilt expression was relatively mild (incidence from 0.5 to 86%). Reoccurring wilt was only detected in two fields, including one virgin field, with an incidence below 1%. Alternaria leaf spot was minor, with severity mostly below 0.6%. Boll rot and tight lock were detected at low levels with a mean incidence of 0.6% compared to 2% in the 2022/23 season. Cotton bunchy top was detected at low levels in three surveyed fields with a mean incidence of below 0.1%.

Verticillium wilt in a field near Griffith appeared to spread rapidly along and across planting rows from a small, isolated patch which was detected the first time in 2019/20 cropping season.
Duy Le, NSW DPI

Gwydir

Again this year, Fusarium wilt was highly prevalent, detected in 10 out of 12 surveyed fields. However, most Fusarium-infested fields had low incidence (around 15%); only three fields had an incidence of over 45%. The mean incidence was 24.2%. Verticillium was detected in 10 fields with the incidence mostly below 15% (mean 16.2%). Nine fields contained both wilt diseases. Reoccurring wilt was detected in three fields, including one virgin field. Alternaria leaf spot was minor, with a mean incidence of 0.1%. Boll rot and tight lock were detected at low levels, the mean incidence was 0.9 and 2.2%, respectively. Only two cotton bunchy top plants were detected outside of surveyed transects in two fields. Evidence of black root rot colonising the vascular tissue was observed in seven surveyed fields.

Border Rivers

Fusarium wilt was prevalent and detected in eight fields; however, the incidence was only 0.5 to 20% (mean 4%). Similarly, Verticillium wilt was prevalent and detected in nine out of 11 surveyed fields with the incidence varying from 1 to 76% (mean 31.8%). Although fusarium and verticillium wilts were prevalent in the surveyed fields, most had a relatively low level of foliar expression and were detectable from examination of cut stems. Reoccurringwilt was detected in four fields with low incidence (below 1%). Alternaria leaf spot was minor; mean disease severity was scored at 0.5%. Boll rot and tight lock were at low levels with a mean incidence of 5.3% and 1.9%, respectively. Cotton bunchy top was detected outside of surveyed transects in one field.

The Fast Facts: Be wilt aware

	FUSARIUM WILT	VERTICILLIUM WILT	SUDDEN WILT	LIGHTNING STRIKE	REOCCURRING WILT
CAUSAL AGENT	Fusarium oxysporum f.sp. *vasinfectum*	*Verticillium dahliae*	Potentially caused by *Fusarium spp./* physiological effect of environmental conditions	Lightning (thunderstorm)	Novel *Eutypella* species
PLANT STAGE AFFECTED	Plants may be affected throughout the season	Most common late season or after wet and/or cool weather	Plants may be affected throughout the season	Lightning can cause damage at all crop stages	Plants may be affected throughout the season
FAVOURED BY	Cool and wet conditions with temperatures below 23°C	Temperatures below 25°C and excessive nitrogen. Disease incidence is most severe during extended wet weather	Hot weather following an irrigation or rainfall. Root damage from cultivation can contribute to incidence	–––––	Unknown
SYMPTOMS	Plant stunting; yellowing or browning of leaves; plant wilting and death. Plants die from the top and may regrow from the base later in the season	Yellow mottling of leaves between veins and around leaf margins; dead tissue replaces mottling. Defoliation can occur depending on severity and strain	Sudden wilting followed by defoliation; plants die and occasionally regrow	Leaves can be completely desiccated or partially blackened; blackening or burnt bark (stems) in mature crops	Sudden wilting and plant death; bronzing of leaves and petioles; dead plants have blackened stems with leaves remaining on the plant
VASCULAR TISSUE & ROOTS	Solid brown/chocolate discolouration of vascular tissue	Speckled dark brown, tan to black discolouration of vascular tissue	Brown discolouration is confined to woody parts of root and lower stem	No vascular discolouration. Roots and lower stems of surviving plants relatively unaffected	When the stem or tap root is cut horizontally, infected tissue may have a wedge-shaped discolouration which is reddish-grey in colour. Discolouration of the roots and vascular tissue. Root decay i.e. if plants are pulled out of the soil, the taproot snaps due to a dry rot.
APPEARS AS	Single plants or small patches, often near the tail drain or low- lying areas in the field	Single plants or small patches	Single plants or small patches. Does not reoccur in the same place	Circular or irregular patches of dead or damaged plants	Single plants or in patches. Reoccurs in the same place
SPREAD BY	Soil inhabiting, spread with soil and plant debris – especially in irrigation water	Soil inhabiting, spread with soil and plant debris – especially in irrigation water	Soil inhabiting, spread with soil and plant debris – especially in irrigation water or floodwater	–––––	Pathogen confirmed to be spread with infected cotton residue. Plants can become infected via buried cotton stems.

Figure 1.
Fusarium wilt can cause some leaves to develop a yellow mottle.

Figure 2.
A key feature of **Fusarium wilt** is the brown discolouration in the woody part of the stem.

Figure 3.
Fusarium wilt can cause plants to die back from the top and may regrow back from the base later in the season.

Figure 4.
An early symptom of **Verticillium wilt** is leaf wilting and mottling.

Figure 5.
Verticillium wilt causes a speckled vascular discolouration throughout the stems.

Figure 6.
Severe **Verticillium wilt** infection may cause defoliation.

Figure 7.
Reoccurring wilt causes plants to wilt and suddenly die with dead leaves remaining on the plant.

Figure 8.
Reoccurring wilt causes root decay i.e. if plants are pulled out of the soil, the taproot snaps due to a dry rot, and reddening of the vascular tissue.

Figure 9.
When the stem or tap root is cut horizontally, infected tissue may have a wedge-shaped discolouration (**Reoccurring wilt**).

Figure 10.
Reoccurring wilt causes blackening of the stem.

Figure 11.
Sudden wilt (right plant) can cause plants to suddenly wilt and die. Does not re-occur in the same place.

Figure 12.
Lightning strike can cause circular or irregular patches of dead or damaged plants.

Biosecurity – we all have a responsibility

Biosecurity is the protection of your property and the entire industry from the entry, spread and establishment of exotic and endemic pests (including insects, weeds and diseases). Exotic pests can affect everyone – farmers, agronomists and the community, so it is important that everyone plays a part in preparing for and minimising their biosecurity risks. While Australia's national quarantine system helps to prevent the introduction of harmful exotic pests, the threat they pose is still very real. Our ongoing reliance on imported goods, as well as existing natural entry pathways (e.g. winds), makes future incursions of exotic pests and diseases almost inevitable.

Biosecurity – a legal responsibility

All Australian states and territories have their own respective biosecurity legislation to minimise the risk of the entry and spread of pests, pathogens and weed seeds. Legislation in Queensland and NSW is based on the principle of a 'shared responsibility' where everyone has a responsibility to contribute to biosecurity and ensure they minimise the risk of spreading pathogens, pests and weeds ('biosecurity matter') which could impact the environment, the economy and the broader community.

It is your responsibility to meet the requirements of your state or territory. If you have any questions or concerns, contact your State or Territory Agriculture Department.

Anyone working on or visiting farms has a biosecurity responsibility

- **Come Clean. Go Clean.** Vehicles, farm equipment and people can carry biosecurity matter. Clean down between farms, including vehicles and footwear. Suggest using an on-farm vehicle where possible.
- **Spotted anything unusual?** Ensure any unusual plant symptoms or suspected exotic pests are reported to the Exotic Plant Pest Hotline (1800 084 881). Vigilance is vital for early detection of an exotic plant pest threat.

Growers have a biosecurity responsibility

- **Monitor your crop frequently** and immediately report unusual pests or crop symptoms to the Exotic Plant Pest Hotline on 1800 084 881 to be directed to an officer from your state or territory's agriculture department. Early reporting improves the chance of effective control and eradication..
- **Communicate your biosecurity requirements using clear signage** to ensure only essential vehicles and equipment gain access to production areas.
- **Provide wash down facilities** for visitors to use with appropriate agricultural detergents and/or disinfectants to clean equipment and tools prior to entry and exit.
- **Develop a farm biosecurity management plan** to assess how pests, weeds and diseases could enter the farm and what practices are in place to manage or reduce these risks. Ensure all staff are aware of and understand your plan.
- **Declare visits to farms overseas on re-entry to Australia.** All clothes and footwear worn on-farm overseas should be left behind or thoroughly washed before you return.
- **Ensure all farm inputs are pest free**, including seed for cotton, refuges and other commercial crops. Keep records of all farm inputs.
- **Maintain zero tolerance of volunteer cotton plants and other weeds** at all times throughout the year to prevent pests harbouring there.

Come Clean. Go Clean.

To work properly, disinfectants need to be applied to a cleaned surface (all soil and trash removed), so effective decontamination of vehicles, machinery and other items involves two steps:

1. Cleaning with detergent, followed by
2. Disinfection.

Agricultural detergents (e.g. Bio-Cleanse™ or most industrial and domestic brands of soaps and detergents) provide optimal soil removal.

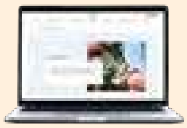
Agricultural disinfectants (e.g. Path-X™, Sporekill®, Steri-maX®, or products containing quaternary ammonium compounds) are effective against a range of pathogens found on agricultural farms.

Products used during wash down must be appropriate for the situation. Always read and follow label requirements.

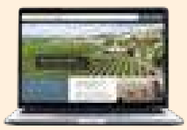
Biosecurity Plan for the Cotton Industry

Plant Health Australia (PHA) is the national coordinator of the government-industry partnership for plant biosecurity in Australia. Cotton Australia is a member and CRDC is an associate member of PHA. The PHA-facilitated *Biosecurity Plan for the Cotton Industry* is a framework to coordinate biosecurity activities and investment for Australia's cotton industry. It provides a mechanism for industry, governments and stakeholders to better prepare for and respond to incursions of pests that could have significant impacts on the cotton industry.

USEFUL RESOURCES:



Cotton Australia
– biosecurity stewardship
☎ (02) 9669 5222
cottonaustralia.com.au/biosecurity



On-farm biosecurity
– prevent endemic and exotic pests entering and establishing on farm
farmbiosecurity.com.au

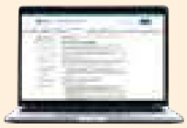
New South Wales

Department of Primary Industries & Regional Development
☎ 1800 680 244

dpi.nsw.gov.au/biosecurity/your-role-in-biosecurity

Queensland

Queensland Department of Agriculture & Fisheries
☎ 13 25 23



daf.qld.gov.au/business-priorities/biosecurity/policy-legislation-regulation/biosecurity-act-2014/general-biosecurity-obligation

Northern Territory

Northern Territory Department of Industry, Tourism & Trade
☎ (08) 8999 2118

industry.nt.gov.au/industries/primary-industry/agriculture/agricultural-developments/nt-biosecurity-strategy-2016-2026

Western Australia

Western Australia Department of Primary Industries & Regional Development ☎ (08) 9334 1800

agric.wa.gov.au/biosecurity-quarantine/biosecurity

Farm biosecurity management plans

A farm biosecurity management plan is a practical way of showing how you are preventing pests, weeds and diseases from:

- Being introduced to your property
- Spreading around your property (or spreading from your property to others).

Developing a farm biosecurity management plan can help you to:

- Identify and assess the biosecurity risks to your farm and business
- Outline the biosecurity practices currently being implemented
- Identify biosecurity practices that can be implemented in the short and long-term to reduce biosecurity risks.

The suggested practices in a farm biosecurity management plan cover a range of farming scenarios and can be adapted to suit your particular circumstances. In some cases alternative practices may be better suited to your farm and business; the important thing is that you are aware of your biosecurity risks and are taking reasonable steps to minimise those risks. If you build your plan around daily, monthly and yearly farming routines, biosecurity practices will become a habit rather than an additional task.

Completing a farm biosecurity management plan provides a point of discussion and clear instructions regarding your biosecurity expectations for farm visitors such as agronomists, researchers, utility workers and hunters. Farm biosecurity management plans are available on the CottonInfo website cottoninfo.com.au.

If you require assistance developing your plan, please contact the CottonInfo Technical Lead for Biosecurity.

Biosecurity Top Tips:

There can be several ways to mitigate a biosecurity risk; the practices you implement should reflect what suits you and your farming business. Check out our Biosecurity Top Tip videos of growers, consultants and researchers sharing how they are implementing biosecurity in their day-to-day routines.

Visit **www.youtube.com/CottonInfoAust**

CottonInfo

Biosecurity Management Plan

Biosecurity Management Plan for broadacre industries

Property Name:	Property Address:
Owner or Manager:	Contact number:
Review date:	
Biosecurity Management Plan completed by:	Emergency Plant Pest Hotline 1800 084 881

Contents

This is a Biosecurity Management Plan in accordance with Section 94Q(4) of the Queensland Biosecurity Regulation 2016 and clause 448 of the New South Wales Biosecurity Regulation 2017. The purpose of this Biosecurity Management Plan is to state the measures to prevent, control or stop the spread of biosecurity matter into, at, or from the management areas defined in the plan, as described in relevant Australian state and territory biosecurity legislation. Various obligations apply to areas where a Biosecurity Management Plan is in place. For details of these obligations, refer to the relevant legislation in your jurisdiction. People entering areas where a Biosecurity Management Plan applies need to be aware of their obligations under the plan and must comply with the measures outlined.

NSW GOVERNMENT | Department of Primary Industries

GRAINS FARM BIOSECURITY PROGRAM

Queensland Government

CottonInfo

Come Clean. Go Clean.

Dirty vehicles, machinery and equipment carry pests, weeds and diseases

A GUIDE TO EFFECTIVE WASH DOWN OF VEHICLES AND MACHINERY

1 WASH DOWN

- Use compressed air or high pressure water to remove caked on trash and mud
- Get into crevices where mud or trash might be trapped
- Clean out the inside of the car, particularly foot pedals and mats regularly in contact with dirty footwear

WHERE

✓ On a clean wash down pad with a hard surface

✓ Located away from production areas

✓ Where wash off contaminants can be trapped

2 CLEAN

- Use a sponge or spray to cover all surfaces with an agricultural detergent
- Leave the detergent to work for 10 minutes* before rinsing, making sure to remove any remaining soil or plant material

*unless otherwise directed by product label

Image: NSW DPI

REMEMBER

To wash all equipment, floor mats, tools and footwear kept in the vehicle as well

3 DECON

- After removing physical dirt, consider using an agricultural decontaminant to kill any remaining pests or pathogens
- Refer to the APVMA for registered decontaminants and follow label instructions
- An additional rinse step may be necessary following disinfection

NOTE

Make sure vehicles and equipment are clean and free of mud and trash before applying a decontaminant

Image: cleananddry.net.au

4 RINSE

- Rinse off vehicle, machine and/or other washed equipment
- Use high pressure water to remove mud and debris from the wash down area so it is clean for the next person

CHECK

Equipment that has not been cleaned on farm should be thoroughly inspected to ensure cleanliness

Images courtesy of Sharna Holman, QDAF, unless otherwise stated

Together we can stop the spread of pests, weeds and diseases.

BE A GOOD MATE STOP IT AT THE GATE

JN14825_APR18

Exotic insects and diseases

Numerous pests of cotton not found in Australia pose a threat to production if they were to arrive and establish. Among these, certain pests are identified as 'high priority', based on risk assessments of the likelihood of entry and potential impact to cotton production. To improve the chance of an effective eradication or containment response, it is important that anyone working on-farm are aware of these pests, as well as what to do if they see anything unusual.

Some of the high priority exotic pests look similar to or are variants of endemic pests and diseases, and are included under 'Are your usual control measures not working?'. For more information on the current high priority list, contact Cotton Australia or Plant Health Australia.

IF YOU SEE ANYTHING UNUSUAL, CALL THE EXOTIC PLANT PEST HOTLINE
1800 084 881

High priority exotic pests

Blue disease

Cotton leafroll dwarf virus

Blue disease is caused by cotton leafroll dwarf virus (CLRDV) that is spread by cotton aphids and infects cotton and some other hosts. In Brazil, blue disease is reportedly capable of reducing productivity of susceptible varieties by up to 80%. Cotton blue disease has similarities to cotton bunchy top and anthocyanosis (a disorder reported from Brazil). CLRDV has not been detected in Australia.

Blue disease-affected leaves tend to be smaller, thicker, more leathery and brittle and are intense green with yellow veins (CBT-affected leaves have an angular pattern of pale green margins and darker green centres). Reddening of stem petioles and leaf veins can occur in some infections. Leaf edges tend to roll downwards and under and plants become stunted (due to shortened branch internodes) and produce many branches, giving a bunchy zig-zag stem habit. Symptoms and stunting are more obvious in plants infected at an early age. Infected plants also produce smaller bolls and boll shedding may occur. Single infected plants can be difficult to spot if overgrown by nearby healthy plants.

Blue disease. Murray Sharman, Qld DAF

Boll weevil. Alton N. Sparks, Jr., University of Georgia, Bugwood.org

Cotton boll weevil

Anthomonus grandis

A pest specific to cotton that damages developing bolls leading to large yield losses. In the USA, the cotton boll weevil eradication program has been largely successful, but has cost hundreds of millions of dollars.

Cotton leaf curl disease (CLCuD)

CLCuD is spread by whiteflies and can cause yield losses of up to 35% in cotton. There are at least seven different begomoviruses and several different DNA satellite molecules associated with CLCuD. A cotton plant needs to be infected with at least one begomovirus and one satellite to develop CLCuD.

Symptoms initially appear as a swelling and darkening of leaf veins, followed by a deep downward cupping of the youngest leaves then either an upward or downward curling of the leaf margins. Leaf-like structures (enations) on the veins are common and vary in size from a few millimetres in diameter to almost the size of a normal leaf. These larger structures are often cup-shaped.

Indian green jassid

Amrasca devestans

A sap-sucking leafhopper that can cause yield losses of up to 25%. Indian green jassids inject a toxin as they feed that causes leaves and bolls to drop and can stunt plant growth. While several leafhopper species are found in Australian cotton (see page 56) the damage they cause is usually relatively minor, rarely if ever affecting yield.

Leaf curl disease. Cherie Gambley, Qld DAF


Indian green jassid. NSW DPI

Lygus bugs

Lygus lineolaris and *L. hesperus*

Tarnished plant bug and western plant bug occur predominantly in North America and have a wide host range. In cotton, feeding causes seed abortion, stem or leaf wilting and poor seed germination. It is likely that control of these bugs would be very disruptive to the current Australian IPM system.

Some high priority exotics are variants of endemic pests and diseases. These exotic strains could become a problem if they reached Australia, either through different insecticide resistance profiles or the potential to overcome host plant resistance bred into Australian cotton varieties.

It is important to report if you've experienced an insecticide spray failure without a reasonable explanation, or are seeing new or unusual disease symptoms so that appropriate sampling and testing can be organised.


Tarnished plant bug. Scott Bauer, USDA Agricultural Research Service, Bugwood.org

Other exotic threats

Brown marmorated stink bug (BMSB)

Halyomorpha halys

Stink bugs have a shield-shaped body and emit a pungent odour when disturbed. A number of native stink bugs look similar to BMSB, but lack the distinctive white bands on the antennae (and legs of nymphs). BMSB can damage more advanced bolls than other stink bug species.


CottonInfo insect ID guide on brown marmorated stink bug
cottoninfo.com.au/publications/insect-id-guide-endemics-exotics-brown-marmorated-stink-bug


Brown marmorated stink bug. Susan Ellis, Bugwood.org

Cotton stainer

Dysdercus spp.

Related to the already endemic pale cotton stainers (see page 46), these colourful red bugs are often found in groups. While feeding on cotton bolls they can transfer microorganisms that increase lint staining.


Adults and nymphs of the cotton stainer, *Dysdercus suturellus*. Lyle J. Buss, University of Florida. entnemdept.ufl.edu/creatures/field/bugs/cotton_stainer.htm

False codling moth

Thaumatotibia leucotreta

False codling moth is a pest of many crops including avocado, citrus, maize, cotton, macadamia, peach and plum. Adult false codling moths are small, brownish-gray moths up to 20 mm, with a 'question mark'-like pattern on the outer forewings.


False codling moth larvae (left) and female moth (right). Marja van der Straten, NVWA Plant Protection Service, Bugwood.org (left) idtools.org (right)

Texas root rot. Chris Anderson, NSW DPI

Texas root rot

Phymatotrichopsis omnivora

Texas root rot is an extremely damaging fungal disease with a wide host range. It causes sudden death, usually during the warmer months and can result in 100% crop loss. Symptoms include yellowing or bronzing of leaves, which then wilt and die but usually remain attached to the plant. At this stage, the roots are dead and their surface is covered with a network of tan fungal strands. External symptoms of Texas root rot are similar to reoccurring wilt caused by Eutypella spp. It is important to investigate any unusual symptoms to determine the cause.

Are your usual control measures not working or is pest damage worse than expected?

Some exotics are variants of endemic pests and diseases. These exotic strains could become a problem if they reached Australia, either through different insecticide resistance profiles or the potential to overcome host plant resistance bred into Australian cotton varieties.

It is important to report if you've experienced an insecticide spray failure without a reasonable explanation, or are seeing new or unusual disease symptoms, so that appropriate sampling and testing can be organised.

American cotton bollworm

Helicoverpa zea

American cotton bollworm, also known overseas as corn earworm, is a pest of many crops including cotton, pigeon pea, soybean, maize, sorghum, chickpea and millet. Larvae are not distinguishable visually from *H. armigera* and cause similar damage. Dissected adult male moth genitalia are required for identification.

Bt-resistant cotton bollworm

Helicoverpa armigera (carrying Bt resistance alleles)

Bt cotton has dramatically reduced the need to control *Helicoverpa*. Exotic strains of *H. armigera* that carry resistance alleles (e.g. dominant resistance to Cry1Ac) would have a significant impact on Australia's cotton industry if they were to establish here. With the movement of *H. armigera* into South America, there is also some concern that *Helicoverpa zea* (American cotton bollworm) may hybridise with *H. armigera*.

Fall armyworm

Spodoptera frugiperda (exotic strains)

Fall armyworm was detected in Australia in early 2020 and has been declared endemic. Although FAW has the capacity to feed on cotton, it appears to prefer grass species with whorls (such as maize and sorghum), and to date no impact on cotton crops has been reported in Australia. Overseas there are strains that can impact cotton.

Cotton aphid

Aphis gossypii (exotic strains)

Cotton aphids are potential vectors for exotic pathogens such as blue disease. As well as the risk of disease, there is a risk that new aphid strains entering the country will have different insecticide resistance profiles, making control more difficult.

Bacterial blight

Xanthomonas axonopodis or *X. campestris pv. mavacearum* (exotic strains)

Although strains of bacterial blight are already present in Australia, they are no longer a problem due to varietal resistance. Exotic strains (races) occur, however, that are 'hypervirulent' and, if established in Australia, could cause large yield losses.

Initial symptoms include angular water-soaked lesions on the undersides of leaves that dry and darken with age, followed by leaf shedding. Black lesions spread along stem and bolls are often infected at the base or tip (where the dried lesions prevent the boll from opening). This seed-borne pathogen is capable of symptomless transfer and could therefore remain undetected through quarantine.

Verticillium and Fusarium wilts

Verticillium dahliae (exotic strains)
Fusarium oxysporum f. sp. vasinfectum (exotic strains)

While Fusarium and Verticillium wilts already affect Australian cotton, it is important to get new or unusual wilt symptoms tested as this could indicate incursion of exotic strains.

Whitefly

Exotic Bemisia species

There is a risk of further incursions of exotic *Bemisia* species, with different genetic profiles to current pest populations (e.g. additional forms of insecticide resistance) entering the country. Invasive whitefly could potentially introduce viruses (such as CLCuD) that they vector.

Applying pesticides

Pesticides are chemical substances or mixtures that control pest species (e.g. insecticides, herbicides, fungicides, or nematicides) or plant growth and development (e.g. plant growth regulators, defoliants, or desiccants).

Pesticides are an important component of cotton farming systems, but their efficacy in both the short and long term largely relies on not only appropriate product choice, but effective handing and application. Many of these products can be highly toxic, not just to their intended target, but to humans, beneficial insects, wildlife, and other crops and vegetation. Some registered products or adjuvants may cause phytotoxicity in certain situations. Always read the entire label before applying any product.

Planning ahead

The development of a comprehensive spray plan, such as a Pesticide Application Management Plan (PAMP) prior to the season is an important part of the Best Management Practice (*my*BMP) program for cotton.

The spray planning process should include discussing cropping intentions and communication proccesses with spray applicators. The spray plan should include consideration of farm layout, weather monitoring and record keeping, identification of sensitive areas and potential hazards, and procedures for communication with staff, contractors and neighbours..

Having a spray plan in place helps to ensure that everyone involved in pesticide application has a clear understanding of their responsibilities.

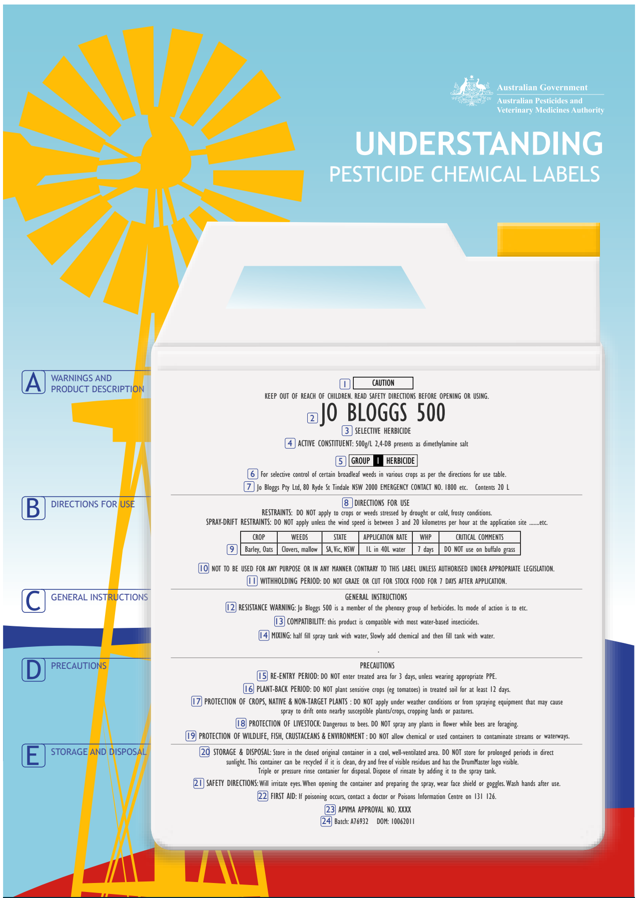
Legal responsibilities

Be aware of federal and state regulations for chemical application. Staff responsible for handling and applying pesticides must be qualified according to relevant state and federal requirements.

There may also be workplace health and safety requirements related to storage and use of hazardous chemicals, such as completing a hazard analysis, maintaining a chemical inventory and easily accessible current copies of relevant Safety Data Sheets.

Always read and follow the label when handling and applying chemicals. Specific label conditions may include minimum spray quality, spray conditions (including wind speed range), no-spray zones/buffers, and record-keeping requirements.

- **Spray quality** (the size of the droplets produced) is influenced by nozzle design, operating pressure, the angle of the spray pattern, the properties of the tank mix, and (for some nozzles) the inclusion of air into the droplet. Nozzles are assigned a spray quality classification by comparing their output (range of droplet sizes) at a given pressure to the output of standard reference nozzles. Select nozzle and ensure that equipment is set up and used appropriately to achieve the required spray quality.
- **Wind speeds** are measured at the application site – the label-specified range is usually above 3 km/h and less than 15-20 km/h.
- **No-spray zones** are a specified distance downwind that must not include a sensitive area (such as a residence, school, public area, water body, pasture, terrestrial vegetation or crop). Always check the product label(s) as the distance required may differ depending on the type of sensitive area and application method. No-spray zones for aerial applications can be larger than those required for ground application.
- **Keep records** of the application details. Specific requirements are included on the label or permit conditions for many products. These records are in addition to any state-based record-keeping requirements.



This poster and the accompanying booklet can be downloaded from the APVMA website
apvma.gov.au/node/11041

Users are not absolved from compliance with the label directions/permit conditions or compliance with other legal requirements by reason of any statement made or not made in this publication. See also the *Pesticides and regulation* section in this chapter.

Monitoring and recording conditions

Labels contain a legal requirement to measure weather parameters (including temperature, humidity, and wind speed and direction) at the site and time of application. This can be done with handheld equipment (e.g. Kestrel or equivalent) or portable weather stations. On-board weather stations that provide live weather information while the sprayer is operating (such as the Watchdog systems) are also available. See page 145 for an example of a pesticide application record sheet.

Best practice...

Product and application technique needs to be matched to the target, tank mix and weather conditions, and you need to be able to demonstrate due diligence for your spray recommendations/actions, including how you have assessed safety risks and mitigated non-target consequences.


Hunter Precision
Agriculture
THE FUTURE IS REMOTE | REMOTE CONTROL UAV

Access to a network of spray hazard identification towers that can quickly detect hazardous conditions is available for free. Sign up at goannaag.com.au/wand-network

There are also subscription websites that provide forecasts of conditions for spraying up to 10 days in advance. These sites evaluate a range of factors to produce tables indicating suitable times for spraying.

Good communication

Prior to product selection and spray application, determine the proximity of susceptible crops and sensitive areas (cotton is extremely sensitive to phenoxy herbicide drift). It is good practice to notify neighbours and staff of your spray intentions, regardless of label requirements.

BeeConnected can help identify nearby location of hives and facilitate communication between spray applicators and beekeepers beeconnected.org.au.

SataCrop is a free online mapping tool that maps all crops, not just cotton, allowing growers and applicators of all products to be better informed of the location of potentially sensitive crops before spraying satacrop.com.au.

Optimising spray application

Application technique needs to be matched to the target and weather conditions. Always consider the potential for off-target drift. Achieving the best outcome requires careful attention to many factors, including:

- Appropriate nozzles for product/adjuvants and target
- Appropriate operating parameters, including nozzle spacing, operating pressure, travel speed and spray release height
- Meeting label requirements for optimising spray quality and minimising drift risk
- Considering the most suitable timing for mobile targets (insects)
- Careful calculation of actual field rates for product and water
- Ensuring the water used is of suitable quality
- Considering potential incompatibilities during mixing
- Regular calibration and rig maintenance.

Mixing order and water quality can have a significant impact on spray efficacy.

GRDC factsheet on tank mixes
grdc.com.au/resources-and-publications/all-publications/factsheets/2019/mixing-requirements-for-spraying-operations

Effective decontamination

Thoroughly decontaminate application equipment after use, particularly when herbicides have been used. Follow decontamination instructions on pesticide and cleaning product labels.

CottonInfo video on decontaminating a spray rig
youtu.be/-zDQwolEcB0

Top tips for agronomists...

1. Run through a pre-season spray plan with your growers (see module 5 of the GRDC spray application manual) and consider if spray practices can be improved.
2. Ensure your growers have realistic expectations of timeframes for pest control.
3. Check that each grower's spray rig set-up is fit-for purpose to deliver your spray recommendations.
4. Highlight the importance of identifying spray drift factors and avoiding hazardous inversion conditions (including halting the spray operation if conditions become unfavourable).
5. Ensure growers are aware of factors that may impact on spray coverage and performance (nozzle selection, pressures, speed, adjuvants, water quality, tank mix compatibilities etc).
6. Recommend a nozzle that complies with label and delivers the coarsest spray quality without compromising efficac.
7. Highlight the importance of reading and understanding the labels of any products used.
8. Follow up on your recommendations by assessing efficacy and efficiency post-spray.

Ground application

Spray rigs for ground application are available in a wide range of sizes and configurations. Tractor-powered booms (mounted or trailed) are relatively cheap to buy and maintain, and the tractor can be used for other farm operations. Dedicated self-propelled spray rigs have better ground clearance and field capacity (hectares sprayed per hour over all operations, including spraying, travelling, refilling and refuelling etc), but are more expensive and less versatile. Automated agbots for spraying are also commercially available. They are responsive, cheaper and lighter (reducing field compaction), but have lower field capacity than larger spraying systems.

Ensure that spray contractors have the appropriate training, accreditations and license. For example, you can search to see if a ground or aerial contractor is licensed in NSW at apps.epa.nsw.gov.au/prrdlapp/plpr.aspx and in Queensland at business.qld.gov.au/industries/farms-fishing-forestry/agriculture/land-management/chemical-controls/licence-search

Banded sprays present an opportunity for strategic and economical use of products by applying the equivalent rate of active per hectare to the target, but using less pesticide overall. Label rates are always given as litres of active/sprayed ha. Advisors also give recommendations as L/sprayed ha, however confusion over banded spraying can lead to significant differences between the consultant's recommendation, the applicator's instincts and what the application equipment can physically achieve. A detailed example of how to calculate banded sprays is available in the *Australian Cotton Production Manual*.

Optical spray technology applies significantly less product by detecting and only spraying individual weeds and weedy patches. This technology can provide savings in time and fuel and helps reduce drift. Not all products can be used in optical sprayers – check product labels for compatibility.

Multi-outlet nozzle bodies can be used to easily change nozzle types across a boom, or operate multiple nozzles in differing directions to increase coverage. Ask whether spray equipment has been recently calibrated and whether poorly performing nozzles have been replaced. Ruth Redfern, CRDC

Aerial application

Aircraft are extensively used to apply pesticides in cotton. Fixed wing aircraft and helicopters are able to cover large areas quickly and in conditions that may not suit ground application (e.g. dense canopies or wet ground).

Large specialist RPA (remote piloted aircraft, often referred to as drones) are also capable of aerial application of pesticides, although the tank size is limited by the capacity of the unit. Aircraft, including RPA, used for commercial operations must be registered with CASA. The business and the pilot must be appropriately licenced to apply pesticides from the aircraft.

Aerial operators are professional spray applicators that understand the parameters required for getting the best out of a spray job. Discuss your requirements in advance with the operator, including the target, timeliness, coverage required, and sensitive crops nearby to assist them in ensuring optimal set up for the aircraft. The best results are achieved when growers and agronomists work closely with their aerial operator in planning, executing and following up on their spray applications.

Some key points that should be discussed are:

- **Target –** e.g. the pest's location within crop canopy or field, or if there are time constraints related to the pest's development.
- **Water rates –** lower water rates increase efficiency but may impact efficacy. It is critical that the correct coverage is achieved (as specified on the product label). Adhere to minimum water rates and increase if needed (e.g. to match weather parameters or to provide sufficient volume to carry all of the products in the tank).
- **Droplet size –** some product labels specify a certain number of droplets per square cm on the target. Aerial operators are well positioned to select the correct droplet size to achieve this. Small droplets may increase the risk of off-target movement.
- **Swath width –** A spray plane's swath width is wider than the wingspan, due to the vortex effect created by the wings as they move through the air. Each aircraft has recommended swath widths that they can use in various conditions. Many aerial operators do regular pattern testing as well to optimise the swath width that they use for each aircraft.

Review this data with your aerial operator to ensure that all parties are satisfied with the spray parameters being used.

It is highly recommended that growers select an aerial applicator with Aerial Application Association of Australia (AAAA) membership, Spraysafe or AIMS accreditations to ensure that they are getting the most professional service. The AAAA has also produced some comprehensive documents about aerial spraying to assist with working more effectively with your aerial operator. Visit the AAAA website aaaa.org.au

Reducing drift

Spray application needs to maximise efficacy against the target pest, while minimising any off-target movement or effect. Movement of spray beyond the target area is undesirable as it represents wastage of product and exposure of sensitive non-target areas to potentially damaging materials.

The risk of spray drift can be influenced by weather conditions, spray rig set-up and operational parameters, and even the types of adjuvants used.

For more information on best practice for aerial and ground spray application go to www.mybmp.com.au Jack Hawkins, Cotton Australia

Neutral conditions favour drifting plume deposition to the near surface but some percentage will also be transferred to the wider atmosphere.
Strongly unstable conditions promote vertical dispersion and widespread dispersion of plumes into the atmosphere.
Strongly stable conditions (hazardous inversions) cause high concentration of drifting plumes near the surface in contained layers.

Three common states of atmospheric stability and their relationship to spray application and drifting sprays.
Source: GRDC: Weather essentials for pesticide application

Consider temperature and humidity

For some products, efficacy can be affected when plants are stressed due to high temperatures.

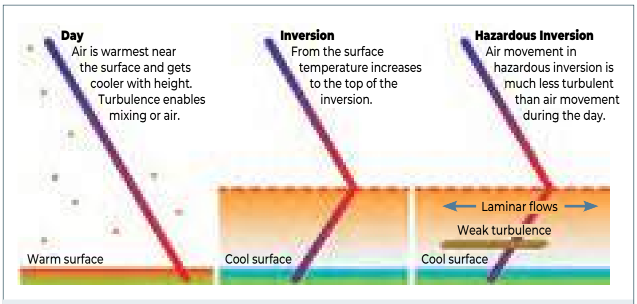
High ambient air temperatures and lower relative humidity conditions can also increase evaporation rates.

Evaporation rate and droplet survival is measured by Delta T. An operator needs to decide whether to stop spraying or to continue using a larger droplet size and higher water rate when Delta T exceeds 8.

See GRDC's factsheet on weather monitoring equipment grdc.com.au/GRDC-FS-SprayEquipment

Avoid hazardous surface temperature inversions

DO NOT apply if there are hazardous surface temperature inversion conditions present at the application site during the time of application. When application occurs in an area not covered by recognised inversion monitoring weather stations, all surface temperature inversion conditions are regarded as hazardous. Surface temperature inversion conditions exist most evenings one to two hours before



Typical vertical temperature profiles for normal, inversion and hazardous inversion conditions. Blue represents cooler air, red represents warmer air and yellow dots represent spray droplets.
Spray applied during a hazardous inversion can become trapped in the cool air layer where there is insufficient turbulence to either deposit or disperse the suspended spray droplets. This lack of turbulence results in the transport of drift over long distances in localised laminar air flows. Not all inversions are hazardous, but they must be considered as such unless recognised instrumentation (e.g WAND) exists to identify them.

Air temperatures during hazardous inversions.
Source: GRDC: Weather essentials for pesticide application

GRDC and CRDC in partnership with Goanna Ag have developed a spray drift hazardous weather warning system that provides real-time weather data and alerts to growers and spray operators about the presence of hazardous temperature inversions. Sign up at goannaag.com.au/wand-network

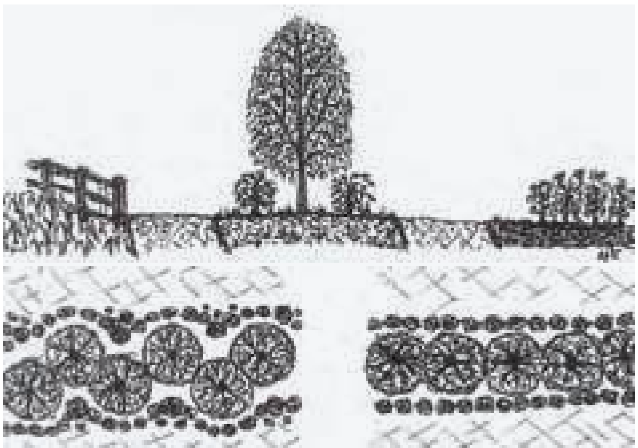
Bayer's XtendFlex® cotton Spray App helps spray planning by providing weather forecasts including inversion risk probability.
crop.bayer.com.au/tools/weather-inversion

For more information refer to chapter 17 of the *Australian Cotton Production Manual* or GRDC's *Weather essentials for pesticide application*
grdc.com.au/resources-and-publications/all-publications/publications/2022/weather-essentials-for-pesticide-application

Optimise spray rig setup and operation

Nozzle types, operating pressures, boom height, delivery speed and the characteristics of the product or products used (particularly adjuvants) will all influence the risk of droplets moving away from the target area. Always check the product label(s) for operation requirements/restrictions, regularly calibrate your equipment and avoid excessive travel speed during application. The GRDC Spray Application GrowNotes Manual includes information on sprayer set-up.
grdc.com.au/resources-and-publications/grownotes/technical-manuals/spray-application-manual

Understorey foliage needs to be thinned a little to increase the porosity of this vegetative barrier to 50%. Stacey Vogel



Side and overhead view showing suggested structure and planting configurations of trees and shrubs for a permanent vegetative barrier. Bill Gordon

Use vegetative plantings as spray drift barriers

Do not use remnant native vegetation or environmental corridors as a vegetative barrier. Identify habitat vegetation as 'sensitive' and protect it from spray drift, along with riparian areas and waterways. Effective planted vegetative barriers (a mixture of tree and shrub species with foliage all the way to the ground) can reduce drift by up to 90%. The optimum barrier is 20 m wide with a 10 m maintenance strip on either side. Don't plant barriers where adjacent objects such as turkey's nests, water storages or large banks will obstruct airflow.

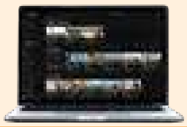
The planting arrangement and density should allow air to partly flow through – dense barriers will act like a wall, directing wind containing the spray drift up and over the top and increasing how far drift may travel. Aim for a porosity of around 50% (you can see 50% light and 50% dark when you look through the vegetation) and a height of at least 1.5 times the release height of the spray. As vegetation density increases, the height of the barrier needs to be increased.

The most effective traps for airborne droplets are trees and shrubs with long thin or needle-like leaves or hairy leaf surfaces. Choose hardy and drought tolerant species with thick cuticles to help them survive small doses of pesticide. For more information, see the CottonInfo fact sheet on vegetative barriers:

cottoninfo.com.au/publications/nrmpesticide-input-efficiency-using-vegetative-barriers-minimise-spray-drift-cotton

A number of spray-related apps are also available for weather forecasting, nozzle selection, calibration and/or tank mixing.

USEFUL RESOURCES:



CottonInfo's Pesticides and application video playlist
youtube.com/cottoninfoaust

Chapter 17 in the *Australian Cotton Production Manual*
cottoninfo.com.au/publications/2024-australian-cotton-production-manual

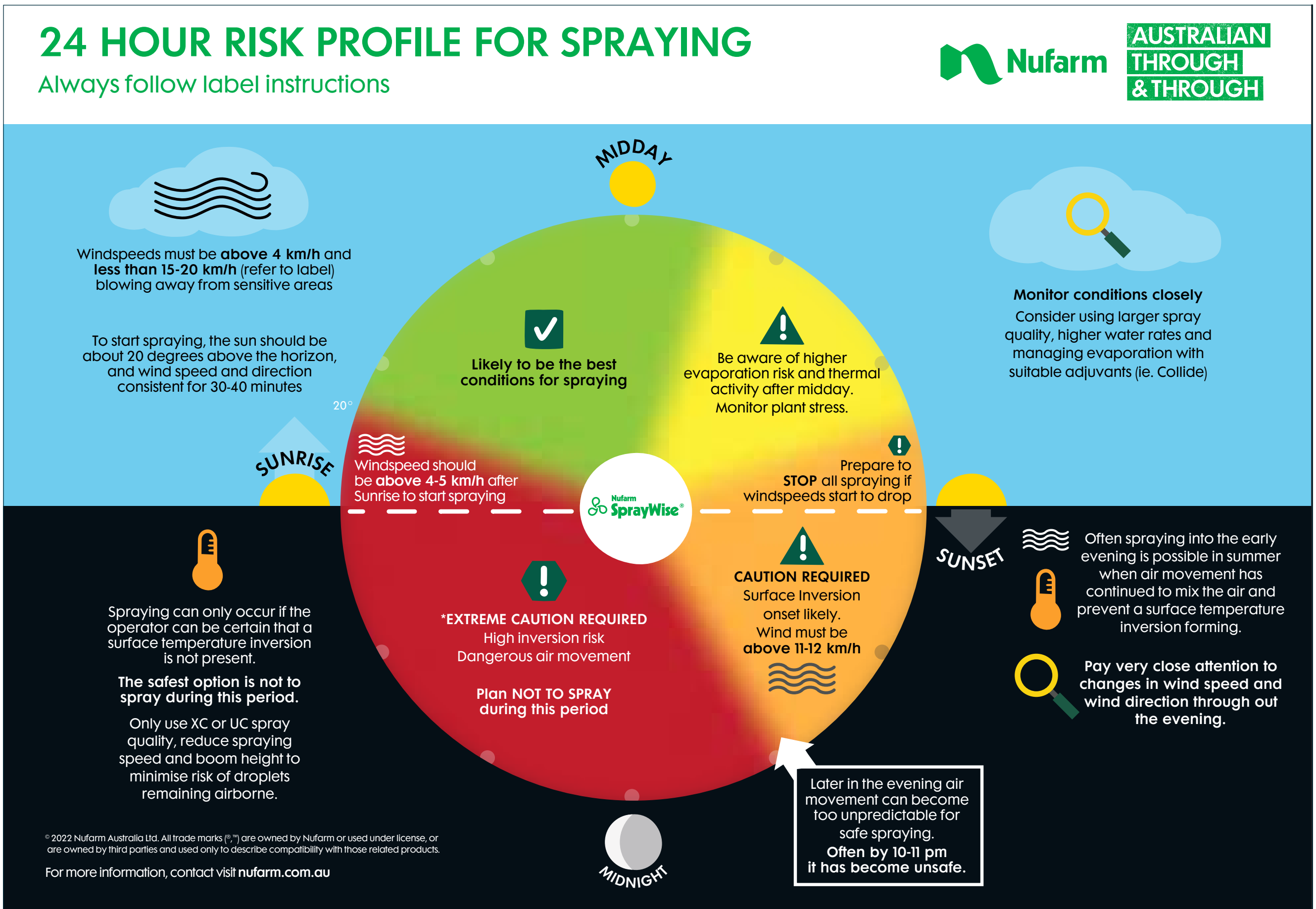
CottonInfo's Pesticide input efficiency page
cotttoninfo.com.au/pesticide-input-efficiency

***my*BMP's Pesticide application module**
mybmp.com.au

GRDC's spray drift hub
grdc.com.au/resources-and-publications/resources/spray-drift

GRDC's practical tips to reduce spray drift
grdc.com.au/GRDC-FS-SprayPracticalTips

Mary O'Brien Rural Spray Drift resources
maryobrienrural.com.au/resources



Guidelines for temperature inversion risk (if access to a wand tower is unavailable). Source: Nufarm Australia

Pesticides and regulation

APVMA product registration

The federal, state and territory governments work together to regulate agricultural and veterinary (agvet) chemicals in Australia. The Australian Pesticides and Veterinary Medicines Authority (APVMA) evaluates the safety and performance of agvet chemicals intended for sale in Australia to protect the health and safety of people, animals, crops, trade and the environment.

Before agvet chemical products can be legally sold, supplied, marketed or bought in Australia, they must be registered by the APVMA. The assessment uses broad risk analysis, including how human and environmental exposure can be minimised through instructions for use and safety directions on the label of registered products. Risks to market access are also evaluated, as one of the criteria for registration is that use of agvet chemicals will not unduly prejudice Australia's international trade. The APVMA approves product labels that explain how the product is to be used, stored, disposed of and managed in the event of poisoning.

Agvet chemical product labels are legally binding. State and territory governments are responsible for monitoring post-sale compliance with label instructions and limitations.

The APVMA website

Visit APVMA's website apvma.gov.au for information on product registrations and permits, active ingredients, residue issues, regulatory operations and to access a wide range of resources about using chemicals.

Check the site regularly as registrations can be amended or revoked at any time. Formal reviews are undertaken to scientifically reassess the risks and determine whether changes are needed to ensure a chemical can continue to be used safely and effectively. This may include modifying the way chemicals are used or if risks cannot be managed, cancelling registrations or label approvals. A list of products currently under review is available at apvma.gov.au/chemicals-and-products/chemical-review/listing

Using the PubCRIS database

The APVMA website hosts the searchable Public Chemicals Registration Information System (PubCRIS) database of agricultural and veterinary chemical products registered in Australia.

The PubCRIS database portal.apvma.gov.au/pubcris can be searched by:

- Product name or registration number;
- Active constituent or other ingredients;
- Permit holder;
- Host; or,
- Pest.

There are also advanced search and filter options, such as product type, the territory/state(s) in which the product is registered and the formulation type.

Simply select the type of search term(s) and enter into the search box. A drop-down list will provide suggestions as you type.

Search results display by product number (with the most recent at the top) and provide links to a summary of registration details or a PDF copy of the label. Search results can also be exported as a CSV file.

Bear in mind that labels usually cover multiple uses and the search engine will provide matches that can occur anywhere on the label. For example, even if a label contains both 'cotton' and the pest name, it could mean that the registation for that pest is in a crop other than cotton.

When going though the search results, always read the product label carefully to confirm that:

1. The product is registered for your intended use in your state or territory.
2. You can meet all other label requirements/restrictions, including no-spray zones, droplet size, adjuvants, withholding periods etc.

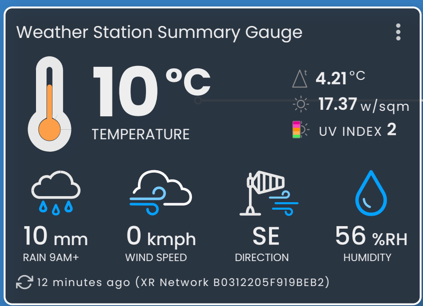
Searching for permits

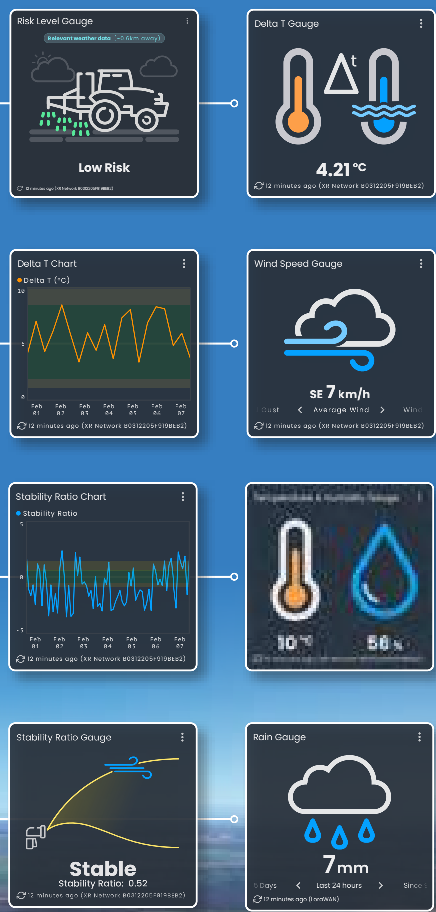
An additional database of products under permit (approved for minor use or temporary emergency use) can be searched at portal.apvma.gov.au/permits (or select the 'Permit search' tab in the menu line of PubCRIS).

Permit searches are similar to registration searches. Terms include permit number (include 'PER' in front of the number) purpose, active, host or pest. Filter options include jurisdiction and permit status (e.g. current versus expired or suspended).

Spray advice using localised data, tailored to your exact situation

Access weather data and and spray advisory information from across your farming operation in one simple-to-use app





Insights include:

- Local Condition Alerts
- Local Spray Risk Indicator
- 7 Day Spray Risk Forecast
- Temperature, Delta T, Wind Speed and Direction
- Local Microclimate Monitoring
- Simplified Opt-in Recordkeeping for Spray Sessions

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Legal responsibilities

All agricultural chemical applications MUST accord with the approved label instructions or permit conditions for that particular registered agricultural chemical, crop, pest and region.

Each state and territory administer their own control-of-use legislation, to enforce the safe and responsible use of agricultural chemicals. Jurisdictions may differ in the various requirements for agricultural chemical use, licensing, training and record-keeping. It is therefore important for all chemical users to gain an understanding of their obligations, as set out in legislation applicable to their state or territory.

Label instructions

All control-of-use legislation focuses on using only registered agricultural chemicals and complying with label instructions. The risks associated with chemical use have been assessed by the APVMA at registration and such risks are primarily managed through controls which appear on labels. For this reason, it is critical that the directions for use, constraints and all other label instructions are read and understood before each use. Keep in mind that labels can be revised and amended, so review EVERY time.

Note that the term 'label' refers to all of the product information attached to the pesticide container, which may include a fold-out leaflet or booklet if space is insufficient.

For more information, visit:

apvma.gov.au/node/935#Label_layoutremains

There are some limited exceptions to the requisite adherence to all label instructions, most notably when an APVMA permit approves a minor, emergency or research use of an agricultural chemical (which may deviate from the use pattern described on the label). Chemical uses supported by permits are also assessed by the APVMA prior to approval. Following all permit instructions and conditions is therefore essential, from both a risk management and a compliance perspective.

The risks managed by regulatory controls on chemical labels and permits include those to human health (occupational exposure on-farm as well as to consumers further down the commodity supply chain), trade and the environment. Such mitigation aligns with best practice chemical application. For example, achieving an appropriate spray quality and maintaining an awareness of the suitability of weather conditions throughout spraying operations (as required by spray drift restraints on certain labels) will manage spray drift risk to non-target crops and the environment. Such practices will also maximise deposition on the target, the cost-efficiency of application and crop protection efficacy.

Chemical use risk management provides a degree of protection to the cotton industry. Management of residue risk contributes to the maintenance of international market access. The minimisation of environmental impacts is important, not only to facilitate biodiversity and ecosystem health in local catchments, but also to support the cotton industry's broader efforts to reduce their environmental footprint. A secondary benefit of regulatory risk management is demonstration of one aspect of social license to farm, increasingly demanded by supply chain stakeholders.

Licensing, training and record-keeping

Pilots and businesses that aerially apply pesticides should be licenced. The commercial application of pesticides through ground application equipment will also often require licensing of both the spray applicator and the business. Check with the agricultural chemical licensing agency in your state or territory for more information about licensing requirements for pesticide application.

Licensing exemptions typically exist for growers applying agricultural chemicals with ground equipment on their own land. In most instances, this means that cotton growers do not need to hold a licence for agricultural chemical application, unless operating under fee-for-service arrangements as a contractor. However, some states require specific training and accreditation for operators. All operators are strongly encouraged to complete chemical application training to improve their skills and knowledge in application technology and the handling, storage and transportation of chemicals.

Most people who use pesticides while working in an agricultural business are required to be trained. The most appropriate vocational education and training competency units for cotton growers to meet this training obligation will generally be AHCCHM304 (Transport and store chemicals) and AHCCHM307 (Prepare and apply chemicals to control pest, weeds and diseases). There may be additional qualification requirements for using Schedule 7 poisons or restricted chemical products.

Best practice is to know the training requirements in your state or territory and ensure that all people handling and applying pesticides are trained and maintain their competency.

Record-keeping obligations may include when a record should be made and a period of time for which records should be kept. The particulars required in each jurisdiction will vary slightly but are largely aligned with best practice spray record-keeping, i.e. that which is relevant in meeting cotton production objectives, as well as managing risk and providing evidence that label conditions have been met. Some of the parameters that need to be recorded include the time, date, location and crop as well as those which identify the agricultural chemical used, the rate of application, equipment and settings, and contact details of the applicator and the contractor business (if relevant).Meteorological conditions, such as wind speed and direction, should be monitored and documented throughout spraying operations, noting that the labels of certain agricultural chemicals also stipulate record-keeping particulars under their spray drift restraints.

An example record keeping sheet (developed by NSW DPI) is provided in this chapter, and is available from

dpi.nsw.gov.au/agriculture/chemicals/farm-chemical-management/records.

Some commercial farm management software and apps include the ability to record spray details.

Further information on relevant State regulations and training requirements:

NSW: dpi.nsw.gov.au/agriculture/chemicals **and** epa.nsw.gov.au/your-environment/pesticides

Qld: business.qld.gov.au/industries/farms-fishing-forestry/agriculture/land-management/chemical-controls

WA: ww2.health.wa.gov.au/Articles/N_R/Pest-industry-licensing-and-registration

NT: nt.gov.au/industry/agriculture/farm-management/using-chemicals-responsibly

VIC: agriculture.vic.gov.au/farm-management/chemicals

Pesticide Application Record Sheet

NSW GOVERNMENT Industry & Investment

Location, Applicator, Date of Application

Property/Holding: (residential address)					Date:
Applicator's Full Name:			Owner (if not applicator):		
Address:			Address:		
		Phone:			Phone:
Mobile:	Fax:	Email:	Mobile:	Fax:	Email:
Sensitive Areas (including distances, buffers): N / W Treated Area E / S			Comments (including risk control measures for sensitive areas):		

Host/Pest

Paddock Number/Name:	Paddock Area:	Order of Paddocks Sprayed:
Crop/Situation:	Type of Animals:	
Crop/Pasture Variety:	Age/Growth Stage:	
Growth Stage:	Mob/Paddock/Shed:	
Pest/Disease/Weed:	Animals — Number Treated:	
	Pest Density/Incidence: Heavy ❑ Medium ❑ Light ❑	

Application Data

Full Label Product Name:			Rate/Dose:		Water Rate L/ha:
Permit No.:	Expiry Date:		Additives/Wetters:		
Total L or kg:	WHP:	ESI*:	Date Suitable for Sale:		
Equipment Type:		Nozzle Type:		Nozzle Angle:	Pressure:
Date Last Calibrated:	Water Quality (pH or description):				

Weather

Showers ❑ Overcast ❑ Light Cloud ❑ Clear Sky ❑

Rainfall (24 hours before and after)
Before: mm During: mm After: mm

Time (show time in this column)	Temperature °C	Relative Humidity (%)	Wind Speed	Direction	Variability (e.g. gusting)
Start					
Finish					

Comments:

* When using herbicides in mixtures with fungicides and insecticides, an ESI may apply to the non-herbicide component of the mixture.

Using pesticides safely

Post-spray periods

Pesticide and other agrochemical labels will usually specify a minimum amount of time after application before:

- The treated field can be safely re-entered by unprotected persons (re-entry period); and,
- The crop can be harvested, or grazed/cut for domestic stock fodder (withholding period).

Always check the spray history and relevant post-spray periods before entering a field or crop and consider any actions required, such as PPE, to protect your health before entering a treated field.

Consider post-spray periods as part of your spray planning and check the label requirements for each product in a tank mix before use. Note they are subject to change and may be different according to concentration or formulation, even if the products have the same active ingredient.

Non-compliance with current label restrictions may result in prosecution under relevant state or territory legislation.

Re-entry period

Re-entry periods and any specific personal protective equipment (PPE) to be worn as advised on the label help manage the risk associated with dermal (skin) contact with spray deposits. Include re-entry periods (see Table 36) when developing workplace health and safety procedures and protocols. More information on WH&S is available in the *Australian Cotton Production Manual*.

All workers must be advised of the appropriate time to wait before re-entering a sprayed field. Also exercise caution when entering previously sprayed crops if foliage is wet from dew or light rain, irrespective of the time between application and re-entry.

While many herbicides do not specify re-entry periods, some herbicide actives are toxic, so care should still be taken to read label safety requirements and avoid contact with wet spray deposits.

For older products that don't specify a re-entry period, avoid re-entering the field for at least 24 hours after treatment, particularly for products with a signal heading of 'Caution', 'Poison' or 'Dangerous Poison'. Newer products will usually state a re-entry period; either 'Do not allow entry into treated areas until the spray has dried' or nominate a specific number of hours – often 0, 12, or 24. If no re-entry period is listed, it is still advisable to wait until the spray has dried before entering the field. If the field needs to be entered before the spray is dry, limit the duration of entry and wear the PPE specified on the label.

If the field needs to be entered prior to the stated re-entry period or before the spray is dry, limit the duration of entry and wear the PPE specified on the label. Even after the re-entry period has been observed, some protective clothing may be advisable. If not specified, appropriate PPE should be determined using a risk assessment.

Withholding period

A withholding period (WHP) is the minimum period from when a pesticide is applied to when the treated area is allowed to be grazed, cut for fodder or harvested (see Table 36). The WHP aims to prevent the presence of inappropriate levels of chemical residues in the harvested crop or in stock that graze the stubble or are fed by-products of the treated crop.

The APVMA sets maximum residue limits (MRLs) for agricultural and veterinary chemicals in agricultural produce, particularly produce entering the Australian food chain (such as cotton seed). MRLs are unlikely to be exceeded as long as pesticides are used in accordance with approved label instructions. Residue limits for exported products are set by the importing country.

Label WHPs assume label compliance and effective application techniques, including even coverage with well-maintained equipment. Excessive residues may still occur due to a range of factors, including mixing issues, inappropriate application volumes, worn nozzles, or an overlap in sprayed areas.

Crop residues MUST NOT be fed to stock if any product that specifically prohibits grazing or cutting for stock feed has been applied to that crop. Crops treated with a product that has a no grazing WHP specified should also not be grazed either before or after harvest. Contact the relevant chemical manufacturer for advice on managing chemical residues in stock.

A permit (PER91054; for use in NSW and Qld only) allows the feeding of cotton gin trash to livestock from crops that have been treated with particular agrichemicals during production. Valid until 30 September 2024, and currently under assessment by the APVMA to extend this validity date, it is conditional on a clean-feeding interval of 60 days prior to slaughter. All product uses must be in accordance with product labels, except where the permit states otherwise. See the permit for a list of included products.

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS.

Handling & storage

A critical part of responsible use of pesticides is their safe storage, transport and handling, as well as appropriate disposal of product that is no longer wanted or able to be used. Storing, handling and applying pesticides correctly greatly reduces any potential negative impacts to you, your staff, your business, your neighbours and the environment.

Many registered pesticides are classified as hazardous chemicals, or pose some degree of health risk to those who use them or are exposed to them. Workplace health and safety regulations exist to protect workers from both short and long term health effects of exposure to hazardous chemicals. *my*BMP provides guidance and resources to meet legal requirements for handling, storage and application of agrochemicals. It also includes templates to help document farm-specific procedures to minimise harm and respond in the event of an injury, fire, or spill. These procedures must be communicated to all staff.

Ensure anyone handling or applying pesticides has the appropriate training/accreditations, and maintain an up-to-date collection of easily accessible copies of Safety Data Sheets (SDS) for all products used.

This storage guide can be downloaded from ChemCert www.chemcert.com.au/resources

Safe disposal

Disposing of empty containers

Empty chemical containers present a risk to people and the environment. Clean empty containers according to the steps below and store securely until they can be recycled. Collect rinsate from cleaning the containers and pour back into the spray tank.

- Triple rinse or pressure rinse your containers immediately after use (residues are more difficult to remove when dry).
- Thoroughly clean the container thread and outside surfaces with a hose and rinse all caps separately in a bucket of clean water.
- Inspect the container, particularly the thread and screw neck, to ensure all chemical residues have been removed.
- Use a steel rod or crowbar to puncture metal containers. Pass it through the neck/pouring opening and out the base of the container.
- Allow the containers to drain completely and air dry.
- Store capless cleaned containers in a sheltered place to keep them clean and dry until they can be returned to the supplier or delivered to a *drumMUSTER* collection centre.

Take empty containers marked 'returnable' back to the supplier. Many 'non-returnable' metal and plastic containers used for farm chemicals can be recycled via Agsafe's national drumMUSTER program (look for the logo on the container). Containers presented at a drumMUSTER receival site will be inspected to ensure that there is no visible product residue (including powder, flake, coloured/dark or clear fluid) on the inside or outside of the container. Some stains (including dirt, dust or mould) are acceptable.

drumMUSTER

Intermediate Bulk Containers (IBCs) are not recycled by the ***drumMUSTER*** program, however a quick and easy Agsafe guide is available on how to send IBCs back for recycling or reuse.

drummuster.org.au/container-recycling/the-abcs-for-your-ibcs

Disposing of unwanted chemicals

Unwanted rural chemicals may result from discontinued use due to changes in cropping or animal practices, development of newer/more effective/safer chemicals, or changes in a chemical's registration and/or banning from use. They may also be due to unknown product, property sale; inherited product or deceased estate. Any unwanted or unknown chemicals held on farm are potentially hazardous and must be disposed of responsibly and lawfully.

ChemClear

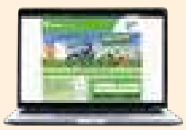
ChemClear is an industry stewardship program that collects currently registered agricultural and veterinary chemicals at the end of their life cycle, or when they become surplus. The program aims to meet disposal requirements of agvet chemical users and prevent potential hazardous chemicals from being dumped in landfills, creeks or otherwise inappropriately disposed of.

1. Take an inventory of any unwanted rural chemicals, including all identifiable container features (e.g. label, manufacturer, expiry date, container size and the remaining quantity left in the container). An inventory form can be obtained from the ChemClear website.
2. Register the inventory for the next collection in your area. Book on freecall 1800 008 182; fax 03 9371 8501 or at chemclear.org.au
3. Continue to store your registered chemicals safely and securely. ChemClear will contact you direct to advise the location for retrieval.
4. Deliver chemicals ensuring that transportation is safe (never place chemicals in the boot of a car or back of a station wagon). Refer to the ChemClear website for more information.

Group 1 chemicals (currently registered, within 2 years of expiry/deregistration, or containers displaying the *drumMUSTER* logo) are collected free of charge under the program. Group 2 chemicals (no longer registered, do not display the *drumMUSTER* logo, unknown, unlabelled, out of date, or mixed product) attract a fee for disposal, although the ChemClear program covers the transport costs. This fee is payable directly to the contractor after a quote has been accepted by the holder of the chemicals. Individual state EPA funding may be available from time to time to subsidise disposal of Group 2 chemicals.

USEFUL RESOURCES:

Agsafe Limited
(02) 6206 6888
agsafe.org.au



drumMUSTER program
1800 008 707
drummuster.org.au

ChemClear program
1800 008 182
chemclear.org.au

TABLE 36: Re-entry and withholding periods of commonly used pesticides (excluding herbicides and seed treatments). Note: This information is provided as a guide only. Post-spray periods may not be the same for all products with that active, and registrations may vary by State. ALWAYS CHECK THE LABEL.

	Active	MoA group	Re-entry	Withholding (days)*	
				Harvest	Stock
Insecticides and miticides	Abamectin	6	dry	20	20
	Acetamiprid	4A	dry	10	NG
	Afidopyropen	9D	dry	7	—
	Alpha-cypermethrin	3A	24 hrs	14	—
	Amorphous silica	—	dry	0	0
	Bacillus thuringiensis	11A	N/A	0	0
	Bifenthrin	3A	dry	14	NG
	Beta-cypermethrin	3A	—	14	—
	Buprofezin	16	dry	14	NG
	Chlorantraniliprole	28	N/A	28	NG
	Chlorpyrifos	1B	dry	28	28
	Chlorpyrifos/ bifenthrin	1B/3A	dry	28	NG
	Clitoria ternatea extract	UNE	dry	0	—
	Clothianidin	4A	—	5	NG
	Cyantraniliprole	28	dry	14	NG
	Cypermethrin	3A	12 hrs	14	—
	Deltamethrin	3A	dry	7	NG
	Diafenthiuron	12A	24 hrs	14	NG
	Dimethoate	1B	dry	14	NG
	Dimpropyridaz	36	—	28	NG
	Dinotefuran	4A	dry	14	NG
	Emamectin benzoate	6	12 hrs	28	NG
	Esfenvalerate	3A	dry	7	—
	Etoxazole	10B	dry	21	NG
	Fipronil	2B	dry	28	NG
	Flonicamid	29	dry	7	NG
	Gamma-cyhalothrin	3A	dry	21	—
	Helicoverpa NPV	—	dry	0	0
	Imidacloprid	4A	12 hrs	91	NG
	Indoxacarb	22A	dry	28	NG
	Lambda-cyhalothrin	3A	dry	21	—
	Magnet®	—	24 hrs	See insecticide mix	
	Methomyl	1A	24 hrs	0	NG
	Paraffinic oil	UNM	—	1	—
	Pirimicarb	1A	dry	21	21
	Phorate	1B	48 hrs	70	70
	Propargite	12C	dry	28	NG
	Pymetrozine	9B	dry	28	NG
	Pyriproxyfen	7C	24 hrs	28	NG
	Spinetoram	5	dry	28	NG
	Spirotetramat	23	dry	21	NG
	Sulfoxaflor	4C	dry	14	NG
	Thiamethoxam	4A	dry	28	NG
	Thiodicarb	1A	24 hrs	21	21

	Active	MoA group	Re-entry	Withholding (days)*	
				Harvest	Stock
Fungicides	*Clitoria ternatea* extract	—	dry	0	—
	Metentrifluconazole (PERMIT)	3	—	30	NG
	Prothiconazole/ Azoxystrobin (PERMIT)	3/11	dry	35	NG
	Quintozene	14	dry	N/A	NG
	Tebuconazole (PERMIT)	3	dry	42	NG
	Tolclofos-methyl	14	dry	N/A	N/A
Other (including aids & adjuvants)	Carfentrazone-ethyl	desiccant (14)	dry	1	NG
	Diquat	desiccant (22)	dry	N/A	1 day
	Ethephon	conditioner	4 hrs	14	NG
	Mepiquat	PGR	dry	28	NG
	Paraffinic oil & other non-ionic surfactants	adjuvant	—	1	—
	Paraquat + diquat	desiccant (22)	dry	7	1-7
	Petroleum oil	adjuvant	—	1	—
	Pyraflufen-ethyl	defoliant (14)	dry	7	7
	Sodium chlorate	desiccant	dry	0	NG
	Thidiazuron	defoliant	dry	N/A	NG
	Thidiazuron/ Diuron	defoliant (-/5)	—	N/A	NG
	Thidiazuron/ Pyraflufen-ethyl	defoliant + boll opener (-/14)	dry	7	NG

dry = do not re-enter field until spray has dried.
NG = no grazing and/or feeding trash to livestock.
— = not specified or unknown.
N/A = not required when used as directed.
*Refer to label for export market requirements and slaughter intervals.

Cotton growth regulators and harvest aids

The application of growth regulators and harvest aids to the crop utilises the same spray equipment as pesticides, and follows the same principles of product registration, safety and application efficiency (including minimising drift risk).

Plant growth regulators (PGRs)

Excessive vegetative growth can result in poor within-canopy light interception, reducing fruit retention, increasing the risk of boll rots, and delaying crop maturity. Large dense canopies also pose a challenge for pest sampling and insecticide penetration efficacy. Mepiquat chloride (also known as pix) is used to moderate canopy expansion by reducing gibberellin (a natural growth regulator within the plant). While it will not alter already expanded/matured growth, it remains active in the plant for up to 2 weeks after application, impacting the actively growing cells of the plant (i.e. the elongating stems, leaves and roots).

When making the decision to regulate crop growth, it is critical to consider the presence (or imminent likelihood) of other factors or stresses that may influence canopy expansion (e.g. temperature, humidity, soil moisture or nitrogen status) and adjust the timing and rate of applications accordingly. Cotton is sensitive to environmental changes and stressed plants will respond differently to mepiquat chloride than crops growing under optimum conditions.

Note: Some defoliant products containing ethephon are labelled as a 'Growth Regulator'. Ethephon is used for preparing the crop for harvest and will cause significant fruit loss if applied to immature crops.

For more information refer the *Managing crop growth* chapter of the *Australian Cotton Production Manual*
cottoninfo.com.au/publications/2024-australian-cotton-production-manual.

For cotton production in the tropics, NORpak Burdekin see cottoninfo.com.au/publications/norpak **for detailed mepiquat chloride usage guidelines for wet season production.**

Harvest aids

Harvest aids can be categorised by mode of action within the plant:

- **Defoliants** (e.g. thidiazuron) impact plant hormonal balances to enhance natural plant senescence and cause the leaves to fall off. Activity is HIGHLY temperature dependent.
- **Desiccants** (e.g. sodium chlorate, paraquat) dehydrate and kill the leaves within one to several days. They are often used to remove stubborn leaves after defoliation or kill juvenile re-growth.
- **Boll openers/conditioners** (e.g. ethephon) are often applied in tandem with defoliants to enhance boll opening through increased ethylene release and within-plant synthesis that promotes abscission and leads to a quicker separation of boll walls (carpels).

Both the crop senescence process and the plant's response to applied harvest aids are heavily influenced by plant and environmental factors. Cotton leaves naturally senesce (detach and fall off) when they get old, but a cotton plant would not normally lose all its leaves at once. The application of defoliants to induce senescence is therefore a key component of harvest management. Artificially-induced defoliation ideally enables leaf separation while the leaf remains green, with the fresh 'weight' of the leaf helping it reach the ground and reducing the potential for leaf trash in harvested modules. Rapid leaf trauma from desiccation by herbicide or frost usually kills the leaf blade before the leaf drops, and can result in dead leaves remaining in the canopy.

Desiccants dry all plant parts (including stems), potentially increasing the trash content of harvested lint. Avoid them unless conditions do not enable the effective use of defoliants (e.g. very cold weather). Desiccants are also a reliable method to reduce leaf regrowth. High rates of some defoliants can act as desiccants.

Boll opening is a largely mechanical process of dehydration of the boll wall, causing the boll to split open and unfurl. Leaf removal exposes bolls to more direct sunlight; the increased temperatures promote maturation, and drying and cracking of the boll walls. Only consider using boll conditioning/opener products if the bolls that will be forced open are mature; if applied prior to boll maturation they may cause bolls to shed and reduce yield. The safe timing for defoliation is when the youngest boll expected to reach harvest is physiologically mature. This usually occurs when 60-65% of bolls are open.

Wetting agents and spray adjuvants (e.g. paraffinic oil, non-ionic surfactants or petroleum oil) are used to assist with defoliation as cool temperatures, low humidity and water stress prior to defoliant application can result in increased wax and thickness of the leaf cuticle, reducing the efficiency of chemical uptake.

Improving defoliation product performance

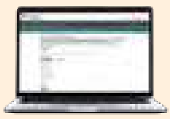
In addition to timing, it is important to consider product, rate and application. If rates are too high, plant cells may die before releasing enough ethylene to cause defoliation, resulting instead in leaf desiccation. Temperature is critical (warmer conditions improve crop response), so defoliate before the onset of frost. Apply defoliants during the day when conditions are warmer to assist uptake. Avoid application if there is a risk of rainfall shortly afterwards.

Plants that are naturally beginning to senesce as the bolls mature will be much more responsive to applied defoliants than plants that are either not in decline or showing signs of continued growth. Encourage senescence by having soil moisture at refill just prior to defoliation and avoid excessive nitrogen application. Crops that are 'navy' green at maturity (as opposed to those showing signs of leaf aging and senescence) are more difficult to defoliate. For more information, refer the *Preparing for harvest* chapter of the *Australian Cotton Production Manual*.

Satisfy yourself that the chemical you choose is the best one for the crop and situation. Before use, note any specific label instructions relating to rates, timing, application and safety. Take every precaution to minimise the risk of causing or suffering spray drift damage.

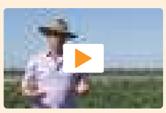
USEFUL RESOURCES:

CottonInfo booklet on defoliation
cottoninfo.com.au/publications/defoliation-optimising-your-end-season-management



Search APVMA's PubCRIS database for current registrations and permits
portal.apvma.gov.au/pubcris

What is pix?
youtu.be/cIFpyymWW6Q



Using harvest aids in cotton
youtu.be/8st4yggcCNY

Pesticides and the environment

The cotton industry's guidelines for minimising risk to the environment are a component of the *my*BMP program.

Pesticides, carriers, surfactants, and pesticide metabolites can be inherently hazardous for aquatic organisms, insects including bees, birds, and other fauna. The risk that a particular product poses to the environment (native terrestrial and aquatic plants and animals) is reflected in statements on the label under headings like 'Protecting wildlife, fish, crustaceans and the environment'.

Pesticide residues may accumulate in animals treated with pesticides or fed any crop product, including crop residues, which have been sprayed with pesticides. Animals that test positive for chemical residues (i.e. with readings which exceed maximum residue limits) at slaughter will be rejected.

Pesticide residues may also contaminate other plant products for human use and consumption. Observe harvest withholding periods on the pesticide label and do not assume that in the absence of a withholding period or after the expiry of a withholding period that plant products will be free of residues.

Significant off-target environmental damage can be reported to APVMA's adverse experience reporting program at apvma.gov.au/node/86336 and to the pesticide control-of-use agency in your State or Territory.

Australian cotton industry sustainability framework

Use of pesticides will attract increasing scrutiny in coming years. Sustainability guidance that customers use are increasingly seeking to eliminate highly hazardous pesticides and discharge of pesticides to the surrounding air and water. The Australian cotton industry has a goal of pesticide use that supports optimal crop production while having no negative impact on human and environmental health. It publishes transparent, science-based data to show the total volumes and hazard of pesticides used each year by the industry. This data is critical in showing customers, governments and the community the industry is using pesticides in line with their expectations. This transparency also means it is critical for growers and agronomists to understand the risks the industry faces around pesticide use, to factor toxicity into decisions, and to continue to explore alternatives that reduce the need for synthetic pesticides.

Environmental toxic load (ETL) is the indicator currently used to assess the average amount of toxic pressure on the environment from pesticides applied on one hectare. To reduce your ETL, aim to reduce total volume of pesticides used, as well as selecting pesticides with lower toxicity. For more information see the links below:

Protecting the environment

The best way to manage any long term adverse environmental risk is to work with spray applicators to develop a spray plan that identifies environmentally sensitive areas, choose products and equipment that have the lowest risk profile without compromising effectiveness, follow the protection statements on labels, ensure that sprays hit the target and that drift is minimised, and to dispose of chemical containers and waste in accordance with label directions and codes of practice.

Aquatic fauna and flora

Aquatic fauna and flora are often highly sensitive to agrochemicals, as are many other species that utilise aquatic areas as part of their habitat. When spraying, always consider the risk of contaminating nearby standing water.

- Prevent drift onto surface waters during application.
- Locate mixing/loading and decontamination facilities well away and use bunding and sumps to prevent movement of either concentrate or rinsate into surface waters.
- Install valves that prevent back-flow in equipment used to fill spray tanks from surface waters and in suction lines for chemigation systems that draw directly from surface waters.
- Avoid aerial application of spray on fields during irrigation.
- Build sufficient on-farm storage capacity (including provision for storm runoff) to contain pesticide-contaminated tail water from irrigation.
- Spray in an upstream direction (when spraying near water is necessary), to reduce the maximum concentration at any one point in the watercourse.
- Use only registered products to control aquatic weeds, e.g. Roundup Bioactive® rather than Roundup®.
- Avoid disposal of used containers in surface waters and on flood plains and river catchments.

Birds

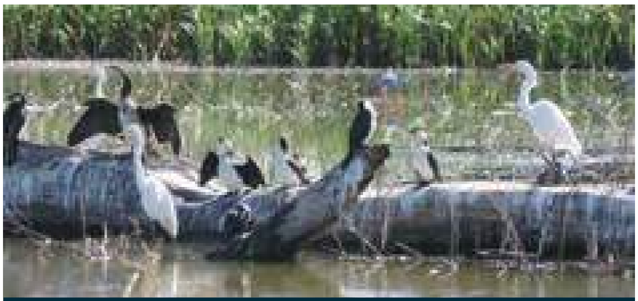
Broad-spectrum insecticides can be particularly toxic to birds, especially in granular formulations, and insecticidal seed dressings can pose similar risks. Spillages can be very hazardous as birds can easily ingest a toxic dose from a small area.

- Ensure complete incorporation beneath the soil, particularly at row ends where spillage may occur.
- Immediately clean up spillage, however small.

Bait materials for control of rodents (PER93458 until 30 April 2025 in cotton and other registrations relevant to rotation crops) or soil insect pests can also be hazardous to birds and other fauna, either through direct consumption of the bait or from feeding on bait-affected animals or pests.

- Ensure even bait distribution, with no locally high concentrations.
- Don't bait over bare ground or in more open situations, such as near crop perimeters, where birds may see the baits.
- Don't bait near bird habitat such as remnant native vegetation.

Whistling ducks. Anne Palfreyman


Protect aquatic environments from pesticides; many aquatic birds such as egrets contribute towards natural pest control. Stacey Vogel, CottonInfo

- Use bait stations to prevent bird access, particularly near bird habitat.
- Only bait where pest pressure is high.
- Bait late in the evening when birds have finished feeding.
- Promptly collect and bury rodent carcasses in open situations.

Foliar-applied insecticide sprays can also be hazardous to birds, either because of direct contact with the sprayed chemical, or by feeding on sprayed insect pests or crops.

Even where birds are not killed, they may be more vulnerable to predation. Contaminated seed and insects collected from sprayed fields by parent birds can also be lethal to chicks still in the nest.

- Communicate with spray operators where known sensitive areas exist (such as nesting sites during waterbird breeding events).
- Minimise drift into remnant vegetation, wildlife corridors, nesting sites, or other bird habitats.
- Actively discourage birds from feeding in crops that are to be sprayed.

Pesticides can also indirectly impact on bird populations through the loss of plants and animals on which they feed and through loss of habitat.

- Protect sensitive areas such as remnant vegetation, riparian areas and waterways from spray drift.
- Where possible use target-specific as opposed to broad-spectrum pesticides (that are more likely to impact on non-target organisms and plants in the environment) and adopt an Integrated Pest Management (IPM) approach to controlling pests.
- Spray late in the day when birds have finished feeding.
- Use only low toxicity chemicals when large concentrations of birds are nesting nearby.


Top arrow – vegetative barrier.
Bottom arrow – remnant vegetation. Guy Roth

Other fauna

Sodium fluoroacetate (1080) baiting has been an essential tool for protecting and recovering threatened species, especially mammals threatened by foxes. For more information on the impacts of 1080 baits on wildlife visit pestsmart.org.au/domestic-animal-safety/the-facts-of-1080-baiting

- Do not lay baits at times or locations where native wildlife are likely to be harmed.
- Place baits and/or design bait stations so that wildlife access is minimised and tie or bury baits (where applicable) to limit removal by non-target species.
- Regularly check and replace baits to reduce excess baiting and to be more effective.
- Check if your state or territory has additional requirements for using vertebrate poisons.

Soil health

Pesticides can have undesirable side effects on soil biota. The impacts are highly variable, influenced by the ingredients and application rate of the product(s), the application method, soil conditions (including temperature, moisture, and organic matter), the speed of chemical degradation, and the extent of leaching from the site. Generally, herbicides are less toxic than insecticides, with fungicides most likely to cause harm to soil biota.

A relatively easy way to check your soil's biological health is the 'Soil your Undies' challenge. Watch CottonInfo's three part video series explaining how at youtube.com/CottonInfoAust

A Soil Sustainability Framework, including management aspects to promote soil health, is currently under development.

Remnant native vegetation

Remnant native vegetation, i.e. any native patches of trees, shrubs or grasses that still remain in the landscape, can be damaged by herbicide and defoliant poisoning either via leaching through the soil or absorption through the leaves.

- Prevent drift by implementing best practices for spray application.
- Install natural or artificial barriers to intercept spray drift.
- Adhere to product label no-spray zone instructions.
- Select target-specific herbicides.
- Select non-soil active herbicides when remnant vegetation is nearby.
- Use an Integrated Weed Management (IWM) approach when managing environmental weeds.

Cotton Landcare Innovations

Under the National Landcare Program's Smart Farming Partnerships initiative, CRDC secured a $1.3 million grant to enhance natural resources and biodiversity on Australian cotton farms.

Focusing on four key activities (biodiversity, innovation, technology and collaboration), the project built on international best practice to implement and develop cutting-edge technologies, such as drone mapping and aerial seeding, acoustic monitoring and big data, to help Australian cotton better report on and improve on-farm biodiversity.

For more information, visit
crdc.com.au/cotton-landcare-tech-innovations

Protecting pollinators

Although cotton is commonly regarded as being largely self-fertile and self-pollinating, pollinators, including bees, provide an important service to catchments and communities in which cotton is grown. Many solitary wild insect pollinators are also present on and around farms but are less easily seen because they do not have the obvious hives of managed honeybees and social native bees. Remnant vegetation and other bushland on the farm should be thought of as pollinator habitat and protected accordingly.

As with many other crops, cotton can be a high-risk environment for bees as they are particularly susceptible to many insecticides. Contamination can occur through:

- Direct contact with spray or spray drift;
- Subsequent contact while foraging; and,
- Carrying of contaminated material back to the hive.

Insecticide contamination can result in individual bee death, diminished productivity or even destruction of the whole hive. Insecticides that are particularly toxic to bees are identified with a special statement on the label such as: **Dangerous to bees. DO NOT spray any plants in flower while bees are foraging.**

The Insecticide Resistance Management Strategy (IRMS; pages 64-65) highlights insecticides with a label warning about bee safety. The relative toxicity of cotton insecticides to honeybees is listed in Table 6 on pages 20-21.

Residual toxicity (how long the product remains toxic to bees post-application), should also be considered. Many insecticides are safer for pollinators and other beneficial species once the spray deposits have dried on the crop. The label provides information about what action must be taken to avoid impacting bees (note label recommendations may vary between different formulations containing the same active ingredient). Refer to the APVMA Pubcris database to search for information about individual insecticides portal.apvma.gov.au/pubcris.

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS.

Protect bees when using fipronil

While bees are susceptible to many insecticides used on cotton, fipronil risk to managed hives has been highlighted due to the extended residue risk. Best practice is to not apply fipronil to flowering crops, and fipronil labels include specific statements regarding bees, for example:

"Dangerous to bees. DO NOT apply where bees from managed hives are known to be foraging, and crops, weeds or cover crops are in flower at the time of spraying, or are expected to flower within 28 days (7 days for pastures and sorghum).

Before spraying, notify beekeepers in order to keep managed bees out of the area. If an area has been sprayed inadvertently, in which the crop, weeds or cover crop were in flower or subsequently came into flower, notify beekeepers in order to keep managed bees out of the area for at least 28 days (7 days for pastures and sorghum) from the time of spraying. Where the owner of managed hives in the vicinity of a crop to be sprayed is not known, contact your State Department of Primary Industries/Agriculture, citing the hive registration number, for assistance in contacting the owner."

Cotton can be a high-risk environment for bees. Susan Maas, CRDC

Bee ecology

Honeybee field activity is temperature and food-related. The bees become more active above 12-13°C with most foraging activity occurring between 19-30°C. With water gatherers, the main flight activity occurs when temperatures are above the mid-thirties. Honeybees usually forage within 2-4 km of their hive, although they will fly long distances (7-10 km) in search of high quality food.

Native bees often have much shorter flight ranges; as little as 500 m for some of the smaller species.

Bees collect nectar from extra-floral nectaries (e.g. under leaves) as well as from cotton flowers so they may be foraging in cotton crops before, during and after flowering. They may also visit weeds in flower in and around fields. Damage can also occur to bees if pesticides drift over hives, water surfaces or neighbouring vegetation being foraged by bees.

Coolibah trees (*Eucalyptus microtheca*), black box (*E. largiflorens*) and river red gums (*E. camaldulensis*) are a primary source of nectar and pollen for honeybees. These trees grow on the black soil plains along many of the river courses in cotton growing areas, and flower in response to good spring rains. In northern NSW trees begin to flower mid to late December, finishing about the end of January. Flowering times may vary by a few weeks in the southern and central areas of Queensland. When heavy flowering is expected, beekeepers may move large numbers of hives into these regions.

Reducing the risk

- Follow the registered label directions.
- Create a spray plan including risk mitigations for pollinators.
- Register with BeeConnected (see details below) and map crops on Satacrop. satacrop.com.au
- If beehives are in the vicinity of crops, notify apiarists at least 48 hours before spraying.
- Inform contract pesticide applicators of apiary locations.
- Pay particular attention to wind speed and direction, air temperature and time of day before applying pesticides.
- Use buffer zones to reduce the impact of spray drift or overspray on non-target crops and native vegetation.
- Avoid contamination of surface waters where bees may drink.
- Use an IPM framework to minimise the need for pesticides.
- Favour pesticides that have lower toxicity to bees and other beneficial insects (see Table 6).
- Where possible, use EC or granular formulations that dissolve completely in preference to wettable powders or microencapsulated formulations as bees can transport the particles back to the hive.
- Monitor crop development closely to identify when flowers will be present.
- Manage weeds to prevent them flowering in or near the crop.

With good communication and goodwill, it is possible for apiarists and cotton growers to work together to minimise risks to bees, as both honey (including pollination services) and cotton are important agricultural industries.

Other information sources

BeeConnected

Communication between growers and beekeepers is critical in reducing the risk of unintended exposure of bees to products that may have the potential to negatively impact bee health. BeeConnected is a nation-wide, user-driven smart-phone app and website that enables collaboration between beekeepers, farmers and spray contractors to facilitate best-practice pollinator protection. Growers log the location of their properties and beekeepers can log the present or future locations of their beehives through a Google Maps-based platform with GPS capability. When a beehive is logged near a farmer's property, both users are sent automated notifications and can chat further about their activities via a secure internal messaging service. CropLife Australia provide BeeConnected to the community free of charge as part of their Pollinator Protection Initiative. The effectiveness of the BeeConnected system is greatest when as many growers and beekeepers as possible use the service. It is important to keep an eye out for bees or apiaries near your property that might not be logged in the system.

For more information and to participate in this great service
beeconnected.org.au

CropLife Australia

Insecticide-treated seed

CropLife Australia's Seed Treatment Stewardship Strategy outlines measures to reduce risks from dust generated during handling and planting of treated seed, and provides guidance on minimising off-target movement of crop protection products to protect important pollinators.

croplife.org.au/resources/programs/seed-treatment-stewardship-strategy

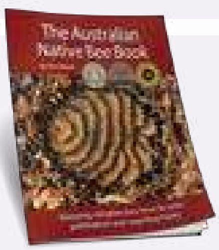
BeeAware

BeeAware is a hub of information for beekeepers and growers about honeybee biosecurity and pollination of agricultural and horticultural crops. The site contains information about the pollination of crops and how beekeepers and growers can work together to provide and receive best practice pollination services.

BeeAware was funded by the Australian honeybee industry, pollinator-reliant plant industries, Plant Health Australia, governments and R&D agencies.

beeaware.org.au

Native bees



More detailed Information on native beekeeping is available from the Australian Native Bee Association website www.anba.org.au

The Australian Native Bee Book
nativebeebook.com.au

Australian cotton industry sustainability reporting: Bees

It is important that the industry continues to practice IPM, and where possible avoid use of products that are highly toxic to bees such as fipronil, neonicotinoids (e.g. clothianidin), abamectin, chlorpyrifos and bifenthrin. The industry's voluntary IRMS (pages 64-65) includes a best practice recommendation to avoid applying fipronil to flowering crops. The Australian Cotton Sustainability Update 2023 reported that the hazard to bees (from insecticides) has reduced by 91% since 2004.

Bees in cotton youtu.be/LBRUaqZaVoQ

Australian Cotton Sustainability Update 2023
crdc.com.au/publications/australian-cotton-sustainability-update-2023

For further information or to notify the owner of beehives not logged in BeeConnected, note the registration number or brand and contact your state agricultural department or apiarist/beekeeping association:

New South Wales

NSW DPI Biosecurity Helpline ☎ 1800 680 244

NSW Apiarists' Association
info@nswaa.com.au
nswaa.com.au

Apiaries on public land in NSW are displayed on the **BPASS** map
bpass.dpi.nsw.gov.au/s/view-sites-public

Queensland

Biosecurity Queensland ☎ 13 25 23

Queensland Beekeepers' Association
statesecretary@qbabees.org.au
qbabees.org.au

Western Australia

DPIRD Apiary and biosecurity officers
PBHoney@dpird.wa.gov.au

Bee Industry Council of Western Australia
info@bicwa.com.au
bicwa.com.au

Northern Territory

honeybee@nt.gov.au
nt.gov.au/bees

Plant Biosecurity Branch – Department of Energy, Environment & Climate Action
☎ (08) 8999 2118

Victoria

Agriculture Victoria ☎ 13 61 86
honeybee.biosecurity@agriculture.vic.gov.au

Victorian Apiarists' Association
vaa@vicbeekeepers.com.au
vicbeekeepers.com.au

Licensed apiary sites in Victoria can be identified in the **Department of Land Water and Planning – Mapshare system**
mapshare.vic.gov.au/MapShareVic

Glossary & acronyms

Abiotic. Physical rather than biological (not derived from living organisms).

ACPM. *Australian Cotton Production Manual* (available from CottonInfo).

ACRI. Australian Cotton Research Institute, based in Narrabri, NSW.

Action threshold. See threshold.

Adjuvant. A substance (e.g. wetting agent, sticker, thickener, buffering agent) added to a spray mixture to enhance performance or overcome an inhibiting factor.

Allelopathy. The chemical inhibition of one organism by another.

AMF (formerly VAM). Arbuscular mycorrhizal fungi symbiotically colonise plant roots, transferring extra nutrients, especially phosphorus, from the soil in exchange for photosynthates from the plant.

Aphid colony. Four or more aphids within 2 cm^2 on a leaf or terminal.

APVMA. Agricultural Pesticides and Veterinary Medicines Authority.

Area wide management (AWM). Growers working together in a region to manage pest populations.

Arthropod. A member of the taxonomic group Arthropoda, that includes insects and mites.

At-planting insecticide. Insecticides applied as a granule or spray in the seed furrow with the seed during planting.

BCI. Better Cotton Initiative.

Beat sheet. Large sheet of yellow or white canvas, placed in the furrow and extended over the adjacent row. Plants are beaten against the sheet with a stick, dislodging insects which are quickly counted.

Beneficials. Biological agents that are beneficial to the crop, including natural enemies and pollinators.

Beneficial to pest ratio. Ratio used to incorporate predatory insect activity into pest management decisions.

Biological insecticides. Insecticides based on or derived from living organisms (e.g. NPV or Bt). Also referred to as biopesticides.

Biotic. Relating to or caused by living organisms.

Bollgard cotton. Genetically modified cotton containing Bt insecticidal proteins.

Box mapping. Segmented hand picking to understand intra-canopy yield distribution.

Broad-spectrum. Insecticides that kill a wide range of insects, including both pest and beneficial species. Their use, particularly early in the season, often leads to pest resurgence or flaring.

Bt. Toxins derived from *Bacillus thuringiensis* that are toxic to targetted insect species. The Bt strains referred to in this publication affect caterpillars, particularly *Helicoverpa* Spp.

Buffer zone. Unsprayed distance between the application site and downwind sensitive areas. For some products the distance is mandated on the label. For boom and aerial spraying, it is measured from the edge of the sprayer swath closest to the downwind sensitive area.

Calendar sprays. Application on a timed schedule, regardless of pest density or the actual need for pest control.

Carbamates. Broad-spectrum insecticides classified into MoA Group 1A.

Chipping. Manually digging out weeds with a mattock or chip hoe.

Cold shock. A delay in cotton growth/development caused by temperatures below 11° C.

Come Clean. Go Clean. Industry slogan promoting thorough cleaning to prevent transfer of pests between fields and farms.

Conditioner. Product used to hasten boll opening.

Consecutive checks. Successive insect checks taken from the same field or management unit.

Conventional cotton. Cotton varieties that are not genetically modified (in this guide the term is usually used to indicate absence of genes that produce Bt-derived insecticidal proteins).

Cotton bunchy top (CBT). Cotton virus vectored by aphids.

Crop compensation. Plant's capacity to 'catch-up' after insect damage without affecting yield or maturity.

Cut-out. Assimilate (photosynthesis products) demand exceeds supply and no more harvestable fruit is set.

Damping off. Wilting, collapse and death of seedlings, usually due to infection by pathogens.

Day degree (DD). Unit combining temperature and time used to monitor and compare crop and insect development. The cotton industry has moved from a base 12 to a 15_32 system of calculating DD.

Defoliation. Leaf removal in preparation for harvest by artificially enhancing the natural process of senescence and abscission.

Desiccant. Harvest aid chemical that damages the leaf membrane, causing moisture loss and dessication.

Diapause. Period of physiologically controlled dormancy in insects (e.g. at the pupal stage in the soil for *Helicoverpa armigera*).

Double knock. Sequential application of two methods of weed control from different control tactics in a short timeframe.

Dryland. Non-irrigated cropping. Also referred to as 'rain-grown'.

D-vac. Small portable suction sampler or blower/vacuum machine used to suck insects from the cotton plants into a fine mesh bag.

Economic threshold. See threshold.

Efficacy. Effectiveness of a product or natural enemy against pests.

Egg parasitoids. Parasitoid species that specifically target insect eggs, killing the developing host.

ETL (environmental toxic load). An indicator used to assess the average amount of toxic pressure on the environment from applied pesticides.

***Eretmocerus* sp.** Parasitoid wasp of SLW that occurs naturally in most cotton regions or can be purchased for commercial release.

Exotic pests. Pests that have not yet been detected in Australia.

Flaring. Increase in an arthropod pest population (usually in species with very fast life cycles) following a pesticide application targeted at another species.

Flush (irrigation). High volume irrigation carried out in minimal time.

Food sprays. Natural food products applied to attract beneficials, particularly predators, into crops to help control pests. Yeast-based sprays attract; sugar-based sprays retain beneficials already present.

F rank. Ranking of each cotton variety in accordance with its resistance to Fusarium wilt.

Frass. Insect faeces is an indicator of insect activity, and sometimes helpful for identification.

Fruit retention. Percentage of fruit (squares or bolls) retained compared with the overall number produced.

Fungicide. A substance used to kill or inhibit the growth of fungi.

GVB. Green vegetable bug.

Herbicide. A substance used to kill or inhibit the growth of weeds.

Herbicide Resistance Management Strategy (HRMS). Voluntary industry strategy designed to delay resistance to herbicides (predominantly glyphosate).

Honeydew. Sticky sugar-rich waste excreted by sap-sucking insects that can interfere with photosynthesis, promote sooty mould, affect lint quality and cause problems with fibre processing.

In-furrow insecticide. See at-planting insecticide.

Infested. A large number of pests are present. Also used as a sampling term to indicate a pest presence of more than a given number of pests (see sampling information within aphid, mite and whitefly sections).

Insect growth regulator (IGR). Compound that influences insect growth and development.

Insecticide. A substance used to kill or inhibit the growth of insects.

Insecticide Resistance Management Strategy (IRMS). Voluntary industry strategy that imposes restrictions on pesticide use to help prevent the development of insecticide resistance.

Instar. Juvenile insect development stages between moults.

Integrated disease management (IDM). The integration of appropriate disease control strategies with management of the whole farming system.

Integrated pest management (IPM). Using knowledge of pest biology, behaviour and ecology to implement a range of tactics in an integrated way to suppress or reduce pest populations.

Integrated weed management (IWM). Strategy to plan and implement a range of different tactics to achieve sustainable weed management.

Knockdown (weed control). Herbicide applied to rapidly control weeds.

Lay-by herbicide. Residual herbicide used to control weeds during crop growth.

Larva. Immature 'grub' stage of insects that undergo complete metamorphosis (e.g. moths, beetles, flies, lacewings). See also pupa.

Lesion. A localised, defined area of diseased tissue.

Lock. Segment of cotton boll.

Management unit. Farm area managed in the same way for the purposes of sampling and insect management.

Maximum residue limit (MRL). Maximum amount of pesticide residue legally permitted on food products, based on levels considered toxicologically acceptable.

Mepiquat chloride. Plant growth regulator used to prevent excessive growth or node elongation.

Miticide. A substance used to kill or inhibit the growth of mites. Miticides may also have activity against other arthropds.

Mode of action (MoA). Pesticide classification scheme based on target site that aims to prevent the development of cross-resistance to related pesticide compounds. Australia adopted the international numbering system for herbicides in 2021.

Monitoring. Checking crops (for insects, damage, weeds, growth stages etc). Also commonly called sampling or monitoring. Often refers to the gathering of data only; interpretation and management recommendations are then generated based on the data collected.

Mycorrhizae. See AMF.

Natural enemies. Predators, parasitoids and pathogens of pests.

Natural mortality. Expected death rate of insects in the field due to environmental factors (including natural enemies).

NAWF. Nodes above white flower, a measurement of crop development.

No-spray zone. See buffer zone.

NPV (nucleopolyhedrovirus). An entomopathogenic virus. Commercial formulations targeting *Helicoverpa* are available in Australia.

Nymph. Immature insect stage that looks like the adult but without wings (e.g. bugs, thrips, mites). Nymphs go through a series of moults and do not pass a pupal stage.

Organophosphates (OPs). Broad-spectrum insecticides classified into MoA Group 1B.

OTT. 'Over the top' of the crop application of herbicides.

PAMP. Pesticide application management plan.

Parasitoid. Insect that lays its eggs on or in another arthropod; the larva develops within the host, killing it on emergence.

Parthenogenesis. Reproduction occurs without fertilisation, resulting in a genetic clone.

Pathogen. Microorganism that causes disease (e.g. Fusarium wilt is the disease caused by a soil-inhabiting fungus *Fusarium oxysporum* f.sp. *vasinfectum* (Fov)).

PAWC. Plant available water capacity.

Peak flowering. Period where the plant has the highest numbers of flowers opening per day.

Permits (APVMA). Permits are issued by the Australian Pesticides and Vetinary Medicines Authority to legalise the off-label use of pesticide product or active for a specific minor use or in an emergency.

Pesticide. A substance used for destroying or inhibiting organisms that are harmful to agricultural production.

Pix. See mepiquat chloride.

Plant-back period. The minimum time recommended between a residual herbicide application and the planting of sensitive crops.

Plant growth regulator (PGR). Chemical that can be applied to reduce growth rate and prevent rank growth.

Plant mapping. Recording the fruiting dynamics of a cotton plant to help interpret the effects of pest damage or environmental factors.

Planting window. Restriction on planting time used to restrict the number of pest generations exposed to particular control measures.

Post-emergent herbicide. Herbicide applied after crop emergence.

PPE. Personal protective equipment used when handling/ applying pesticides.

Pre-emergent herbicide. Residual herbicide applied prior to or at planting.

Presence/absence (sampling). Noting presence or absence of a numerous pest rather than counting absolute numbers.

Prophylactic sprays. Insecticides applied in anticipation of a potential pest problem (rather than in response to a threshold). These 'insurance' sprays are usually not recommended due to increased costs, selection for insecticide resistance, and the risk of secondary pest outbreaks.

PSO (petroleum spray oil). Petroleum-derived oil used to control insect pests. Can also be used to deter egg lay of some pests.

PubCRIS (Public Chemicals Registration Information System). APVMA's searchable database of agrochemcials registered for use in Australia including products with off-label permits (portal.apvma.gov.au/pubcris).

Pupa. Stage where larva undergoes transformation into an adult (e.g. from caterpillar to moth).

Pupae busting. Tillage to reduce the survival of overwintering pupae.

Rank growth. Excessive vegetative growth; usually managed using mepiquat chloride.

Ratoon cotton. Regrowth from the previous season's rootstock.

Re-entry period. Mandatory period between chemical application and re-entry to the treated area.

Refuge. Area left untreated with an insecticide or technology that generates unexposed susceptible individuals to act as a dilution factor when mating with resistant adults. Refuges are a requirement of the Bollgard RMP.

Remnant vegetation. Patches of native trees, shrubs and grasses that remain in the landscape post-clearing.

Resistance (to pesticides). When individual pests (arthropods, weeds or pathogens) develop a mechanism for dealing with a particular pesticide or mode of action group, potentially resulting in poor control (less than expected) or control failures (much less than expected).

Resistance management plan (RMP). Proactive plan to mitigate the risks of resistance (to Bt toxins) developing. Complicance to the Bollgard 3 RMP is required under the Bt cotton Technology User Agreement.

Resurgence. Increase in a targeted arthropod pest population following a pesticide application. Usually due to a reduction in beneficial populations.

Retention. See fruit retention.

Rogueing. The systematic removal, usually by hand, of plant off-types (inferior, unhealthy, nontypical or not displaying sufficient characteristic varietal traits).

Rotation crops. Other crop types grown before or after the cotton crop.

Sampling (for pests). See monitoring.

Scouting. See monitoring.

Secondary pests. Pests that do not usually become a problem unless their natural enemies (predators or parasitoids) are reduced in number by insecticides. See also pest flaring.

Seed treatment. Insecticide/fungicide coating on cotton seeds that offers protection during germination and establishment.

Selection pressure. Pesticide sprays remove susceptible individuals. More selection events from a particular chemical group leads to greater 'pressure' or chance of selecting a resistant population.

Senescence. Biological deterioration associated with aging where plant cells stop growing and dividing, but without dying.

Shedding. Abortion/loss of reproductive structures (squares, flowers or bolls) caused by environmental factors or pest damage.

Siphunculi. Pair of wax-secreting tubular organs on the abdomen of aphids (also called cornicles).

SLW. Silverleaf whitefly.

'Soft' approach. Managing insect and mite pests using options that have minimal impact on beneficial populations.

Square. Cotton flower bud.

Stacked genes. Two or more genes that express similar activity (e.g. in Bollgard 3 there are three genes Cry1Ac, Cry2Ab and Vip3a), or different activities in the same variety (e.g. Bollgard + Roundup Ready®).

Sucking pests. Bugs with piercing mouthparts (e.g. mirids, aphids, whitefly).

Sweep net. Large cloth net with long handle used to sample insects in the upper canopy.

Synthetic insecticides. Non-biological insecticides (artificial versions of natural insecticides or synthetic molecules with insecticidal/miticidal activity).

Systemic pesticide. Pesticide that is taken up through plant tissue (as opposed to remaining on the surface) and transported through the plant's vascular system.

Synthetic pyrethroids (SPs). Broad-spectrum insecticides classified into MoA Group 3A.

Terminal. Uppermost growing point, particularly on the main stem.

Threshold. The point at which an action is taken. Action thresholds are based on a level/number of pests/damage. Economic thresholds consider the commodity value and treatment cost to identify a 'break even' point.

TIMS. Transgenic & Insect Management Strategy (Committee).

Tipping. Loss of the terminal, causing the plant to develop multiple stems.

Trap crop. Small area of more attractive host plants that concentrates a pest population to allow easier management. Trap crops are not the same thing as refuges, which aim to dilute the occurrence of resistant genes in pest populations.

Tubercles. Small knob-like or rounded protuberances between the antennae of some insects (e.g. aphids).

Vegetative barrier. Deliberately planted vegetation strips designed to protect adjacent sensitive areas (remnant vegetation, waterways, other crops) by capturing airborne spray droplets.

Visual sampling. Counting insects in the field without the use of additional equipment such as a beat sheet.

Volunteer cotton. Plants that have germinated and established unintentionally in-field or elsewhere (roadsides, fencelines etc).

V rank. Ranking of each cotton variety in accordance with its resistance to Verticillium wilt.

Waterlogging. Excess water in a plant's root zone decreases the oxygen available to roots.

Wildlife corridors. Narrow areas of habitat that provide either direct or discontinuous connection allowing fauna to move between larger areas of natural habitat.

Withholding period. Minimum period allowed between application of an agrochemical and crop harvest (or use for stockfeed).

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Bolded page numbers indicate the primary location and/or photographs. Italics indicate a glossary entry.

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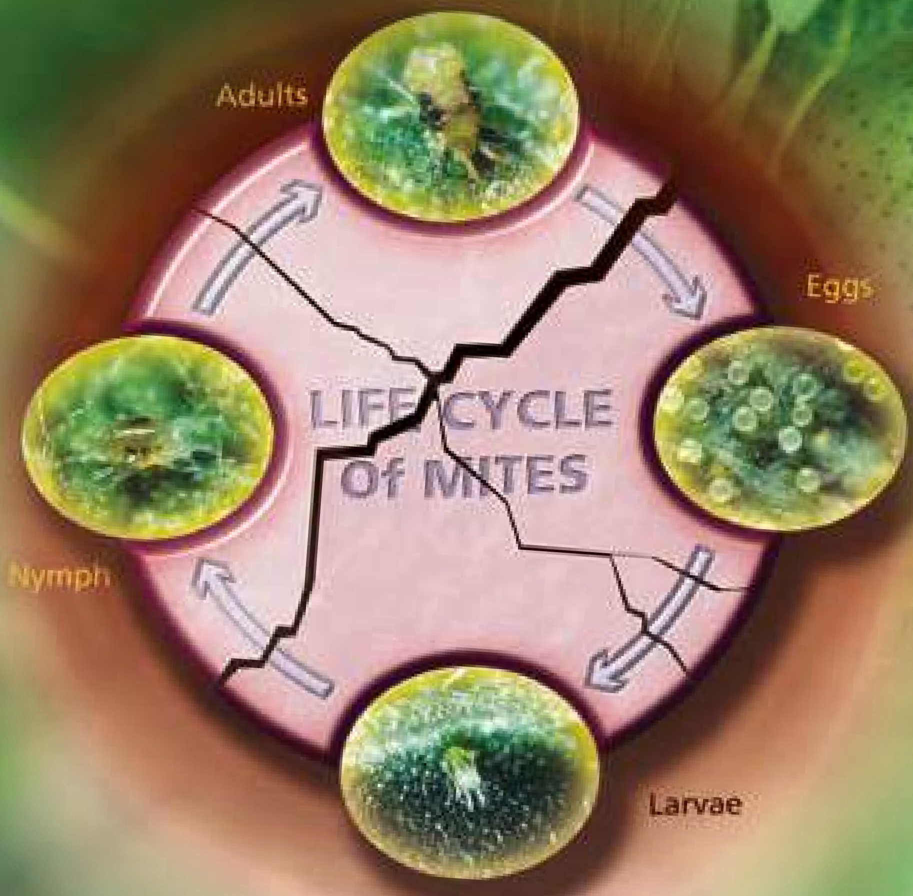

For use in cotton, maize* and popcorn*. Controls the mite population by:

- Inhibiting the moulting process of nymphs
- Ovicidal activity – sterilises eggs
- Sterilises females

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