

2026-27 COTTON PEST MANAGEMENT GUIDE



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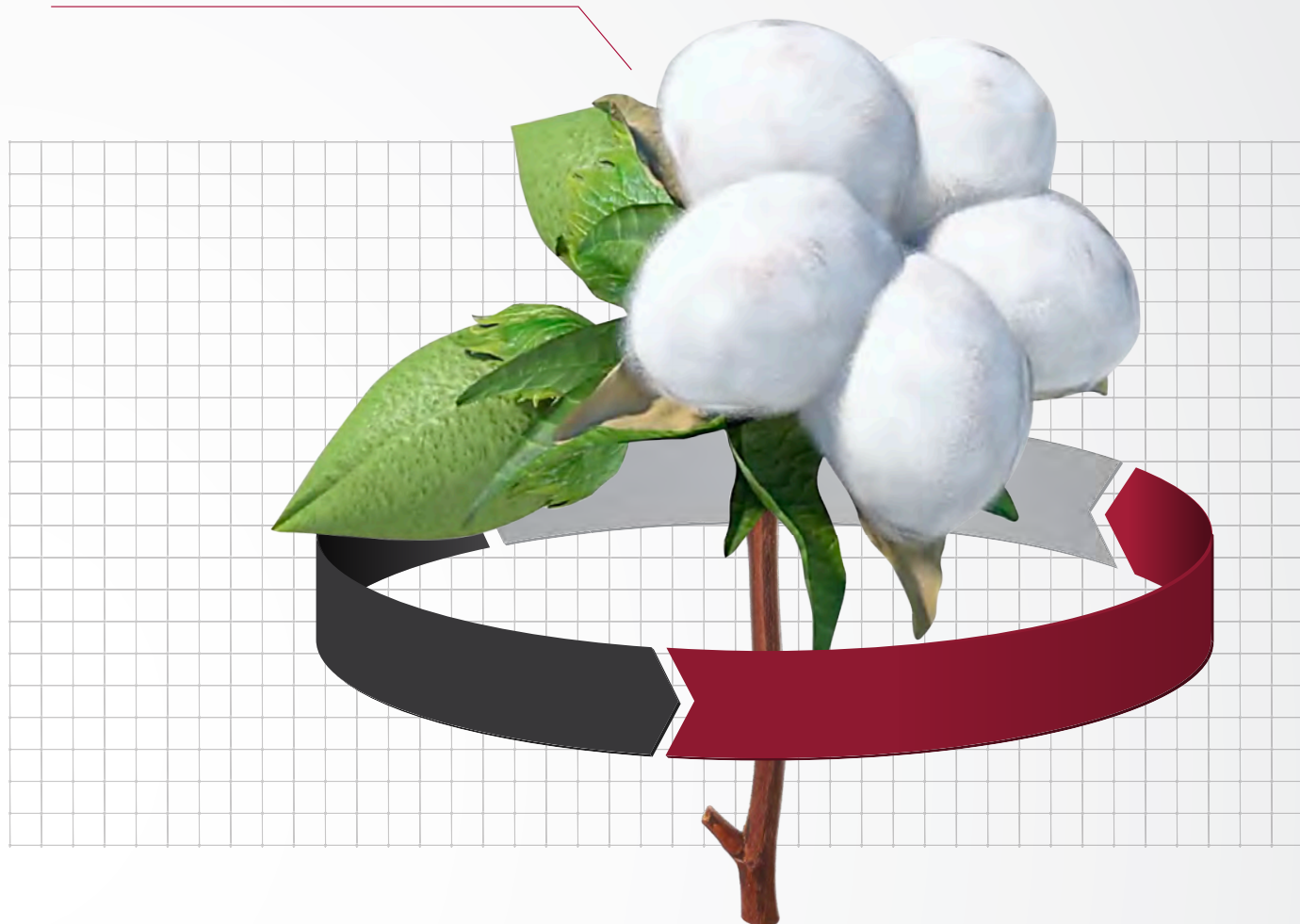
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Foreword

Megan Woodward (CottonInfo and CRDC)

Welcome to the 2026-27 *Cotton Pest Management Guide* (CPMG). Whether you're planning, monitoring or making in-crop pest management decisions, this guide brings together the latest information on managing pests and protecting your cotton crop. Developed by the Australian cotton industry's research, development and extension (RD&E) organisations, the Cotton Research and Development Corporation (CRDC) and CottonInfo, it provides practical, up-to-date advice to help you make informed decisions on farm throughout the season.

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 Strategic RD&E Plan for 2023-28, *Clever Cotton*, is built on three investment pillars: Paddock, People, and Planet. In 2026-27, Australian cotton growers and the Commonwealth Government will co-invest \$36.42 million through CRDC into *Clever Cotton*.

CottonInfo is the Australian cotton industry's extension program. It is a partnership of CRDC, Cotton Australia and Cotton Seed Distributors (CSD) to deliver industry good. The program 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 other research organisations, 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, *myBMP*, 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. The manual contains additional information on spray application and integrated management and is available to download from cottoninfo.com.au/news-and-publications or crdc.com.au/publications.

In this edition, the potential impact of pesticide exposure to honeybees has been reviewed and updated using international sources and APVMA reports. Risk ratings now include separate columns for contact and oral toxicities.

Remember, the CottonInfo team of Regional Extension Officers (REOs), Technical Leads and *myBMP* experts are available to assist you with all your cotton information needs. Find our contact details and other information online at our website cottoninfo.com.au, while best practice information for your farm is available at the *myBMP* website mybmp.com.au. And you can find information about all of CRDC's investments online at crdc.com.au.

This guide is the result of a huge team effort. On behalf of CRDC and CottonInfo, we thank coordinating editor Tonia Grundy and everyone across the cotton industry and research community who contributed their time, expertise and feedback. We hope you keep this guide close at hand and find it a valuable reference throughout the season.

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Pests and crop protection

In cotton, pests can be any living organism (animal, plant or microbe) that adversely impacts yield and/or quality either directly or indirectly, including:

- 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 may also be unintended impacts from pest management actions, such as crop damage from herbicide residues or spray drift, a reduction in beneficial insects, or accelerated pesticide resistance.

Determining the culprit

Not all crop symptoms are caused by pests. A range of abiotic influences can also damage crops, or exacerbate pest impacts (Table 1). Keep detailed records of environmental conditions, nutritional analyses and all field operations to assist with symptom diagnosis. Before taking action, correctly identify the cause of the damage and ensure that it is still present AND still causing damage, AND able to be controlled.

Regional influences

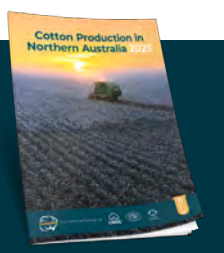
The majority of the information in this guide was originally developed primarily for temperate growing regions (i.e. from southern Queensland to central New South Wales).

For many years, Central Queensland was the only established cotton production area that experienced sufficiently different conditions and pests to warrant specific pest management recommendations. However, over the last decade or so, cotton production has expanded into southern New South Wales and across northern Australia, including the tropics. These are areas that often have different abiotic challenges and divergent pest priorities that need to be factored into management plans. For example:

- Southern production regions usually have significant temperature and season length constraints.
- Cotton within 20 kilometres of the coast is more likely to be exposed to higher humidity and showers.
- In northern regions, higher temperatures, rainfall and humidity lead to a higher risk of shedding, can promote disease and accelerate arthropod or weed development. Northern Australia is also a potential geographic pathway for entry of exotic pests or diseases from South East Asia, including insect-vectored diseases.

'Cotton Production in Northern Australia' highlights some of the considerations related to insect and disease issues in tropical cotton production.

 cottoninfo.com.au/news-and-publications



Integrating your pest management approach

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

- **Farm hygiene.** Prevention is better than cure. **CLEAN FARMS USUALLY HAVE LESS PEST AND DISEASE PROBLEMS THAN DIRTY ONES.** Manage pests year-round across the entire farm (including non-field areas) 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. Learn when pests are most vulnerable to available control methods and choose 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. 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. Also, check for nearby beehives or sensitive areas/crops before applying pesticides.

Whenever you're 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. Some product registrations are restricted to specific states, and registrations/permits are subject to change. **ALWAYS** check the product label for allowable usage relevant to your region, and ensure you can meet any related legal requirements related to application, record-keeping etc.

If you come across something unusual, take multiple photographs, both of the suspected pest/damage and unaffected crop (for comparison), and shots of the wider area (for context). Have a selection of bags, containers and collecting tools handy to allow you to take samples, including somewhere to store them so they won't deteriorate too much before you have a chance to examine them more closely or send off for diagnosis.

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. **III**

TABLE 1: Crop symptoms and potential cause(s)

Crop damage	Biotic factors	Abiotic factors
Seedlings not emerging	Seedling diseases Soil/establishment pests Seed with low germination rate	Residual herbicides (MoA Groups 3, 5, 14, 15) 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 (MoA 2, 3, 4, 5, 14, 15) 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 (MoA 2, 4, 5, 10, 22, 27) Frost Fertiliser burn Wind damage Nutritional issues (B, Mg, K, P, Zn) Sunspot or sunscald
Leaf discolouration (mottled, spots or interveinal)	Viruses (cotton bunchy top, tobacco streak virus, blue disease*) Fungal wilts (fusarium or verticillium) Ramularia/grey mildew Sucking insects (aphids, mites or leafhoppers)	Nutritional issues (Fe, Mg, P, K, Zn) Herbicide damage (MoA 2, 4, 5, 10, 27) Chimera (genetic fault)
Leaf discolouration (whole leaf) or premature senescence	Nematodes Exotic root rots* Leaf disease (leading to senescence)	Salinity/sodicity Waterlogging Herbicide damage (MoA 2, 4, 5, 9, 34) Nutritional issues (B, N, K, S)
Abnormal growth (including leaf wrinkling)	Viruses (cotton bunchy top, blue disease*, cotton leaf curl*) Verticillium wilt Sucking insects (aphids, thrips, mites or leafhoppers) Black root rot Bacterial stunt	Herbicide damage (MoA 2, 4) Soil compaction Nutritional issues (B, Mg)
Leaf cupping	Cotton leaf curl disease*	Herbicide damage (MoA 4)
Petiole twisting and stem reddening	Cotton blue disease* (can cause petiole reddening)	Herbicide damage (MoA 4)
Physical damage to leaves/terminals	Caterpillars (cluster caterpillar, helioverpa, loopers, bollworms) Redshouldered leaf beetle Locusts	Hail
Fruit shedding	Sucking bugs (mirids, stink bugs or cotton stainers) Excessive fruit set	Cloudiness Heat and/or moisture stress Waterlogging Herbicide damage (MoA 2, 4, 5, 9, 10, 22, 27) Nutritional issues (B, N)
Wilting or sudden death	Fungal wilts (reoccurring, fusarium, verticillium or sudden) Nematodes Exotic root rots*	Herbicide damage (5) Lightning Insufficient soil moisture
Defoliation	Alternaria leaf spot Ramularia/grey mildew Fungal wilts (fusarium, verticillium or sudden) Mites Bacterial blight (exotic variant*)	Herbicide damage (MoA 4, 5, 10, 22) 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 (MoA 22)
Damage to boll/lint/seed	In-field or post-harvest boll rots Sucking bugs (stink bugs, cotton stainers or mirids) Caterpillars (bollworms or helioverpa) Boll and seed rot pathogens Rodents Boll weevil*	High temperatures Rainfall
Sticky cotton	Whitefly Aphids Mealybugs	

* exotic pests

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 arthropods, the crop, and the environment to minimise the likelihood of outbreaks and reduce reliance on insecticides. There are limited chemical control options for some arthropod pests (such as mites, mealybug and whitefly), and effective integration of management options is needed to prevent populations from rapidly increasing.

IPM is not a fixed recipe, but instead requires a mix of both 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 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.



What is IPM?
youtu.be/BdQRLx4hN5o



IPM – the basics

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

- **Good farm hygiene.** To limit the survival and spread of overwintering pests such as mealybugs or resistant aphids that might also carry bunchy top disease, manage cotton volunteers, ratoons and other weeds in fallow fields, field edges, roadways and drainage lines.
- **Prevent problems.** Sowing date, crop sequences and field selection are just some of the tactics available to disadvantage pests. Examples of how to strategically avoid giving pests the upper hand include avoiding back-to-back cotton in fields that had mealybugs to limit season carryover, and not planting as late so that your crop is not exposed to displaced populations of silverleaf whitefly (SLW).
- **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 during regular sampling.

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.
- Aim 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.

Plant monitoring can also 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.

- **Effective sampling.** Detecting and quantifying pests and beneficials is necessary for good decision making. Recommended sampling techniques will depend 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 locally or migrated in recently.
- **Consider crop stage.** Crop development stage has a big bearing on both susceptibility to yield loss and recovery 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 usually compensate for early season vegetative damage, and even square loss, provided 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.** Common pests that you are likely to deal with on a regular basis when growing cotton are outlined in this guide. You need 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 (thresholds), and what types of control techniques (chemical, biological or physical etc) are likely to be suitable and effective. Knowledge of a 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) and noting which beneficials are present when sampling can help inform your control decisions. Conserving beneficials can have a significant impact on the likelihood of developing a mite or mealybug problem later in the season. Table 5 (pages 16-17) 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.

Your IPM needs covered





Transform[®] WG

Isoclast[®] active

INSECTICIDE

Applaud[®]

INSECTICIDE

Cotton pests can suck the profitability right out of your crop, that's why switched-on growers have been turning to **Transform[®] WG** and **Applaud[®]** insecticides as part of a strategic integrated pest management (IPM) program.

Transform containing **Isoclast[™] active** controls a range of cotton pests including green mirid, aphids, greenhouse whitefly and suppression of mealy and rutherghlen bugs, whilst proving soft on beneficials. Because of its unique mode of action, Transform can control insects that have become resistant to other insecticides.

Applaud Insecticide is now exclusively registered for use in cotton for control of Silverleaf White Fly (SLWF) and solenopsis mealybug. A unique and targeted mode of action means that SLWF resistant to pyriproxyfen will be controlled. Selectivity to beneficial insects makes it ideally suited for use in IPM systems.

Corteva is committed to developing IPM compatible, sustainable products for the Australian cotton industry.

For more information contact
Corteva Agriscience on
1800 700 096



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Green Mirid image courtesy of CSIRO Photographer : David McClenaghan
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- **Consider if a spray is actually required.** Scientifically-based action thresholds to help with control action decisions are available for many key pests. Resist the urge to use insecticides prophylactically by combining them with herbicide applications. Economic thresholds calculate the pest density or damage level at which control must be implemented to prevent economic loss, and should be considered along with other factors that may influence the need to spray. For example, if pest abundance is just over threshold but damage is low and beneficial populations are high, consider delaying control for several days. This low risk strategy allows beneficials time to reduce pest levels to below threshold and avoids a potentially disruptive spray thus reducing insecticide costs and selection for resistance. For high pest damage with low beneficial populations, immediate control with an insecticide may be the best option. Thresholds based on cumulative population changes (cotton aphid, two-spotted mite and SLW) require comparison of multiple samplings to determine if action thresholds have been reached.
- **Choose insecticides wisely.** If insecticide control is warranted, select a product that appropriately balances effectiveness against the target pest with any potential harm to natural enemies. Where possible, actively avoid using broad-spectrum disruptive insecticides (e.g. organophosphates, pyrethroids and some neonicotinoids), especially early to mid-season, to help minimise 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 58-63). If several options are available, examine their selectivity profiles (Table 5). For example, clothianidin will reduce populations of ladybird beetles (aphid predators) and *Eretmocerus* wasps (whitefly parasitoids) but conserve predatory bugs and thrips (mite predators). The low rate of fipronil will reduce predatory bug populations but conserve ladybird beetles. Populations of non-target pests such as aphid, mite and whitefly may increase after insecticide applications if the beneficial populations keeping them in check are disrupted. Using 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 crops.** Follow label directions and consider both application technique and environmental conditions to optimise chemical efficacy. Adhere to resistance management programs to ensure continued access to pest control tactics that give good control. The effectiveness of insecticides or *Bacillus thuringiensis* (Bt) protein-expressing Bollgard crops also depends on pest populations remaining susceptible.
- **Look after bees.** Bees are particularly susceptible to many of the insecticides used on cotton farms (see Table 5). Hive productivity can be damaged by direct or indirect contact with products by foraging bees, or when insecticide drifts over hives or neighbouring vegetation. Always look for and follow label directions regarding impact on bees. Refer to the 'Protecting pollinators' section for more information.
- **Work 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 actions to reduce pest survival. 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 bring both prospective benefits and potential trade-offs (e.g. a more selective insecticide may cost more to apply than a broad-spectrum option but reduce the likelihood of secondary pest outbreak that 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. III

USEFUL RESOURCES:



Download *Pest and Beneficial Insects in Australian Cotton Landscapes* from
cottoninfo.com.au/news-and-publications



Download *IPM: Optimising your early season crop management* from
cottoninfo.com.au/news-and-publications



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 your IPM strategy. Download a PAMP template from cottoninfo.com.au/effective-spray-application		
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) 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. Also consider disease risk when making rotation decisions.	
Think beyond the crop	Participate in area wide management (AWM) all year round. Apply IPM principles to all crops, not just cotton. Regularly check long and short term weather forecasts, and factor them into your management planning. 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 its health and diversity, preventing pesticide drift from reaching it, and controlling weeds.			
Have good on-farm hygiene	Zero tolerance of weeds (including volunteer cotton) across cropping and non-crop areas all year round. Ensure a host free period to minimise pest and disease carryover between seasons.	Consider pre-irrigation, to allow control of weeds with non-glyphosate options 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 destruction to prevent ratoons.
	Practice Come Clean. Go Clean. all year round			
Consider options to avoid or reduce pests	Before planting cotton, consider paddock history and proximity to sensitive areas, pest hosts and beneficial habitats. Manage vegetation areas to encourage beneficials. Consider a summer trap crop. Assess risk of soil pests.	Use a variety suited to your region. Optimise 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 the farm.
Sample crops effectively and regularly	Remain up-to-date with key pests, beneficials, sampling techniques and thresholds. Monitor for soil pests pre-planting.	Monitor fields at least twice weekly, checking for pests, beneficials, parasitism, fruit load and plant damage (keep an eye out for weeds and diseases also). Consider both current pest numbers and population trends. Use tools like economic 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, and also take 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 weeds (including volunteer and ratoon cotton) across the entire landscape.	Adhere to refuge requirements Consider choice of at-planting insecticides/ seed dressings and resistance 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 confirmed that square loss during early squaring (9-13 nodes) prior to first flower does 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.



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



Cotton plants can rapidly compensate for early fruit loss if growing conditions are good. 

Fruiting versus 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 video and pictures below show what to look for during squaring. Check 5-10 plants in several locations to get a reasonable idea of the crop's development status.

Environmental stress

No amount of insecticide will help if the shedding is due to environmental causes. Temperature extremes (below 12°C and above 35°C) or cloudy weather for even 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.



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). 

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 (i.e. >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:



Various retention-related videos are available on the CottonInfo YouTube channel, including:

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



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



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.

Natural enemies

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

Building and/or conserving natural enemy 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 species present, their activity on pests (see Table 4 for common examples), and the potential impacts of other pest control measures (including insecticides – see Table 5) helps ensure the best management decisions are made for your crop.

Choose insecticides wisely to conserve beneficial species

Balance the contribution of natural enemies against the need to protect the crop from significant loss. Take into account both their impact on pest species, and the time needed to build effective populations. 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.

Very selective ('soft') products may have minimal impact on natural enemies, while others are highly disruptive to beneficial populations ('broad-spectrum' or 'hard'). The relative selectivity of insecticides available for use in cotton can be found in Tables 5 and 6, to help you assess the risk of other pest populations 'flaring' (increasing rapidly).

Table 5 includes both general impact and the product's selectivity to specific types of beneficials. For example, if mealybugs are present, choose insecticides that have less effect on parasitic wasps and key mealybug predators such as lacewings and ladybird beetles. Using lower rates (if available) may provide sufficient efficacy against some target pests, while minimising impact on beneficials. Note that these ratings are based on 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 62-63) to reduce the risk of resistance, and always follow the product's label directions.

III



Conserving beneficials in cotton
youtu.be/g3CYrt6QoN8



TABLE 4: Natural enemy activity against key pests

	Helicoverpa	Aphids	Mealybugs	Spider mites	SLW	Mirids	Jassids	Thrips	Notes
Ladybird beetles		✓	✓	✓	✓		✓	✓	Also feed on scale insects.
Red and blue beetle	✓	✓	✓		✓				Feed on eggs, small larvae, slow-moving insects, and pollen.
Damsel bug	✓	✓		✓		✓			Feed on helicoverpa eggs and small caterpillars, and nectar.
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				✓	✓				Also attack squares, but only 1/4 as damaging as green mirids.
Glossy shield bug	✓								Primarily predators of caterpillars.
Spined predatory bug	✓					✓			Primarily predators of caterpillars.
Minute pirate bug				✓	✓			✓	Effective predators of eggs. Also feed on nectar.
Assassin bugs	✓					✓			Primarily predators of caterpillars.
Lacewings (brown)	✓	✓	✓	✓	✓			✓	Both adults and larvae are predatory.
Lacewings (green)	✓	✓	✓	✓	✓			✓	Only larvae are predatory.
Spiders	✓			✓	✓	✓	✓		Generalist predators.
Parasitoid wasps	✓	✓	✓		✓				Different species target specific pests and lifestages.
Parasitoid flies	✓								Can also parasitise adult and late instar stink bugs.
Hoverfly		✓							Larval stage is predatory.
Silverfly		✓							Larval stage is predatory.
Thrips				✓	✓				Pest of seedlings. Also feed on pollen.

Examples of beneficial species

PREDATORY BUGS



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



Large Australian assassin bug. 25 mm.
© L. Wilson



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



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



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)

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. 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). Only larval stage is predatory.
© T. Grundy and M. Miles

SPIDERS



Christmas spider. 15 mm. © P. Grundy



Tangle web spider. 5 mm. © P. Grundy

TABLE 5: 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			Risk to bees ⁹							
			Helicoverpa	Mites	Mirids	Aphids	Thrips	Silverleaf whitefly	Persistence ³	Overall ranking	Predatory beetles			Predatory bugs				Spiders	Hymenoptera				Mites	Aphids	Helicoverpa	Contact	Oral		
											Total ⁴	Ladybirds	Red and blue	Total ⁵	Damsel bug	Big-eyed bug	Others		Lacewing adults	Total (wasps) ⁶	Eretmocerus ⁷	Trichogramma						Ants	Thrips ⁸
Bt ¹⁰	11A		✓					Very short	Very low	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	
NPV ¹¹	31		✓					Very short	Very low	VL	VL	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	L	L	M	VL	VL	VL	VL	L	M	VL	L	M	VL	M	VL	M	
BioPest ^{®12}		2-4%				✓		Short	Very low	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	L	—	L	VL	VL	VL	VL	VL	VL	
Pyriproxyfen	7C	50					✓	Long	Very low	M	M	—	VL	—	—	—	—	—	—	L	VL	VL	VL	VL	VL	VL	VL	VL	
Parachute ^{®12}		2%	✓		✓	✓		Short	Low	VL	VL	L	VL	VL	VL	VL	VH	VL	M	VH	M	M	L	M	VL	VL	VL	VL	
Sero-X [®]	UNE	800	✓		✓		✓	Short	Low	VL	L	VL	VL	VL	VL	VL	VL	VL	—	—	L	VL	VL	VL	VL	VL	VL	VL	
Etoxazole	10B	38.5		✓				Short	Low	VL	L	VL	VL	VL	VL	VL	VL	VL	M	L	—	VL	VL	VL	VL	VL	VL	VL	
Buprofezin	16	440					✓	Long	Low	L	VL	H	VL	L	VL	VL	H	VL	L	VL	L	VL	VL	VL	VL	VL	VL	VL	
Chlorantraniliprole	28	52.5	✓					Long	Low	L	L	M	VL	VL	VL	VL	VH	VL	M	M	L	L	VL	VL	VL	VL	VL	VL	
Afidopyropen	9D	10				✓		Medium	Low	L	M	L	VL	VL	VL	VL	—	VL	L	H	VH	H	VH	VL	VL	VL	VL	VL	
Spinetoram	5	48	✓				✓	Long	Low	M	H	M	VL	VL	VL	VL	VL	VL	VL	H	VH	H	VH	VH	VH	VH	H	H	
Diafenthiuron	12A	350		✓		✓		Medium	Low	M	M	H	L	M	VL	VL	VL	VL	L	M	H	VL	L	L	VL	M	M	M	
Pymetrozine	9B	150				✓		Short	Low	M	M	M	L	L	L	VL	VL	M	L	L	VL	L	M	VL	VL	VL	VL	L	
Indoxacarb	22A	127.5	✓		✓			Medium	Low	H ¹⁸	VH	L	L	M	L	L	L	M	VL	M	M	VL	VL	VL	VL	VL	VH	H	
Dimpropridaz	36	120				✓		Long	Moderate	L	L	L	M	L	VH	VL	VH	VL	M	M	M	H	VH	L	VL	L	L	L	
Cyantraniliprole	28	60	✓			✓ ¹⁷		Long	Moderate	M	L	M	M	M	M	H	VH	M	M	M	VH	VL	VL	VL	H	H	H	H	
Sulfoxaflor (low)	4C	48			✓	✓		Medium	Moderate	L	M	L	L	L	VL	L	M	H	VL	H	H	VH	M	H	H	H	H	H	
Spirotetramat	23	96				✓		Medium	Moderate	M	H	L	VL	VL	VL	VL	VH	M	M	M	VL	M	M	M	M	VL	VL	VL	
Flonicamid	29	70			✓	✓		Medium	Moderate	VL	VL	VL	H	H	VH	H	VL	M	M	M	H	VL	VL	H	H	L	L	L	
Sulfoxaflor (mid)	4C	72			✓	✓		Medium	Moderate	M	H	L	L	VL	L	M	H	VL	M	H	VH	H	H	H	H	H	H	H	
Dinotefuran (low)	4A	18			✓		✓	Medium	Moderate	M	VL	M	M	VL	VH	M	VL	L	VL	VH	VH	VH	H	M	M	VH	VH	VH	
Abamectin*	6	5.4	✓ ¹⁹	✓				Medium	Moderate	L	VL	M	M	M	L	M	M	VL	M	M	M	H	M	M	M	M	VH	VH	
Emamectin benzoate	6	8.4	✓					Medium	Moderate	L	VL	VL	H	H	H	H	L	M	M	H	VH	VH	M	M	M	VH	VH	VH	
Propargite	12C	1500		✓				Medium	Moderate	M	M	H	M	H	VL	VL	VL	M	M	H	VH	H	H	H	M	L	L	VL	

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%); '—' 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. Ratings for total wasps have been revised to consider recent assays (see Footnote 7), and represent the highest potential impact on wasps, which may differ with crop stage and pest status in the field. Overall ranking has not been adjusted at this stage.
7. Rankings for *Eretmocerus* sp. primarily based on data from Qld DPI in laboratory bioassays.

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 (1 mm) 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


Lysiphlebus sp. wasp recently emerged from aphid 'mummy'. 2-3 mm. © M. Miles

Microplitis wasp pupa (3 mm) attached to medium helioverpa larva. © M. Dillon


Tachinid fly attacking helioverpa larva. 5-6 mm. © J. Wessels

TABLE 6: 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
*Bifenthrin	3A	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 registrations 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 post-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.

*Actives considered HHPs under the Better Cotton™ initiative.

CROP TO TOP

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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 regions now cover a diverse range of environmental conditions, planting dates and agronomic strategies. Be aware of any regional differences in plant development, 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 damage symptoms (such as shedding of squares or young bolls) may not be due to pests, but other causes, including physiological/environmental stresses.

Sampling and thresholds

'Sampling' in IPM 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.

Highly hazardous pesticides (HHPs) are pesticides that present particularly high levels of acute or chronic hazards to health or environment, according to internationally



Animals can also damage cotton – these gnawing marks are caused by mice. Permits are sometimes issued for rodent control in cotton – search for current permits at APVMA's PubCRIS database (permits tab).  Roger Lindeman

accepted classification systems or relevant international agreements/conventions, such as those listed in the Stockholm convention, Montreal protocol and Rotterdam convention. The Better Cotton™ initiative has banned the use of certain pesticides, and is looking to phase out others. In Australia, if an alternative is not available or appropriate (e.g. for resistance management or furrow application) temporary extended use may have been negotiated. Better Cotton™ growers are encouraged to regularly check the list of banned and restricted HHPs.

Note that registration of a pesticide active or product does not constitute a recommendation for its use.

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 6 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 58-63 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 (RMP) 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 'Applying pesticides' chapter of this guide. Insecticides and miticides can be highly toxic to humans and the environment. Carefully read and follow all label directions.

KEY INSECT PESTS	Page
Aphids	22
Armyworm (<i>Spodoptera</i> species)	27
<i>Helicoverpa</i> species	28
Mealybugs	32
Mirids	35
Mites	39
Soil and establishment pests	43
Stink bugs and stainers	45
Thrips	48
Whitefly	50
Other pests	56

USEFUL RESOURCES:



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



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



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Aphids

Cotton aphid – *Aphis gossypii*

Cowpea aphid – *Aphis craccivora*

Green peach aphid – *Myzus persicae*

Cotton aphid is the most common aphid 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 aphid incidence in most fields, but occasional outbreaks can still occur, particularly late in the season. Nymphs and adults can feed in the terminals, on young stems, on the undersides of leaves, and on developing fruit.



Aphids in cotton
youtu.be/Vi07GhSoQtg



Damage

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 also 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 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 for assistance. If cotton aphid hotspots occur early season, also check these areas for CBT symptoms.



Cotton aphid.  Tonia Grundy, Qld DPI



Cowpea aphid.  Tonia Grundy, Qld DPI



Green peach aphid.  Andrew Weeks, Cesar Australia

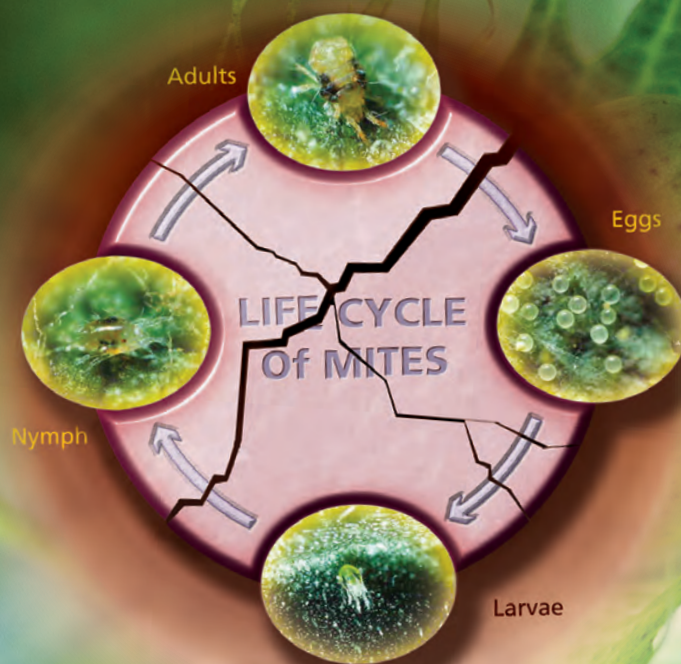
Green peach aphids are pale green and oval, and have 'W'-shaped tubercles (bumps on the head between the antennae) and long siphunculi (tubes between the back legs). Cotton aphid and cowpea aphid are rounder, don't have tubercles and the siphunculi are shorter. Adults and nymphs of cotton aphid are matt 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.

Sample 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 25).
- **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 cm² area is considered 'infested'. Also assess plants for the presence of honeydew.



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- Inhibiting the moulting process of nymphs
- Ovicidal activity – sterilises eggs
- Sterilises females

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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 (page 25) 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*.



Spot the parasitoid (mummy) amongst the aphids.

© Paul Grundy, Qld DPI

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 62-63) to help conserve beneficial populations that can assist in controlling any survivors from the insecticide.

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 has re-emerged 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 6).

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 prefers ratoon/volunteer cotton (that can act as a green bridge for CBT). Winter hosts include marshmallow, capeweed, thistles, and some legume crops such as faba bean. Spring and summer hosts include thornapples, nightshades, paddy melon, bladder ketmia, Bathurst burr and sunflower crops/volunteers.

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.



Aphid sampling and management in cotton
youtu.be/L9N64u1yi8E

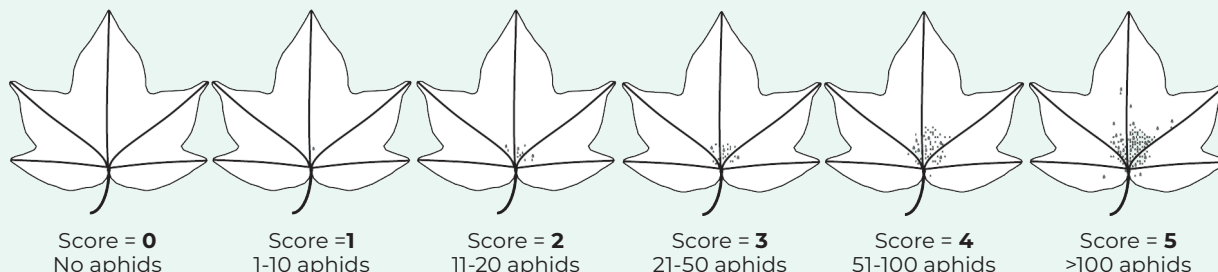


To submit surviving aphids for resistance testing, see the 'Sending samples for resistance testing' protocol on page 42.

COTTON APHID SAMPLING PROTOCOL – USE UNTIL FIRST OPEN BOLL

STEP 1: Collect and score leaves – calculate the Average Aphid Score.

Visit several locations and collect 20 leaves from each, taking 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**.



STEP 2: Calculate the Cumulative Season Aphid Score.

Use the table below to convert the Average Aphid Score calculated in Step 1 to a score that accounts for how long the aphids have been present in the crop. Multiply the value where the average scores from 'this check' and the 'last check' intersect by the number of days 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**.

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

Aphids can disappear due to predation by beneficials, changes in the weather or insecticide application. If aphids are sprayed, or the Average Aphid Score returns to '0' in 2 consecutive checks during the season, reset the Cumulative Season Aphid Score to '0'.

STEP 3: Estimate the percentage 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 and residual control to 21 days. 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 of 2 consecutive applications (and no more than 4 applications in total) 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 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 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 organosilicone 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.

Phorate (1B ; classified as a HHP in the Better Cotton™ initiative) is also registered for application at planting in some states (see label).

*See Table 5 for more details about impact on beneficial insects (including bees).

#For all control options always refer to the label for instructions.

Armyworm

Cluster caterpillar – *Spodoptera litura*

Lesser armyworm – *Spodoptera exigua*

Fall armyworm – *Spodoptera 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.

Although Bollgard® 3 (currently registered in Australia for the control of *Helicoverpa* spp.) has reduced the survival of *S. litura*, this species is naturally more tolerant

of Bt proteins than *Helicoverpa*, with control relying primarily on the Vip3A protein. When crops experience environmental stress, such as prolonged cloudy weather, Bt efficacy may be temporarily reduced, resulting in increased larval survival and, in some cases, population outbreaks. Larval survival may also increase when *S. litura* has intermittent access to non-Bt food sources. Effective weed management within Bollgard® 3 crops can help minimise alternative host plants and reduce opportunities for larvae to survive.

The only registered chemical insecticide for *S. litura* in cotton is chlorantraniliprole. High levels of resistance to Group 28 insecticides including chlorantraniliprole have been detected in *S. litura* populations in some regions of northern Australia.

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. First reported in Australia in 2020, it has since spread to many crop production districts. Although FAW has the capacity to feed on cotton, it appears to primarily prefer grass species with whorls (such as maize and sorghum), and to date no impact on cotton crops has been reported in Australia.



Cluster caterpillar eggs. © Paul Grundy, Qld DPI



Cluster caterpillar feeding on cotton flower.

© Sharna Holman, Qld DPI



Fall armyworm. © Melina Miles, Qld DPI



Lesser armyworm. © Melina Miles, Qld DPI

Helicoverpa

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

In conventional (non-Bt) 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 even in Bollgard® 3 crops larvae may still be present, and the risk of resistance requires careful management.

Damage

Larvae attack all stages of plant growth. In conventional 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

Examine 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 pest 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 (including parasitised eggs). Once squaring begins also note fruit retention, to gauge the potential 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 impact). 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	<i>Trichogramma</i> spp., <i>Telenomus</i> spp.
Larvae	glossy or spined predatory shield bugs*, big-eyed bug*, damsel bug*, assassin bugs*, red and blue beetle*, lacewings*, common brown earwig, lynx, tangleweb and jumping spiders; wolf spiders and carabids can attack late instar larvae	<i>Microplitis demolitor</i> , orange caterpillar parasite, two-toned caterpillar parasite
Pupae	common brown earwig	banded caterpillar parasite
Moths	orb-weaver spiders and bats	

*Key species for use in the beneficial to pest ratio formula.

Using the beneficial to pest ratio

The beneficial to pest ratio for helicoverpa can be used in both conventional and Bt cotton:

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

A minimum of 30 plants (or 20 metres of row by suction sampling) is needed as a representative sample. Only include the key beneficial insects (marked with * in the list above); at least three key beneficial species need to be present. Also estimate egg parasitism and deduct from the total number of eggs. Parasitism rates can vary greatly, although levels usually decline as the season progresses. To confirm 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.



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

	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.

Insecticide selection

Insecticides registered for the control of heliCOVERPA in cotton are presented in Table 8. Using more selective insecticide options will help to conserve beneficial insects (refer to Table 5). Be aware of resistance status in *H. armigera* and follow the insecticide resistance management strategy (IRMS).

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 DPIRD and supported by CRDC and GRDC, indicates resistance to indoxacarb is generally <10%, 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.

Although the industry has ceased monitoring broad-spectrum chemistry for resistance, field failures of synthetic pyrethroids and carbamates are still likely.

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 58-63). 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 where heliCOVERPA is likely to diapause. For Bt cotton crops, follow the pupae busting guidelines in the Bollgard Resistance Management Plan (RMP).



The larvae of *H. armigera* (left) have pale hairs compared to darker hairs on *H. punctigera* (right). © Hugh Brier, Qld DPI

More detailed information on identifying heliCOVERPA is available at thebeatsheet.com.au/key-pests/helicoverpa-identification-and-behaviour

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 section on pages 66-70.

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 appropriate Bollgard 3 RMP for cotton for your location.

Overwintering habit

In colder regions, *H. armigera* overwinters 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 to 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 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 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.

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

Active ingredient	MoA group	Resistance (<i>H. armigera</i>)	Overall impact on beneficials*	Comments#
<i>Bacillus thuringiensis</i>	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	Minimum of 80 L/ha water. Apply before crop closure by ground rig only.
Magnet®	Attractant	None detected	Very low	Use with insecticides as per label instructions.
Indoxacarb	22A	Widespread – moderate	Low	Maximum 3 applications per season.
<i>Clitoria ternatea</i> extract	UNE	Unknown	Low	Ensure good coverage. Treatment effects may take 3 or more days. Target egg hatch and small larvae. Maximum 5 applications per season.
Amorphous silica	—	Unknown	Low	Target egg hatch. Best results from two sequential applications 6-7 days apart. Will not control larvae >3 mm.
Chlorantraniliprole	28	Occasional – low	Low	Target brown eggs to 2 nd instar larvae (before they enter 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 2 nd 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 <i>H. punctigera</i> 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 to stressed plants. 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 neonates. 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 <i>H. armigera</i> . 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 <i>H. punctigera</i> >10 mm and/or <i>H. armigera</i> <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.
*See Table 5 for more details about impact on beneficial insects (including bees).
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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 DPI



Mealybug predators: Cryptolaemus ladybird beetle (left) and lacewing (right) larvae can look very similar to mealybugs.

© Zara Hall and Paul Grundy, Qld DPI

Beneficial insects are highly effective in keeping mealybug populations in check. No insecticide option provides 100% control, so mealybug management over the life of the crop is usually dependent on beneficials. Chemical insecticides should be used only in very specific circumstances, and good coverage is critical for effective control. 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). It is also important to 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 in 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.

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RIGHT ROTATION

- provides effective control at a range of life stages

RIGHT FIT

- soft on beneficial insects
- soft on pollinators
- ideal for IPM programs



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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 DPI



The pupal (top) and adult wasp (bottom) lifestyles of *Aenasius bambawalei*. © Zara Hall, formerly Qld DPI

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:



Several videos on the identification, management and natural enemies of mealybug are available on CottonInfo's YouTube channel

www.youtube.com/CottonInfoAust



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.
*See Table 5 for more details about impact on beneficial insects (including bees).

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 bugs 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 helioverpa 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. Mirid 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 DPI



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 highly mobile and easily disturbed so be careful when sampling to ensure numbers are not underestimated. When using a beat sheet, ensure you look for and count the fast-moving insects (including mirids, leafhoppers etc) first, to gain the most accurate estimate of pest numbers. It is also important to distinguish between nymphs and adults, as 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 pick up any rapid changes in pest activity 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, give comparable estimates of mirid abundance on plants up to about 10 nodes. After this, the efficiency of visual whole plant sampling declines (because the plants are too big to sample quickly and effectively), and 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.

Immediately start counting the number of adult mirids dislodged onto the beat sheet (before they have a chance to run or fly away). Also keep an eye out for mirid nymphs, as their more rounded bodies can easily be confused with other small green insects, such as aphids. Mirid nymphs have noticeably long antennae and are capable of moving much faster across the beat sheet than most other insects their size.

Accurate estimation of mirid numbers is closely linked to sample size (i.e. more is better), doing a minimum of 12-15 beat sheets per management unit (break larger paddocks into approximately 50 ha units) should provide reasonable estimates of the mirid density.

If using a standard (380 mm diameter) sweep net during early season checks, 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 12-13.

Thresholds

Economic thresholds highlight when the damage by a given population of pests exceeds the product and application costs of controlling it. Note that other costs that may arise later as a result of the control operation (e.g. the flaring of secondary pests such as silverleaf whitefly), and while cheap broad-spectrum products may appear to justify low pest control trigger points, 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 per hectare), 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/m² up until flowering aims to prevent an economic yield loss (see Table 10).

TABLE 10: Mirid thresholds

Economic factors		Thresholds (adults or nymphs/m ²)		
Product value	Cost of control*	Planting to 1 st flower	Flowering to 1 st open boll	
\$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 ²)	
Product value	Cost of control*		Planting to 1 st flower	Flowering to 1 st open boll
\$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 ²)	
Product value	Cost of control*		Planting to 1 st flower	Flowering to 1 st open boll
\$450	\$60	5	3	
\$550		4	2.5	
\$650		3.5	2	

Thresholds are based on beat sheet sampling, but are also applicable to sweep net sampling. Visual sampling is not recommended at low densities. At high densities, visual thresholds will be approximately half of the corresponding thresholds for beat sheet sampling.

*Cost of control indicates break-even point (1:1 cost benefit).

Deciding when to spray

Sometimes only a 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 mirids. Mirid nymphs are predated by big-eyed bugs and smaller instars of the above spiders.

Predatory shield bugs may also attack mirids. While none of these beneficials are considered to be specialist mirid predators, their presence can reduce overall mirid numbers and impact survival of developing nymphs.

Selecting an insecticide

Insecticide products registered for mirid control in Australian cotton are presented in Table 11. Using more selective insecticide options will help to conserve beneficial insects (see Table 5 on pages 16-17). 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.

Resistance profile

Mirids are not known to have developed resistance to insecticides in Australian cotton. However, it is possible that resistance could develop and so 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, several neonicotinoid (Group 4A) insecticides (acetamiprid, clothianidin, dinotefuran) could lead to 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 on 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, and mirids can migrate between these crops. Weed hosts include turnip weed, Noogoora burr, yellow vine, variegated thistle and volunteer sunflowers.

USEFUL RESOURCES:



Several CottonInfo videos featuring mirids are available on YouTube



www.youtube.com/CottonInfoAust



Download *IPM: Optimising your early season crop management* from cottoninfo.com.au/news-and-publications

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.
<i>Clitoria ternatea</i> extract	UNE	Low	Ensure good coverage. Maximum 5 applications per season. Treatment effects may not be seen for 3 or more days. May require a repeat application at 14-20 days if conditions favour pest development.
Indoxacarb	22A	Low	If populations are high, may only achieve suppression. Maximum 3 applications per season. 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 organosilicone penetrant. If populations are high, may only achieve suppression. 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 refer to the product label.

*See Table 5 for more details about impact on beneficial insects (including bees).

**Classified as HHPs under the Better Cotton™ initiative.

Mites

Spider mites:

Two-spotted – *Tetranychus urticae*

Bean – *Tetranychus ludeni*

Strawberry – *Tetranychus lambi*

Broad mite – *Polyphagotarsonemus latus*

Two-spotted spider mite is the main pest species; other spider mites rarely 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 may also be visible on the upper surface. Symptoms can differ markedly between species.

Two-spotted mites create 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.

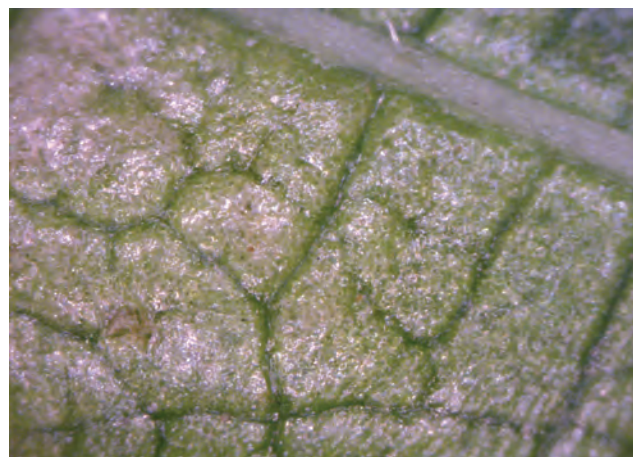
Bean spider mites result in white, intensely stippled areas on the lower leaf surface, but there is generally no reddening of the upper surface. Severe damage may result in some leaf shedding.

Strawberry spider mites can be very abundant (>90% of plants infested) but rarely affect yield. Damage is a light, sparse stippling or white dots on the underside of the leaf, with 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.



Damage to top and underside of leaves by two-spotted spider mite (left), strawberry spider mite (centre) and broad mite (right). © Carlos Trapero Ramirez, CSIRO; Paul Grundy, Qld DPI



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



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

© L. 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

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 at several widely separated locations within the field. At least 4-6 sites are usually needed to obtain a good estimate of mite abundance. 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

These thresholds and yield loss charts have been specifically developed for two-spotted mite. Bean spider mite is only half as damaging, and strawberry spider mite does not cause significant damage.

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). When >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 >20% of leaf area.
- **Squaring to first open boll:** Implement control if mite populations increase is >1% of plants infested per day in two consecutive checks, or if >30% of plants are infested.
- **First open bolls to 20% open bolls:** Control is only warranted if mites are well established (>60% plants infested) and are increasing rapidly (>3% per day).
- **Crop exceeds 20% open bolls:** Control is no longer warranted.

Using the yield reduction charts

A relationship between 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.

These charts only provide a guide for potential yield losses. You will also need to consider crop vigour, other pests (i.e. the potential for a control spray to flare mites) and the environmental conditions (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 around 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 helioverpa or mirid control, such as synthetic pyrethroids, fipronil, and organophosphates because key beneficial species are removed allowing resistant mite populations to flourish (see Table 5 on pages 16-17 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 62-63).

Resistance in mites

Two-spotted mite has a long history of developing resistance to miticides and effective product options are now limited, with currently no control option available for early season cotton that fits with IRMS principles.

Avoid consecutive sprays of the same miticide. If mite numbers rebuild after a miticide application, rotate to a product from a different chemical group. It is critical to avoid following up a field failure with a product from the same MoA group. Refer to the IRMS for more information.

Resistance profiles in two-spotted mites differ between growing regions. In northern NSW, there is moderate to high resistance to abamectin and diafenthiuron, while resistance to etoxazole remains very low. In contrast, resistance to etoxazole is moderate to high in southern NSW. Resistance to abamectin is low to moderate and diafenthiuron resistance is very low in southern regions.

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-leaved 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.

USEFUL RESOURCES:



Several videos featuring mites are available on CottonInfo's YouTube channel

www.youtube.com/CottonInfoAust



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	1.8	5.2	17.2	10.3	36.1	94.7	100	3.1	7.3	13.2	20.8	41.2	100	100
20	1.0	3.5	7.4	12.9	28.2	76.7	100	1.6	4.6	9.0	14.9	31.2	81.6	100	2.6	5.8	10.3	16.0	31.2	76.7	100
30	0.9	3.0	6.3	10.9	23.9	65.0	100	1.5	4.0	7.8	12.9	26.7	69.6	100	2.6	5.8	10.3	16.0	31.2	76.7	100
40	0.7	2.5	5.3	9.2	20.0	54.3	100	1.3	3.5	6.7	10.9	22.6	58.4	100	2.4	5.2	9.0	13.9	26.7	65.0	100
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	100	2.3	6.7	13.5	22.6	47.9	100	100	3.7	9.0	16.7	26.7	53.9	100	100
20	1.3	4.7	10.1	17.6	38.8	100	100	2.0	6.0	12.0	20.0	42.3	100	100	3.4	8.2	15.0	23.9	47.9	100	100
30	1.2	4.1	8.8	15.4	33.8	92.0	100	1.9	5.3	10.6	17.6	37.1	97.4	100	3.2	7.4	13.5	21.3	42.3	100	100
40	1.0	3.6	7.7	13.3	29.1	79.1	100	1.7	4.7	9.3	15.4	32.2	84.2	100	2.9	6.7	12.0	18.8	37.1	92.0	100
50	0.9	3.1	6.5	11.3	24.8	67.3	100	1.5	4.1	8.0	13.3	27.6	71.9	100	2.7	6.0	10.6	16.5	32.2	79.1	100
60	0.8	2.6	5.5	9.5	20.8	56.3	100	1.3	3.6	6.9	11.3	23.4	60.6	100	2.5	5.3	9.3	14.3	27.6	67.3	100
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
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	100	2.6	7.7	15.7	26.5	56.3	100	100	4.1	10.2	19.2	30.9	62.8	100	100
20	1.6	5.6	12.1	21.0	46.4	100	100	2.3	7.0	14.1	23.7	50.3	100	100	3.8	9.4	17.4	27.9	56.3	100	100
30	1.4	4.9	10.7	18.6	40.9	100	100	2.1	6.3	12.6	21.0	44.5	100	100	3.5	8.5	15.7	25.0	50.3	100	100
40	1.2	4.3	9.4	16.2	35.7	97.4	100	1.9	5.6	11.1	18.6	39.1	100	100	3.3	7.7	14.1	22.3	44.5	100	100
50	1.1	3.8	8.1	14.1	30.9	84.2	100	1.7	4.9	9.8	16.2	34.1	89.3	100	3.0	7.0	12.6	19.8	39.1	97.4	100
60	0.9	3.3	7.0	12.1	26.5	71.9	100	1.6	4.3	8.5	14.1	29.4	76.7	100	2.8	6.3	11.1	17.4	34.1	84.2	100
70	0.8	2.8	5.9	10.2	22.3	60.6	100	1.4	3.8	7.3	12.1	25.0	65.0	100	2.6	5.6	9.8	15.1	29.4	71.9	100
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	2.3	4.9	8.5	13.1	25.0	60.6	100
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

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. for heavy infestations collect 20 leaves, for light infestations collect 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 to prioritise products for testing.

7. Attach the sample details and send by overnight courier to:

Lisa Bird
Department of Primary Industries and Regional Development
Tamworth Agricultural Institute
4 Marsden Park Rd. Calala NSW 2340
Ph: 02 6763 1128 or 0438 623 906
Em: lisa.bird@dpird.nsw.gov.au

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	Low in northern NSW; Moderate to high in southern NSW	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	Moderate to high in northern NSW; Low in southern NSW	Low	Treatment at higher infestations may lead to unsatisfactory results. Maximum 2 applications per season.
Abamectin**	6	Widespread – medium/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 – medium/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 in some states (check label for application rates).

#For all control options ALWAYS refer to the label for instructions.

*See Table 5 for more details about impact on beneficial insects (including bees).

**Classified as HHPs under the Better Cotton™ initiative..

Soil and establishment pests

True wireworms – *Agrypnus* spp.

False wireworms – *Gonocephalum* spp.
Pterohelaeus spp.

Black field earwig – *Nala lividipes*

Symphyla – *Hanseniella* spp.

High numbers of soil pests can reduce plant establishment and vigour, particularly if seedling development is slow due to climate, allelopathy, disease or soil constraints. Note that a range of other factors with similar symptoms can also affect establishment (see Table 1 on page 6).

Sampling for soil pests

Pre-plant sampling is recommended, particularly in fields with a history of soil pest activity as there are no spray options available after planting. The most appropriate sampling method to use will depend on the pest type.

Grain or potato baiting (wireworm larvae and earwigs) is best done following planting rain or irrigations:

1. Soak insecticide-free sorghum 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).
2. Bury a dessert spoon's worth of soaked seed or a potato half (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 bait positions so you can easily find them again (high soil insect populations 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 marks on the potato will be immediately obvious.

Soil surveying (scarabs and symphyla) involves inserting a shovel to full depth at the plant line on the hill and carefully levering the soil out for closer inspection. Starting with the deepest soil, carefully break clods apart looking for signs of pests or movement.

Adult wireworm beetles are active in late spring, early summer and can be found aggregated near the soil surface under weeds (e.g. sowthistle, bulls head, grasses, volunteer cotton plants) and crop residue.

Factors influencing pest numbers

Distribution within a field is generally patchy, typically correlated with the presence of prior crop residues and weeds. Therefore, farm management practices can influence the composition and abundance of the pest species complex (for example poor control of weedy fallows may increase the abundance of soil pests).

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. Incorporating grain stubble prior to planting cotton may actually increase damage potential as any pests present may switch feeding activity from stubble to seedlings.

While no specific thresholds have been developed for establishment pests in cotton, one wireworm larvae or 2-3 earwigs per bait are considered potentially damaging in summer grains. Insecticide-treated grain baits at sowing may be useful for some pests, such as earwigs. Adjustments to planting times or irrigation management to minimise stress and improve the speed of establishment should be considered if pest numbers are high.

If establishment due to pest damage is low enough to warrant replanting, consider rotating to a less susceptible crop.

True and false wireworms

Both true wireworms (e.g. *Agrypnus* spp.) and false wireworms (*Gonocephalum* spp.; *Pterohelaeus* spp.) can attack germinating seeds, the hypocotyl and roots of young cotton plants.

The thin, creamy-yellow beetle larvae cause seedling death, young plant 'felling' and the result of this is patchy plant stands. Adult beetles can also chew seedlings at ground level. Wireworms are found under a range of cultivation and stubble retention regimes.

Conduct bait sampling prior to planting to determine wireworm abundance. Infestations detected after crop emergence cannot be controlled with baiting or surface spraying, so early detection is essential for effective management. Larvae are unlikely to be controlled with standard seed treatments, so if populations are high, consider an in-furrow insecticide treatment at planting (Table 14).



True wireworm larva. © Tonia Grundy, Qld DPI



False wire worm larvae and adult beetles – *Gonocephalum* sp. (left) and *Pterohelaeus* sp. (right).
© Jamie Hopkinson and Paul Grundy, Qld DPI



Sampling for soil insects
youtu.be/i_ODxTAeASw



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.

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.

Earwig adults and nymphs are an occasional establishment pest that can be quite difficult to spot in dark soils. Species vary by region: black field earwig (*Nala lividipes*) is more common in warmer regions, and European earwig (*Forficula auricularia*) in southern cotton areas. In-furrow insecticide treatments are ineffective against dense populations and the efficacy of seed dressings is currently unknown.

Symphyla (*Hanseniella* sp.) are small pale centipede-like arthropods found in most soils. Usually organic matter feeders with minimal crop impact, they may contribute to crop establishment issues in some fields, particularly under dry conditions. Chemicals are usually ineffective: symphylans can avoid exposure to in-furrow applications, and standard seed dressings are unlikely to provide protection at high densities. Irrigation may decrease symphyla activity in the upper profile for up to two weeks, which may assist crop recovery.

Whitegrubs (various species) 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.



Black field cricket. © J. Wessels



Cutworm larvae. © P. Room



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



Various microfauna are relatively common in most soils, but rarely cause significant crop damage. Pictured above: a symphylan (left) and dipluran (right). Sample for symphyla using soil surveying rather than baits. © Paul Grundy, Qld DPI



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	Expected impact on beneficials*	Comments#
Phorate**	1B	Very low	Maximum 1 application per season.
Bifenthrin**	3A	Very low	Use a coarse spray in a total volume of 60-100 L/ha. Maximum 1 application per season.

#For all control options ALWAYS refer to the label for instructions.

*Excluding thrips. Note that the assessments of impact on beneficial insects in this guide are based on contact, which is unlikely to occur for pesticides applied at planting. For the impacts of foliar-applied products on beneficial insects (including bees), see Table 5.

**Classified as HHPs under the Better Cotton™ initiative.

Stink bugs and stainers

Brown stink bug – *Dictyotus caenosus*

Coreid bug – *Aulacosternum nigrorubrum*

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 listed 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.

Several exotic stink bugs are considered a biosecurity risk and if suspected should be reported to the plant pest hotline on 1800 084 881 (see the '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 feeding. 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. Consider the potential loss of seed viability when managing seed production crops.



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

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

Cotton 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.

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 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).



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

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	1 st or 2 nd instar GVB nymphs (cluster of 10+)	1.0
	3 rd instar GVB nymphs	0.5
	4 th or 5 th instar GVB nymphs	1.0

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.

Key beneficials

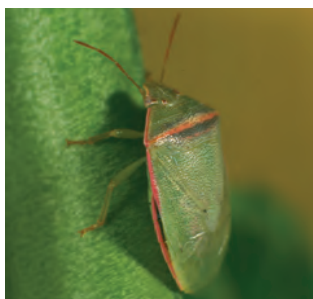
GVB eggs are frequently parasitised by a small, introduced parasitoid (*Trissolcus basalis*). After hatching, the larvae remain inside the GVB egg, turning it black as the wasp develops. Note that some predatory shield bug eggs are also dark, but have a ring of spines near the top.



Green vegetable bug. © Paul Grundy, Qld DPI



Green stink bug. © Joe Wessels



Red banded shield bug. © Joe Wessels



Brown stink bug. © Joe Wessels



Harlequin bug. © Tonia Grundy



Mating red cotton bugs (top). Adult and juvenile pale cotton stainers (bottom). © Paul Grundy, Qld DPI and Lewis Wilson



Stainer-like bugs that may be present in northern crops. Top: Coreid bug 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, NT DAF



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 introduced tachinid fly, *Trichopoda giacomellii*. Eggs are laid externally, often around the pronotum (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 impact of natural enemies on stainers in Australia has not been studied.

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 Group 1 resistance in aphids, particularly if an organophosphate (OP) has been used 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 helioverpa 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 secondary pests.

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 (turning a bronze or purplish 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:



Green vegetable bugs in cotton
youtu.be/U9bCoVtgsN8



See page 15 of this guide for images of predatory shield bugs. More images of stink (podsucking) bugs and predatory bugs can be found at
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 February 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.
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.
Emamectin benzoate/Acetamiprid	6/4A	High	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.

#For all control options ALWAYS refer to the label for instructions.

*See Table 5 for more details about impact on beneficial insects (including bees).

Thrips

Seedling thrips – *Thrips tabaci*

Tomato thrips – *Frankliniella schultzei*

Western flower thrips – *F. occidentalis*

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

Both nymphs and adults can damage seedlings. The most obvious symptoms are smaller, crinkled leaves with a visible 'silvering' on the undersides. At very high densities, the growing terminal may die, delaying the plant's growth.

Populations can also be found in flowers and on leaves mid-late season, particularly in crops with minimal pesticide use – development (egg to adult) can happen in as little as 10 days. Extremely high numbers can lead to leaf stunting and damage, especially along the veins, but late season damage rarely justifies control. Thrips feeding on pollen is unlikely to affect pollination or fruit set.

Sampling

Count thrips using a hand lens on 20-30 separate seedlings. Also assess the damage severity by estimating the percentage reduction in leaf area (if damaged young leaves are less than 1 square centimetre then the reduction is usually >80%). If high numbers are present (>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 seed or furrow-treated crops indicates that the population is actively breeding and the early insecticide offered insufficient control.



Thrips nymph on underside of leaf. © Tonia Grundy, Qld DPI



Thrips feeding on pollen can transmit tobacco streak virus (TSV), but are unlikely to significantly impact yield, either directly or indirectly. © Tonia Grundy, Qld DPI



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

© Simone Heimoana

Monitor 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). Mid to late season, monitor for thrips in flowers and on the undersides of upper canopy leaves. Also look for thrips when sampling for mites, as their presence in mite colonies indicates potential natural control of the mites.

Thresholds

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

Early severe leaf damage can result in delayed maturity or yield loss. Northern and central regions with warmer climates have lower risk because plants can outgrow and compensate for damage, with yield loss only occurring about one year in 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, and in Southern NSW regions other issues relating to a cool start and associated maturity delays can further compound thrips impact, and the ability of the crop to compensate after damage must be carefully considered.

Thrips populations 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. Cotton seed treatments will not control western flower thrips, but this species is not normally abundant early in the season.

THRESHOLD: Seedling to 6 true leaves

80% reduction in leaf area
+
10 thrips (adults and nymphs) per plant



Thrips damage to lower nodes with terminal showing new growth without damage. © Lewis Wilson

Neonicotinoid (imidacloprid; Group 4A) resistance has been detected in seedling thrips from cotton, and may affect neonicotinoid seed dressing efficacy. Other control measures may be required if significant leaf damage continues past 6-8 nodes.

In older crops, the feeding damage rarely affects yield. Thrips are also predatory, which may moderate their feeding on plants (for example tomato thrips nymphs can eat 2-6 mite eggs per day), so do not consider management action unless over 30% of leaf area is damaged in the top six nodes in pre-cut-out crops or more than 50% of leaf area is damaged after the crop has cut-out.

Key beneficials

Predators of thrips include minute pirate bug, lacewings and ladybird beetles, but high numbers of natural enemies are unlikely to be present in seedling crops.

Selecting an insecticide

Insecticide products registered for the control of thrips in Australian cotton are presented in Table 17. Insecticide seed treatments usually provide protection from thrips during crop establishment, however a neonicotinoid (4A) 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.

In Australia, western flower thrips are resistant to pyrethroids (3A). Pyrethroid and organophosphate (1B) resistance has been detected in some seedling thrips in horticulture but resistance has not yet been detected in tomato thrips. Resistance to fipronil (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 is suspected.

Overwintering habit

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

Alternative hosts

Thrips can feed and reproduce on a range of weed hosts during winter and spring, and while adults may migrate into flowering wheat crops they 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.

USEFUL RESOURCES:



Several videos featuring thrips are available on CottonInfo's YouTube channel

www.youtube.com/CottonInfoAust



Silva, R. et al. (2018). Seasonal abundance of cotton thrips (Thysanoptera: Thripidae) across crop and non-crop vegetation in an Australian cotton producing region. *Agriculture, Ecosystems & Environment* 256: 226-238

doi.org/10.1016/j.agee.2017.12.024

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; classified as a HHP under Better Cotton™) 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 Tables 5 and 6.				

Whitefly

Silverleaf – *Bemisia tabaci* (MEAM1)

Greenhouse – *Trialeurodes vaporariorum*

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

Greenhouse whitefly is an infrequent pest of cotton, distinguished from SLW by wing shape and the presence of hairs on the nymphs (see photos on right). Other native *Bemisia* species are also occasionally present in cotton crops but their population growth is relatively slow. The recommendations in this section therefore focus on management of 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, dried SLW honeydew has a non-sticky matte sheen that can be difficult to visually detect. However, trehalulose melts at 48°C, a temperature reached during ginning and milling. Its presence can result in downgrades or rejection for stickiness during processing.

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



Adults and nymphs of SLW (left) and greenhouse whitefly (right).

© Richard Lloyd, Qld DPI

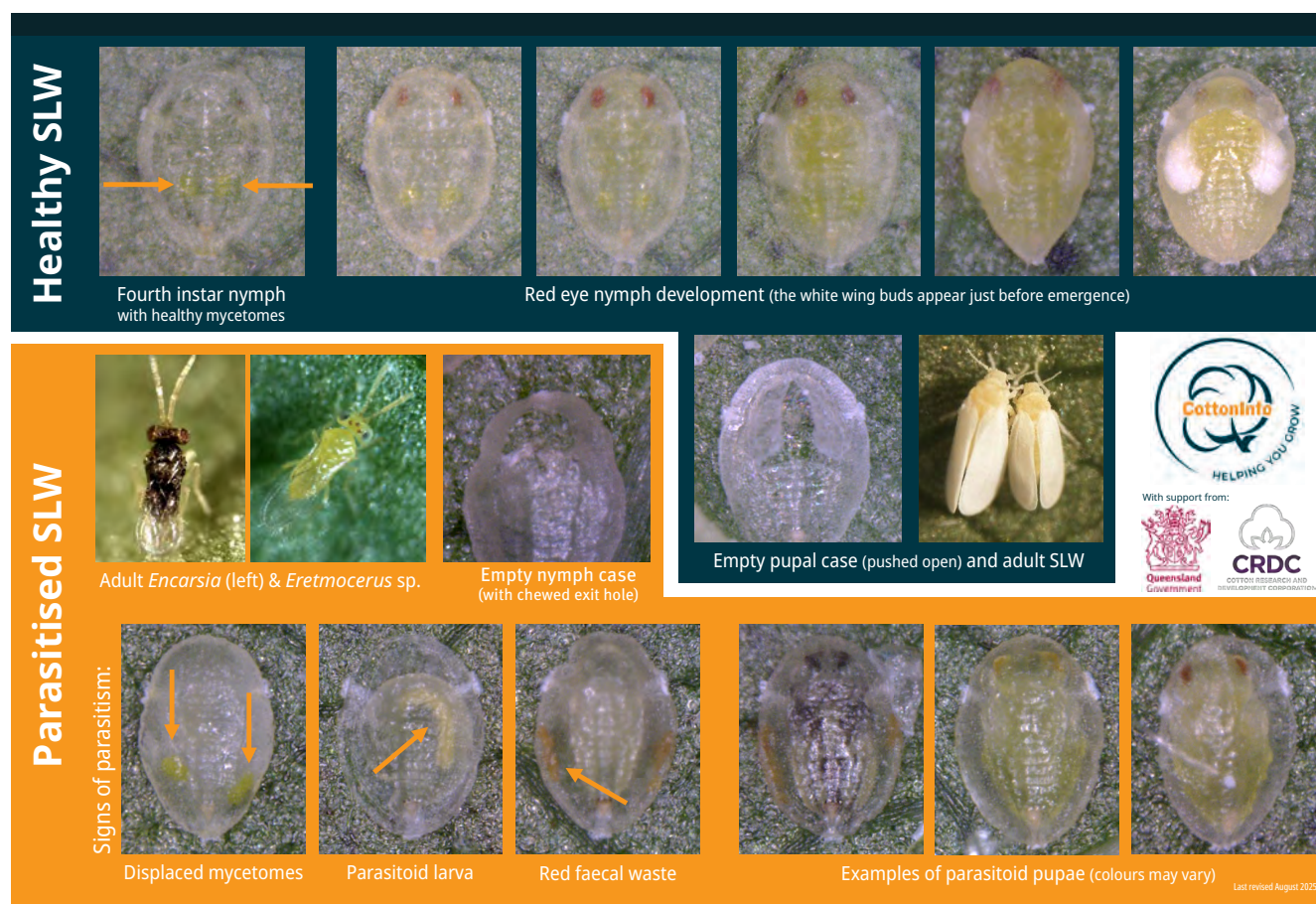
Key beneficials

Natural enemies can play a vital role in the successful management of whitefly.

The tiny wasps, *Encarsia* and *Eretmocerus* species are important parasitoids of SLW nymphs (see examples of parasitised SLW nymphs below). The augmentative release of *Eretmocerus* sp. is a management approach that is used by some growers.

Predators of nymphs include big-eyed bugs, pirate bugs, lacewing larvae, apple dimpling bugs, brown smudge bugs and ladybird beetles.

Avoid early season use of broad-spectrum insecticides, particularly synthetic pyrethroids and organophosphates.





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Sampling and the threshold matrix

SLW populations can grow rapidly, particularly when natural enemies have been disrupted by insecticides. 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. Start sampling during early flowering (750 DD) and establish a population baseline to compare against as the season progresses. Avoid field edges and take sufficient samples (30+ leaves) to represent the field.

1. Sample from 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 lower surface. **If two or more are present, the leaf is considered infested.**
2. Calculate the proportion of infested leaves and consult the threshold matrix to identify your risk area in relation to the DD crop development stage:
 - 'Low risk': no immediate action is needed. Continue to monitor the situation.
 - 'Moderate risk': assess the level of infestation over 2-3 consecutive checks. If the population is increasing a control decision is likely.
 - 'High risk' (mid-flowering; i.e. after about 800 DD): management action is required.
4. Consider natural enemy conservation when making control decisions; *Eretmocerus* spp. in particular can be effective biocontrol agents from first open boll onwards. Although parasitism levels are not specifically included in the matrix, they can provide a general indication of future nymph density trends, particularly after cut-out.
5. Assess nymph mortality (due to parasitism, predation or an applied insecticide) from cut-out or after an insecticide targeting SLW has been used. Nymph viability is an important factor in management decisions, particularly during open bolls.

Parasitism in younger crops is usually very low; populations undisturbed by pesticides build up quickly, but can lag behind SLW population increases. Insect growth regulator (IGR) products (pyriproxyfen and 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.

The activity of surviving parasitoids and other natural enemies is usually sufficient while bolls are opening to prevent a SLW population rebound. However, consider your timing carefully as these products have a restricted number of sprays per season.

Actively monitor nymph viability from crop cut-out onwards. During defoliation, falling leaves take nymphs with them to the ground but adult SLW leave the crop, moving to nearby hosts. **The matrix is unlikely to be useful in cotton that has received an influx of these relocating adults.**

Distinguishing healthy from parasitised or dead nymphs requires magnification and experience:



Identifying parasitism in silverleaf whitefly
youtu.be/SO0cedrGIQI



The SLW parasitism visual guide on the previous page can be downloaded from

thebeatsheet.com.au/resources/factsheets



Two large nymphs is considered 'infested'. No further counting on this leaf is required.  Georgia Ditchfield, Qld DPI

Late season considerations

If there is late season mass-immigration of adult SLW into crops, base your management decisions on:

1. expected time to defoliated leaf drop
2. lint contamination level
3. prior chemical use (from a resistance management perspective) – avoid multiple applications from the same mode of action.

For SLW management at or prior to the first pass of defoliant, consider the potential efficacy of products, along with any control delay, residual impact and withholding periods (WHPs). If honeydew contamination risk is high, consider defoliating early.

Also monitor for honeydew on lower leaves (particularly if there is open cotton) that would indicate some remedial action should be taken to prevent boll contamination.

- If defoliation is not due for 10-14 days and honeydew is collecting on the leaves, consider managing SLW numbers with a knockdown product.
- 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, use a systemic product with residual activity to target both nymphs and adults within the canopy.

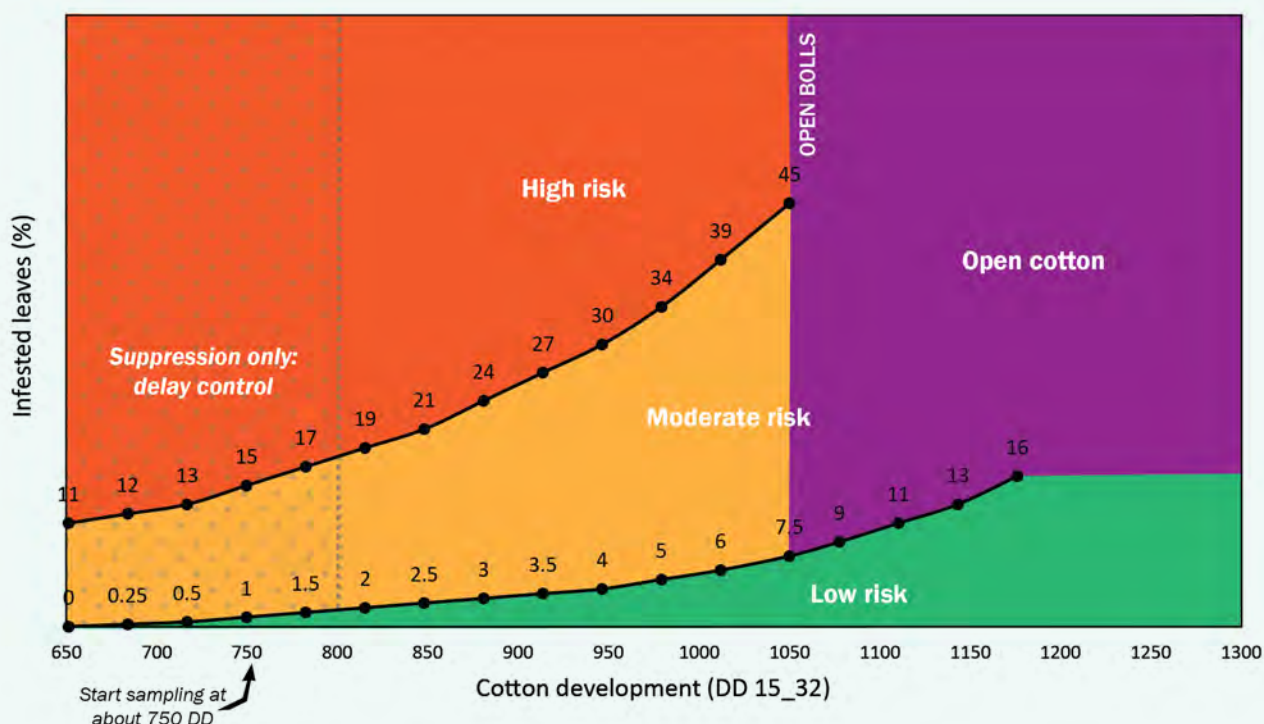
Selecting an appropriate insecticide

Insecticides registered for SLW control are presented in Table 18. A key challenge in managing SLW 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).

When applying insecticides to control SLW consider:

- **Impact on natural enemies** that can assist in controlling SLW that survive the insecticide.
- **Insecticide mode of action.** Is the impact immediate or delayed? 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** as post cut-out, insecticides with limited plant penetration and or poor application may not provide adequate control.

SLW SAMPLING AND THRESHOLD MATRIX



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.		
Mid-flowering to first open bolls (800-1050 DD)	ZONES		
	Low risk:	Moderate risk:	High risk:
	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. Sampling results are naturally variable, so 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 to assist in 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.	

Resistance profile of SLW

When SLW was first detected in Australia in 1994 it already possessed resistance to many older insecticide groups, including pyrethroids (3A) and organophosphates (1B). Resistance to bifenthrin (3A) is geographically widespread but at a low frequency within populations.

SLW also have widespread, high frequency partial cross resistance to neonicotinoids (4A). Resistant SLW can detoxify imidacloprid and clothianidin, but not acetamiprid or dinotefuran.

The severity of resistance to the insect growth regulator pyriproxyfen (7C) has declined in recent years, but low level resistance is still widespread.

Resistance to spirotetramat (23) is also widespread, but outside of horticultural regions remains at a low frequency. Very high resistance to Group 23 is known to be present in the Lockyer Valley and Burdekin regions. Group 23 resistance is due to a dominantly-inherited target site mutation, meaning it can develop rapidly and once established, reversal is unlikely.

Selection for resistance in SLW populations can happen very quickly. Comply with the IRMS (pages 62-63) and avoid reliance on the same insecticide every year to help ensure the products available for SLW control remain efficacious into the future. **DO NOT APPLY PYRIPROXYFEN OR SPIROTETRAMAT MORE THAN ONCE WITHIN A SEASON.**



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

Overwintering habit

Whitefly does not have an overwintering diapause stage, relying on alternative host plants to survive. Winter generation times are temperature dependent: 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 cucurbits. 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.

Avoid planting cotton near preferred SLW host crops such as melons and 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.

If SLW populations are consistently high in your area over multiple seasons, consider planting okra-leaf varieties, which tend to have lower populations of SLW.

USEFUL RESOURCES:



Sampling for and managing silverleaf whitefly
youtu.be/suhplrtHpa4



The CottonInfo website has two SLW factsheets available: one on general identification and management, and another specifically on sampling and the threshold matrix:



Find both fact sheets via
cottoninfo.com.au/news-and-publications



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



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 4 th instar nymph to adult, and reduces adult female fertility. Ensure good coverage. Maximum 1 application per season.
<i>Clitoria ternatea</i> 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	Unknown	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	Not detected	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	Target early developing populations. Maximum 2 applications per season.
Spirotetramat	23	Widespread – low (very high in Lockyer Valley and Burdekin regions)	Moderate	Controls nymphs and causes sterility in females. Translaminar and systemic mobility (phloem and xylem). Use high rate for 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. 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 higher rate if rapid population increase is likely. 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.

*See Table 5 for more details about impact on beneficial insects (including bees).

**Classified as HHPs under the Better Cotton™ initiative.

Other insect pests

A range of other minor and/or sporadic pests can also occur in cotton, with some only found in specific regions. In some cases, their damage is superficial (e.g. Rutherglen bugs) or they are just passing through and no action is required. If encountering an unfamiliar specimen, aim to take photos and/or collect a sample, as it could be an exotic pest.

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*) is present in Central Queensland and coastal areas and attacks 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

Cotton looper – *Anomis flava*

Named for the distinctive looping movement of larvae, cotton looper is rarely a pest in modern cotton farming systems as it is usually incidentally controlled by Bt toxins in Bollgard crops and/or spray applications for other pests.

Cotton tipworm – *Crociosema plebejana*

Newly hatched cotton tipworm larvae look similar to *helicoverpa*, but remain cream with a dark head capsule. They graze on cotton terminals before burrowing into the stem, causing tipping-out and potential developmental delays to younger plants. They are usually only found in cotton when their preferred host (marshmallow weed) dies off in early summer. Once in the stem, larvae are difficult to reach with insecticides, but this species is rarely been a pest in current production systems, as Bt cotton appears to provide good incidental control.

Cottonseed bug – *Oxycarenus luctuosus*

A dark body and folded transparent wings centered with a black spot give these small bugs a distinctive appearance. They can be found on plants from the early vegetative stages on, but don't feed or reproduce in cotton until the bolls are open and ripe seed is accessible. Nymphs are bright red and can be found in clusters amongst the lint.

While both adults and nymphs can feed on seed, their impact is usually minor and confined to late season bolls, and active control measures are not required.



Cotton looper larva. © Lewis Wilson



Cotton tipworm egg and young larva. © C. Mares



Cottonseed bug adult and nymphs. © T. Smith and C. Mares

Leafhoppers (jassids)

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

An exotic leafhopper species (Indian cotton jassid) is reported to be capable of causing up to 25% yield loss overseas. See the 'Biosecurity' chapter for more information.

Redshouldered leaf beetle – *Monolepta australis*

Redshouldered leaf beetle adults chew leaves, terminals, squares and the surface of cotton bolls.

They are rarely found in the majority of cotton-growing regions, however, in the tropics (particularly after good rains), swarms of beetles can cause significant damage to patches of plants.

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.

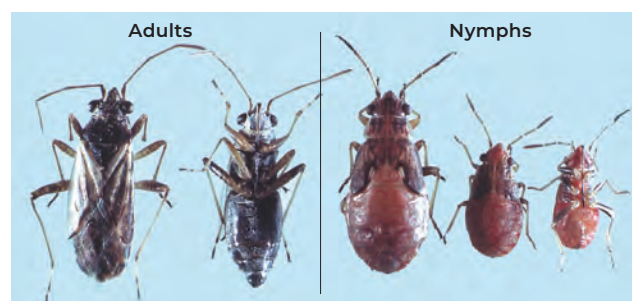
However, in some seasons, extremely high numbers of starving nymphs can migrate by walking from adjacent fields, particularly those with maturing sunflower or canola crops. These nymphs have the potential to damage border areas of cotton fields.

Cage experiments exposing 5 day old bolls to RGB 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 – monitor the crop for other sucking pests.

Weevils

Occasionally leaf or root-eating weevils such as the garden weevil (*Phlyctinus callosus*) are found in cotton crops. They are not the same as cotton boll weevil, a high priority exotic pest that burrows into bolls (see the 'Biosecurity' chapter for more information).

The bicoloured weevil (*Eudelodes bicolor*) has been reported in cotton in the Northern Territory, and its pest status is currently under investigation. III



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



Garden weevil. © C. Mares



Bicoloured weevil adults and larva on cotton flowers (insert). © Simon Ong, NT DAF



Cotton leafhopper (insert) and suspected lucerne leafhopper damage. © Paul Grundy, Qld DPI



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

Insecticide Resistance Management Strategy (IRMS) for 2026-27

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 66-70).

Principles underlying the IRMS

- Monitor pest and beneficial populations. Consider species as well as abundance.
- Levels of resistance can vary significantly between regions. Be aware of the current resistance risks in your area.
- 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.

The general principles of the IRMS are applicable to all pests and growing regions. 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 2026-27 cotton season

- **Current resistance levels mean two-spotted mite control options are limited.** There is widespread medium to high resistance to Group 6 (e.g. abamectin), Group 3A (bifenthrin), and Group 12A (diafenthiuron), and emerging resistance to Group 10B (etoxazole). There is also currently no control option available for early season cotton that fits with IRMS principles.
- **Ensure adherence to IRMS for all silverleaf whitefly products.** Resistance to pyriproxyfen in SLW is increasing in some regions, most noticeably in the Namoi and St George areas. To avoid loss of product efficacy DO NOT use more than 1 application of pyriproxyfen per season. Resistance to spirotetramat is low but widespread in most regions but could develop rapidly, with reversal unlikely if it becomes entrenched. Both products are limited to one application per season, except for a 'double knock' use of spirotetramat for mealybug (2 applications 14 days apart). Continue to consider resistance risk when utilising any SLW product.
- **Aphid resistance to Group 1 actives is likely to lead to field failures in most regions when using these products.** Cross resistance also occurs between Group 1A (dimethoate and phorate) and pirimicarb (Group 1B). If using an at-planting treatment of phorate, do not apply pirimicarb or dimethoate as the first foliar spray. Do not use pirimicarb and dimethoate in the same field. Avoid dimethoate usage until late season. Targeting aphids with diafenthiuron has contributed to mite resistance – always consider the presence of other pests when making control decisions.
- **Consider risk to bees.** Bees are susceptible to many insecticides used on cotton, however fipronil risk to managed hives is highlighted in the IRMS due to the potential for extended residues. The industry recommends that fipronil should not be used on flowering crops. Refer to product label for any specific statement about risk to bees.
- **Maintain an area-wide perspective when considering your management options.** 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 42.



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|  Horizon®* |  Wizard® 36 |
|  Lascar® | |

Herbicides

- | | |
|--|--|
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|  Durion 900 |  Shogun® |
|  Elevate® |  Sierra® 160 SL |
|  Firepower® 900 |  Spraytop® 330 |
|  Monsoon® | |

PGRs

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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 (pages 7-11) 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 pyriproxyfen 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). III

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

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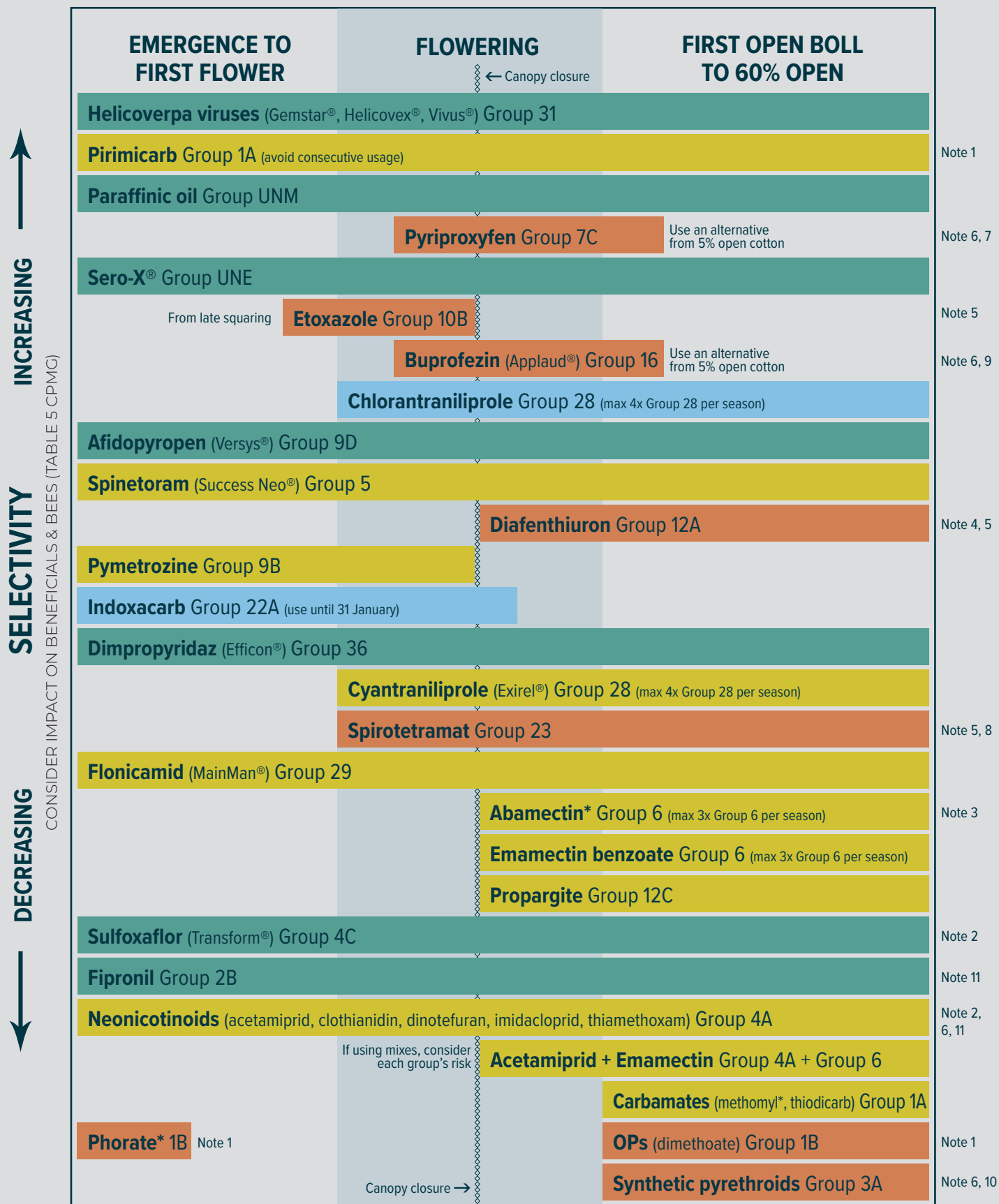


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Insecticide Resistance Management Strategy 2026/27

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



*examples of highly hazardous pesticides (HHP) under Better Cotton™: accredited growers must consider current HPP status of products before use.

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 silverleaf 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 noted on the right of the table 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 resistance to pirimicarb/dimethoate (Group 1) mean **field failures in most areas are likely.**

1. Early season dimethoate application for mirids has contributed to strong pirimicarb resistance in aphids and field failures. DO NOT use pirimicarb and dimethoate in the same field. If applying phorate at planting DO NOT use pirimicarb or dimethoate early season to avoid cross resistance.
2. DO NOT follow a neonicotinoid seed treatment (4A) with a foliar neonicotinoid (4A) when aphids are present. If there is an alternative, do not follow a neonicotinoid with sulfoxaflor (4C) to avoid cross-resistance.

Mites: A high level of caution is recommended as **mite control options are limited.** In northern NSW there is moderate to high resistance to abamectin and diafenthiuron. In southern NSW there is high resistance to etoxazole (10B). No miticides are recommended before late squaring – sow into clean fields to avoid mite displacement from herbicide-treated weeds. There is potential for mites to exchange between cotton and maize when grown in close proximity.

3. Do not prophylactically add abamectin (6) to mirid sprays.
4. Moderate resistance to diafenthiuron (12A) continues to be identified in northern NSW. DO NOT use more than 1 application/season irrespective of target pest (see label for pest registrations).
5. Low levels of etoxazole (10B) resistance has been detected in northern NSW and very high levels likely to cause field failures are present in southern NSW. DO NOT use more than 1 application per season and avoid consecutive etoxazole usage in maize and cotton crops grown within close proximity. see IRMS for product window recommendations.

Silverleaf whitefly: After a period of stability, pyriproxyfen (7C) resistance has increased along with continued increases for spirotetramat (23). SLW has low levels of resistance to pyrethroids in all regions.

6. For more guidance, see cottoninfo.com.au/publications-and-resources/2024-silverleaf-whitefly-sampling-and-thresholds
7. Resistance to pyriproxyfen (7C) is low but widespread, with elevated levels in the Namoi and St George regions. To avoid loss of product efficacy DO NOT use more than 1 application of pyriproxyfen per season. Buprofezin would be a suitable substitute IGR in these regions for 2026/27.
8. Low level spirotetramat (23) resistance has been detected consistently in most regions and continues to worsen. Resistance levels are EXTREME in Lockyer and Bowen regions. Notably higher levels are present in the St George, Border Rivers, Gwydir and Namoi regions. ALL REGIONS - switch to another product, particularly if spirotetramat (23) was utilised in the previous season. Resistance can develop rapidly and reversal of resistance is unlikely. DO NOT use more than once per season unless targeting mealybugs.
9. Unless targeting mealybugs, do not use buprofezin (16) more than once per field.

Helicoverpa armigera: Resistance has stabilised. Continue to adhere to IRMS.

10. High pyrethroid (3A) resistance in *H. armigera* populations. Expect field failures.

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

11. Imidacloprid (4A) and fipronil (2B) resistance in cotton seedling thrips is likely. If resistance is suspected, consider phorate as an at-planting alternative. Consider alternatives to neonicotinoids and fipronil for first foliar spray.

- ALWAYS FOLLOW LABEL DIRECTIONS.
- ALWAYS CONSIDER PRODUCT IMPACTS AND LABEL DIRECTIVES FOR BEES. NOTE THAT WITH ADVENT OF VARROA MITES HIVES MAY BE MORE SENSITIVE TO INSECTICIDE IMPACTS.
- CONSIDER IMPACT ON BENEFICIALS (Table 5 in the *Cotton Pest Management Guide 2026-27*). IMPLEMENT AN IPM STRATEGY THAT INCLUDES GOOD FARM HYGIENE AND CONTROL OF OVERWINTER HOSTS.
- PUPAE BUST CONVENTIONAL COTTON CROPS AFTER HARVEST.

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
1B (organophosphates)	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	<i>Bacillus thuringiensis</i>
12A	diafenthiuron
12C	propargite
16	buprofezin
22A (oxadiazines)	indoxacarb
23	spirotetramat
28 (diamides)	chlorantraniliprole cyantraniliprole
29	flonicamid
31 (baculoviruses)	<i>Helicoverpa</i> sp. viruses
36	dimpropyridaz
UNE (botanical extracts)	<i>Clitoria ternatea</i> extract
UNM (mineral oils +)	paraffinic oils

*Actives with HHP status under the Better Cotton™ initiative

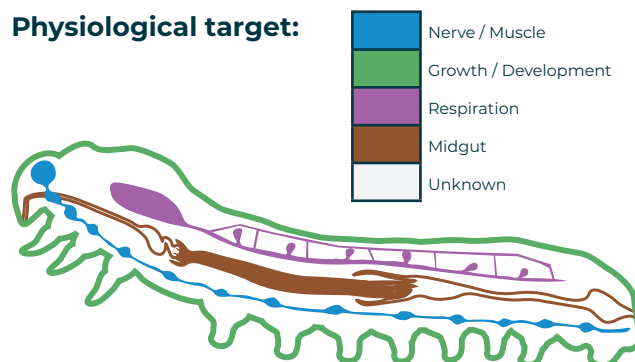
Insecticides are classified by how they affect arthropods. Grouping products by their mode of action (MoA) and further into subgroups with distinct chemical structures (denoted by letters) allows the user to see which products act on the pest in a similar way and choose products that are less likely 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. Also note that some products may take significantly longer than others to kill the target pest.

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:



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

HHP restrictions

Under the Better Cotton™ initiative (certification is available through the myBMP program), several actives classified as highly hazardous pesticides (HHPs) are being phased out, and their use by Better Cotton™ growers is either banned completely or temporarily permitted for a specific purpose. While some of these HHPs are no longer used in the Australian cotton industry, examples of products still available include methomyl (Group 1A), phorate (1B), lambda-cyhalothrin (3A), bifenthrin (3A) and abamectin (6).



USEFUL RESOURCE:

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:

[irc-online.org/mode-of-action](https://www.irc-online.org/mode-of-action)



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Bollgard® 3 Resistance Management Plan (RMP)

Resistance is the greatest threat to the continued availability and efficacy of Bt cotton in Australia. The Resistance Management Plan (RMP) for Bollgard® cotton was established as a pre-emptive measure to mitigate the risk of resistance developing to any of the insecticidal proteins contained in Bt varieties, with the aim of preventing field level changes in resistance that could lead to control failures.

The RMP is based on three principles:

1. Minimise exposure of *Helicoverpa* spp. to the Bt toxins
2. Provide a susceptible population of moths to mate with resistant individuals
3. Remove resistant individuals at the end of the cotton season

There are currently two versions of the RMP: one for central and southern growing regions, and one for northern Australia.

Bollgard® 3 cotton contains Cry1Ac, Cry2Ab and Vip3A toxins, derived from the soil bacteria *Bacillus thuringiensis*. Although crops with multiple toxins should be relatively robust, especially if the 'stacked' toxins kill insects in different ways, stack resilience depends on both the efficacy on larvae and the levels of resistance to each individual toxin.

The offspring of matings between resistant (RR) and susceptible (SS) moths carry one gene from each parent (RS) and are referred to as heterozygotes. If the susceptible gene is dominant, the RS individual remains susceptible to the Bt toxin, however, the offspring of two heterozygotes will have a 25% chance of carrying both R genes. In a Bt crop where susceptible individuals have high mortality rates, these RR offspring are more likely to survive and mate with other individuals that carry an R gene.

Until the widespread adoption of Bt cotton there would have been less exposure of *Helicoverpa* sp. to these toxins, and therefore minimal selection for resistance. However, with most of the industry now using the technology, it is possible that *Helicoverpa* sp. could adapt, and 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

Resistance monitoring of field populations is undertaken in Australia as a cooperative effort between Bayer and CSIRO. The data sets show that while there has been no significant increase in the frequencies of Cry2Ab and Vip3A resistance alleles in *H. armigera* and *H. punctigera* over the longer term, levels are still higher than expected. Also, the expression of Cry1Ac and Vip3A can vary throughout the season and is not always high enough for the individual insecticidal proteins to control susceptible insects.

However, according to the 2025-26 monitoring program, there is currently no resistance to Bollgard 3 as a stack that would affect its field performance.

Cry1Ac: Although the Cry1Ac toxin is more common in Australian soils than the Cry2Ab and Vip3A toxins, resistance to it is rare. A low frequency (<0.05%) recessive gene detected in *H. armigera* has the potential to confer

high-level resistance to Cry1Ac. At least 2 different forms of resistance to Cry1Ac (at 0.1% frequency) have been isolated from *H. punctigera* populations.

Cry2Ab: A recessive gene conferring high level resistance to Cry2Ab is present in *H. armigera* populations at an estimated frequency of 4% or less. A second recessive gene conferring high level resistance to Cry2Ab and demonstrating the same broad characteristics is present in *H. punctigera* 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%.

How is resistance monitored?

Annual monitoring of *Helicoverpa* spp. field populations for resistance of all three proteins contained in Bollgard 3 cotton (Cry1Ac, Cry2Ab and Vip3A) provides an early warning of the onset of resistance. The program measures known forms of resistance and detects any new forms present in *Helicoverpa* populations. The results are used by industry to modify the RMP if needed to ensure its ongoing effectiveness.

Most testing uses offspring of single-pair matings between a moth from resistant strains maintained in the laboratory and a moth raised from field-collected eggs.

The vast majority of detected resistant individuals carry only one copy of the resistance gene and would therefore be controlled by Bollgard 3. Some individuals carrying two copies of the resistance gene have been detected for all toxins in both species, but none have had resistance to more than one toxin, meaning they should still be controlled by the stack in Bollgard 3.

Developments in resistance monitoring have revealed that the genetic control of Bt resistance is much more complicated than we first thought. The molecular monitoring tools are being implemented in collaboration between CRDC, CSD, Bayer and CSIRO. At this stage the evidence is that there are multiple different resistance alleles for each Bt toxin. No single allele is increasing in frequency across the population, which suggests the current RMP is doing a very good job of managing Bt resistance and we as an industry need to keep up the good work!



A *Helicoverpa* larva damaging a maturing boll is no longer a common sight in Australia, thanks to insecticidal protein technology and the industry's adherence to the RMP.

Paul Grundy, Qld DPI



Attract and Kill for RMP

Magnet® is the attract and kill alternative to pupae destruction for the Bollgard® 3 Resistance Management Plan (RMP)



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Elements of the Bollgard® 3 RMP

The RMP is a legal document approved by the APVMA that imposes limitations and management requirements on farms that grow Bollgard 3 cotton. Its five elements are:

1. Planting window and related restrictions
2. Mandatory growing of refuges
3. Control of volunteer and ratoon plants
4. Incorporating other management activities (pupae busting, trap crops, moth attractants)
5. Limitations on spraying.

In theory the combination 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 baseline frequency of Cry2Ab and Vip3A is a concern, and it is imperative that all Bollgard 3 users are responsible stewards of the technology. 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 (Transgenic and Insect Management Strategies) 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 Australian cotton industry.

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 (listed at the back of the relevant RMP).

A closer look at RMP tactics

1. Planting windows

The planting window limits the number of *helicoverpa* generations exposed to Bollgard 3 cotton in any one season, restricting the selection pressure to develop resistance. Crops must be planted into moisture or watered up within the relevant window, and there may be additional restrictions regarding the timing of crop destruction and refuge size, based on planting date and season length.

Planting windows are particularly important as a mitigation tactic in warmer climates where *helicoverpa* can survive and reproduce all year round. However, the RMP is predominately focused on reducing the risk of late crops (and Bollgard 3 volunteers), as they are more likely to increase resistance risk due to increased length of seasonal exposure.

2. Using refuges

While planting windows and Bt gene stacks aim to reduce selection pressure for Bt resistance, refuge crops help balance or counter the selection that will still occur, assisting 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 join the local mating population, reducing the risk that resistant moths (RR) emerging from Bollgard 3 crops will meet and mate.

To maximise refuge effectiveness, the timing of moth production from refuges MUST match moth emergence from Bollgard 3 crops.

Managing resistance is important at more than just the farm level. Every refuge makes an important contribution

to not only the local valley, but the whole industry. It is imperative that all refuges produce their quota of susceptible (SS) moths.

Refuge areas need to be in relatively close proximity to the Bollgard 3 crop(s) to maximise the likelihood that moths emerging from the crop will mate with susceptible moths from the refuge. During summer moths may only move a few kilometres, depending on the crop mix and relative attractiveness at moth emergence. Locate the refuge within 2 km (but not directly adjacent to) the Bollgard 3 crop. Ensure sufficient separation to prevent movement of large larvae from the refuge into the crop and minimise spray drift from the crop onto the refuge.

The relative size required for refuges is based on moth emergence for different refuge types. Originally it was an equal size of sprayed (excluding Bt products) conventional (non-Bt) cotton OR 10% unsprayed non-Bt cotton OR 5% unsprayed pigeon pea (which produces on average twice as many moths as unsprayed cotton). The introduction of Bollgard 3 has enabled unsprayed refuge requirements to be reduced to 5% cotton or 2.5% pigeon pea in some regions. Refer to the latest RMPs (at Bollgard3.com.au) for the refuge requirements for your location. Refuges must be a minimum of 0.5 ha and at least 24 m wide (to account for possible insecticide drift) and be planted within specific windows around the Bollgard crop sowing date.

Refuge productivity varies considerably across regions and seasons. Ensure refuges are planted within the refuge window listed in the relevant RMP, and make refuge management a priority, as appropriate nutrition, weed control, timely irrigation and making the refuge 'attractive' to female moths laying eggs, is the key to maximising refuge effectiveness. Bayer audits the quality of refuges on every farm that grows Bollgard 3 to ensure that they are well maintained and effective. Guidelines on refuge management are provided in the RMP and the unsprayed pigeon pea refuge agronomy guide on pages 72-73).

*Note that the term 'unsprayed' incorporates ANY management activities that might reduce *helicoverpa* survival in the refuge. Insecticides with *helicoverpa* activity, moth attractants laced with insecticide, inundative beneficial releases, or food sprays to attract natural enemies must NOT be used.*

3. Controlling volunteers and ratoons

It is essential 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. If heterozygous (RS) larvae that emerge from eggs laid on conventional cotton move onto Bollgard 3 cotton plants, they could become exposed to Bt insecticidal protein at later growth stages when they can survive to produce offspring, potentially leading to an increase in the frequency of individuals carrying the resistance gene (RS and RR) in the population. Ensure crop destruction of Bollgard 3 plantings within 4 weeks of harvest, and see pages 98-99 for more information on controlling unwanted cotton plants. Failed or abandoned Bollgard 3 crops also need to be destroyed – see your relevant RMP for details.

4. Other management activities

Pupae busting is a highly effective mitigation tactic for reducing resistance risk in areas where *helicoverpa* have a diapause stage (Southern Queensland, New South Wales and Victoria), provided it is done well and at the right time. While larvae survival in Bollgard 3 cotton should be

minimal, the few that persist are more likely to be 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.

The RMP links Bollgard 3 defoliation date to pupae busting requirements to ensure that only those fields most likely to contain highest risk pupae in diapause are being cultivated. Crop destruction must occur within 4 weeks of harvest.

- If first defoliation occurs by 31 March (when the likelihood of diapause occurring is 50%, based on a Diapause Induction and Emergence model developed from field research), pupae busting is encouraged but not required.
- If defoliation is later, pupae busting is mandatory, with the completion date linked to the production valley. Most pupation occurs within the hill, so soil disturbance needs to target the area within 30 cm each side of the plant line and to a depth of 10 cm.

For growers with prior approval, an option is available to use an attract and kill product (Magnet®) as an alternative to pupae busting. However, if the sprays are not completed as required the fields will be listed as non-compliant.

Do not pupae bust unsprayed refuges. Once Bollgard 3 crops begin flowering and are highly attractive to helioverpa moths, the corresponding refuge should not be cultivated (e.g. for weed control etc). Do not destroy unsprayed refuges 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), helioverpa 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 to pupae busting. Trap crops 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. 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. It is critical to time the destruction so that it corresponds with the period that most effectively kills the widest range of helioverpa life stages.

Trap crops must be irrigated. Dryland growers will need to discuss alternative options with their technology provider.

Pigeon pea trap crops must be at least 1% of the planted Bollgard 3 area; minimum dimensions depend on the presence of conventional cotton. If the refuge area was pigeon pea, the refuge can also act as the trap crop, provided peak attractiveness can be maintained until 2-4 weeks after final defoliation.

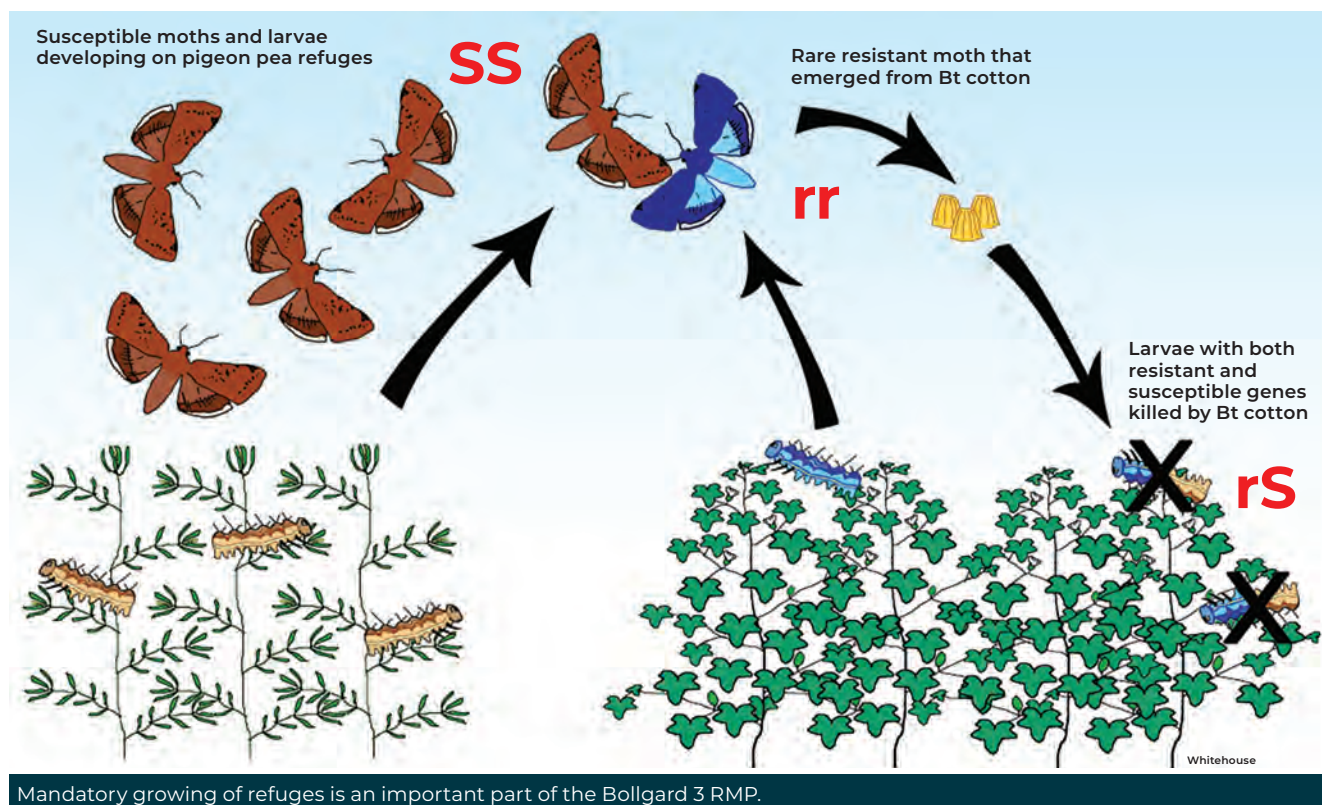
Refer to your region's RMP for specific details on the options and requirements for your local area.

5. Spraying limitations

Insecticides containing Bt may be used on Bollgard 3 cotton but NOT on any refuge crops. Preventing foliar Bt use on all refuges (sprayed and unsprayed), reduces the exposure of helioverpa within the refuges to Bt and maximises the likelihood of producing moths that are susceptible (SS) rather than resistant (RR) to Bt.

If your unsprayed refuge is under sufficient caterpillar pressure (from helioverpa or other species) to potentially render it unviable, immediately contact your technology provider.

Trap crops 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 the 31st of October) 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.



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

Management guidelines for *Helicoverpa* spp. in Bollgard® 3 cotton

Presence of larvae

There are occasional reports of larvae (*H. armigera* and *H. punctigera*) surviving for several weeks at threshold levels in Bt fields at mid to late-flowering.

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 and their attempts to avoid the 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. Work conducted by Bayer suggests that a yield penalty in Bollgard 3 fields associated with larvae survival is unlikely. Bt cotton plants can 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, compensation by Bt cotton to larval damage means 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* spp. is recorded. Part of the end of season general survey of Crop Consultants Australia (CCA) members includes questions about control of *Helicoverpa* spp. in Bollgard 3 fields.

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

- **Amanda Padovan (CSIRO): 0400 358 051 or**
- **Kristen Knight (Bayer): 0429 666 086**

Selecting insecticides for Bollgard 3 crops

When controlling *Helicoverpa* spp. within Bollgard 3 crops, ensure your insecticide selection complies with the cotton industry's Insecticide Resistance Management Strategy (see pages 58-63).

The beneficial/pest ratio (described on page 28) 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 5). While foliar Bt can be used on Bollgard 3 crops, it can NOT be used on any refuge crops.

Economic thresholds

Do not include eggs or any larvae <3 mm long in your spray threshold counts. Control larval populations 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.

To ensure count accuracy, check the whole plant including the terminals, squares and especially flowers and small bolls, and always assess larval size objectively. A complete description of the sampling protocols for *Helicoverpa* spp. can be found on page 28.

For the Bollgard 3 Schedule, refer to your Technology User Agreement (TUA).

Note that occasional changes can be made to the RMPs for Bollgard 3 cotton after industry consideration of resistance data and APVMA approval.

Visit the Bollgard 3 website Bollgard3.com.au to view or download the latest versions. III



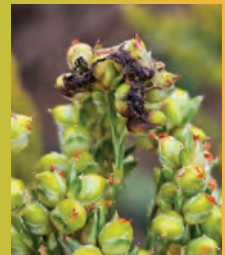
The RMP for eastern Australian production areas includes Central Queensland, Southern Queensland, New South Wales and Victoria.



The RMP for northern Australia covers tropical production areas including the Ord, Leichhardt, Leichhardt West, Flinders, Normanby River, Gilbert, Wiso, Burdekin, Mareeba/Dimbulah, Katherine and Douglas/Daly regions.

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AgBiTech

Managing unsprayed pigeon pea refuges

Establishing and growing an attractive refuge is a mandatory component of the Resistance Management Plan (RMP) for Bollgard® 3. A refuge generates 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 produces twice as many moths as the same area of unsprayed non-Bt cotton.

It is crucial that moth production from refuges has synchrony with Bollgard 3 cotton crops. A well-watered refuge with adequate nitrogen is more likely to attract moths and sustain larvae through to pupation. Producing large numbers of susceptible moths at the right time 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.

This information is intended to assist you to establish and maintain effective pigeon pea refuges. For mandatory refuge requirements, refer to the Resistance Management Plan (RMP) for your region.

Field selection

Pigeon pea can grow on many soil types but is susceptible to waterlogging, so select fields with good post-irrigation/rainfall drainage. Avoid fields that were sown to cotton the previous season to reduce the risk of volunteers and ratoons, as the presence of Bollgard 3 cotton in a refuge area diminishes the resistance mitigation potential. Select fields with a low weed seed bank to minimise the number of weeds that could compete with the pigeon pea and reduce refuge effectiveness.

Ideally, sow refuges adjacent to the Bollgard 3 crop, but ensure sufficient separation to buffer against the drift of herbicides or insecticides applied to the cotton or other crops onto the refuge area.

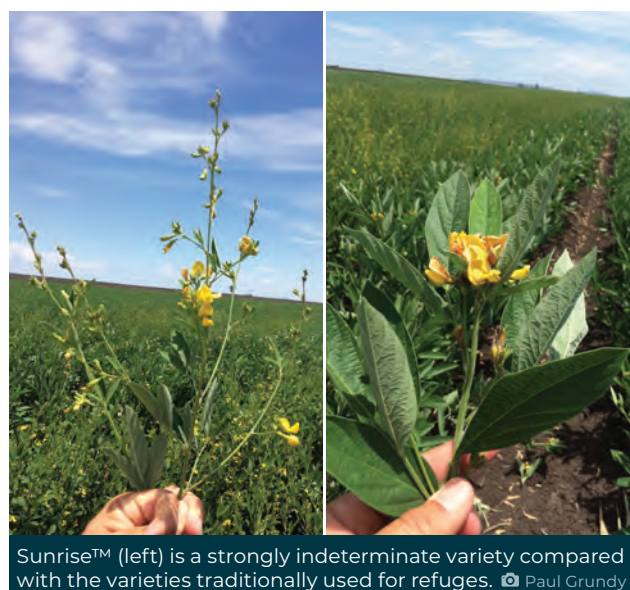
Note that (as with many other legumes), pigeon pea can have allelopathic effects on subsequent crops.

Use seed suitable for refuges

Ongoing recycling of seed from undamaged refuges had caused an evolutionary shift towards pigeon peas that flowered 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. Sowing rates for Sunrise™ typically fall within 25-40 kg/ha. 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.

Sunrise™ flowers much longer, and on average generates 2-3 times more pupae per hectare of refuge than Quest (an older determinate cultivar originally used in refuges).



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

Pigeon pea varieties currently under development for the grains industry are also likely to be determinate, and thus unsuitable for use in refuges.

Establishment

Timing

Aim for a minimum soil temperature of 17°C and rising (October to November in many cotton production regions). Under the RMP, sow pigeon pea within the two weeks prior to planting Bollgard 3, or if not possible, within 3 weeks of the first day of sowing (irrigated crops only).

Seed inoculation

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

Seed bed preparation and planting

Match refuge row spacing to the corresponding Bt cotton crop. Ensure good till to maximise seedling emergence and establishment, and don't sow seed deeper than 5 cm. Level any seed trenches created during planting, particularly when residual herbicides have been used and/or the field is to be watered up. Using press wheels with light pressure will improve emergence.

Pre-irrigation

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

Nutrition

Well-grown inoculated pigeon pea can add up to 38 kg/ha of nitrogen; soils already high in N may inhibit nodulation, resulting in a net reduction in N levels.

Pigeon pea is much more sensitive to phosphorus deficiency than cotton, and is likely to respond to the addition of phosphorus and zinc in soils with long cropping histories.



Larvae in pigeon pea refuge. © Johnelle Rogan

Weed management

Pigeon pea is a poor competitor with weeds during establishment, particularly when planted under cool conditions.

Both herbicides (Table 19) and inter-row cultivation can be useful tactics, however as cultivation can inadvertently kill (the Bt-susceptible) *helicoverpa* pupae present in the soil, the RMP requires that once Bt cotton begins to flower, the corresponding refuge must not be cultivated.

The presence of volunteers/ratoon Bollgard 3 cotton in any refuge will diminish its value and they must be removed as soon as possible. Avoid planting refuges in areas that contained cotton in the previous season, and ensure effective end of season crop destruction of your cotton.

Irrigation

Pigeon pea is very sensitive to waterlogging on heavier soils. Select a site with good drainage, avoid irrigation if heavy rainfall is predicted 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.

Pigeon pea is drought-tolerant, with a lower water requirement than cotton. However, avoid moisture stress as this reduces attractiveness and truncates the flowering period.

In some circumstances irrigating too frequently can prolong the vegetative growth stage, delaying the onset of flowering. It's best to plant Sunrise™ on a full profile of moisture and 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 bud initiation, Sunrise™ can be irrigated on a similar schedule to the adjacent cotton to prolong flowering and ensure rapid regrowth after insect attack.

Refuge destruction

Only harvest/destroy a pigeon pea refuge after the corresponding Bollgard 3 cotton has been fully picked. In NSW and Southern Queensland, do not disturb the refuge area soil until the 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 as a trap crop should refer to the late summer pigeon pea trap crop requirements of the RMP for full details.

Do not feed crop product or residues to livestock. III

TABLE 19: Herbicides available for use in pigeon pea

Active ingredient	MoA group	Comments
Fluazifop-p	1	QLD & NT only. See label for rates against specific grass weeds.
Flumetsulam	2	Post plant pre-emergence to moist soils only. Do not harvest seed or grain. May be tank mixed with trifluralin or pendimethalin.
Flumioxazin	14	Can be used as a pre-plant burndown 'spike' with glyphosate. See label for adjuvant details.
Pendimethalin	3	Qld, NSW, ACT. NT only. Incorporate into the soil within 24 hours of application. Use higher rate on heavy textured soils or those high in organic matter. In Macquarie Valley area, only apply by air when ground is too wet for ground application.
Metribuzin	5	Qld, NSW, ACT only (except sandy soils). Check label for soil moisture recommendations. Can be combined with trifluralin if grass weeds are expected.
Trifluralin	3	NSW and ACT only. Apply between 4 weeks and just before sowing. See label for incorporation instructions.

PER13758 (currently valid until 31 August 2026) allows the use of several products in pigeon pea trap crops. An extension has been requested – check the pubCRIS permits database to see the current availability.

Integrated Weed Management (IWM)

Integrated Weed Management is about being strategic with your weed control, using a range of tactics across the season to tackle existing weeds and reduce the number of weed seeds returning to the paddock.

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 unless weed control has 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 (HRMS; available later in 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.

WEEDpak, a key resource that can assist with these decisions, is available from cottoninfo.com.au/publications-and-resources/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.

TABLE 20: Control of weeds in dry channels

Active ingredient	MoA group
Amitrole + ammonium thiocyanate	34
Imazapyr	2
Pendimethalin	3
Flumioxazin	14
Diuron	5

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.

Think about the whole farming system

Consider weed management in the context of other in-crop agronomic issues, other crops and across the whole farm, including non-crop areas.

Consider crop competition

An evenly established, vigorously growing cotton crop can compete strongly with weeds, especially later in the season. Plant into weedy fields last to provide more opportunity to control weeds that emerge before planting, and better conditions for cotton emergence and early vigorous growth.

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

Good weed control is also integral to effective pest and disease management. Many cotton insect and mite pests utilise weed hosts and/or cotton volunteers prior to migrating into cotton fields. Weeds and cotton volunteers/ratoons may act as a reservoir for plant viruses such as cotton bunchy top disease, or allow disease inoculum to build up in the soil, increasing the risk for subsequent crops. Weeds in fallow fields also reduce the starting soil moisture/nutrients available to the crop. Never plant into a weedy field expecting to control the weeds later, as insects on dying weeds may migrate to emerging cotton seedlings and can cause seedling losses.

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 when crop competition suppresses weed growth. Rotation between summer and winter cropping provides opportunities to use cultivation and knockdown herbicides in-fallow year-round. If rotating with other crops, such as winter cereals or maize, retain the stubble cover from the rotation crops for as long as possible to reduce weed establishment and encourage 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 (see Table 20), 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 (Group 9) is also registered for many non-crop situations, but its use should be limited to minimise the risk of resistance. Always ensure any weeds that survive a glyphosate application are controlled by an alternative option before they set seed. DO NOT rely on glyphosate only to manage weeds.

Australian herbicide modes of action (MoA) groups changed from letters to numbers in 2021. More information at

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



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Strict hygiene on water structures can be challenging, but allowing weeds to flourish and set seed will only create greater in-field problems for the future. No survivors. This is especially true for glyphosate-resistant weeds such as this tridax daisy.  Graham Charles, CottonInfo

Dryland cotton

Weeds are very efficient at robbing the soil of vital moisture and nutrients. Control weeds in winter crops and pre-cotton fallows to improve sowing opportunities. It is vital to run the weed seed bank down during this period 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 reliance on glyphosate.

Tactics such as rotating to other chemical MoAs for knockdown weed control are essential to minimise development of herbicide resistance (see the HRMS for available tactics).

Cultivation is often seen as detrimental in dryland systems due to moisture losses from cultivation passes, but late in-crop strategic cultivation to remove weed escapes is an ideal non-chemical weed control option, where the impact of moisture loss is reduced. Alternatively, consider planting into stubbles or desiccated 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, clean down boots, vehicles, and equipment between fields and between properties (give special attention to pickers and headers). 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 also be carried in irrigation water. Control weeds that establish on irrigation storages, supply channels and head ditches.

Control survivors BEFORE seed is set

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 fields after each spray application to assess efficacy. Weeds may need to be examined closely, as some are capable of setting seed while very small. Many weeds respond to varying day-length, so a winter weed emerging in late winter or spring may rapidly become reproductive in response to lengthening daylight hours.

Preventing survivors from setting seed is critical to the longer term success of an IWM strategy. Research indicates that high efficacy with an alternative tactic is good, but high frequency control is even better.

Cultivation after glyphosate application is likely to achieve >80% survivor control, whereas cultivation PLUS chipping can achieve 99.9% survivor control. Other supplementary tactics for survivor control (such as shielded or spot-spraying with an effective knockdown herbicide) could be equally as effective.

Special consideration should be given to herbicide applications to other crops in the farming system where it may be very difficult to control survivors. Ensure herbicides are rotated as much as possible and weed escapes are targeted in following fallows. Remain aware of plant back periods to cotton (Table 21) of herbicides applied to cover crops or fallow fields.

Manual chipping or rogueing

Ideally suited to dealing with low densities of weeds, especially those that occur within the crop row, manual chipping (using an implement like a hoe) or rogueing (pulling weeds out) 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. It is also the ideal tool for eliminating any new weeds that might enter a field before they become widespread. Use GPS to locate individual plants or patches and scout these areas regularly during the season.

Spot spraying

Spot sprayers can be a cheaper alternative to manual chipping for controlling low densities of weeds in-crop. Ideally, spray remaining or recently emerged weeds with a relatively high label rate of a herbicide from a different mode of action 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.

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 an 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. Note that not all herbicide products have registrations for use with optical spot sprayer technology (OSST).



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 DPIRD

TABLE 21: Herbicide plant-backs from rotation crops to cotton

Active ingredient	MoA	Plant-back to cotton	Notes
Aminopyralid + fluroxypyr	4	9 months*	Plant-back interval on black cracking clay soils.
Aminopyralid + picloram + 2,4-D	4	12 months* (Nth NSW, Qld)	Under drought conditions conduct a bioassay before planting the next crop.
Atrazine	5	6 months	Rates <1.4 kg/ha.
		18 months	Rates 1.4 to 3.3 kg/ha.
Atrazine + S-Metolachlor	5 + 15	6 months	Rates <3.2 L/ha.
		18 months	Rates <3.2 L/ha. On alkaline soils, undertake a bioassay or analytical test.
Chlorsulfuron	2	18 months	Where soil pH is 6.6-7.5 and 700 mm of rain has fallen. If soil pH >7.5, only grow cotton after growing a test strip.
Clopyralid	4	3 months*	Rates <30 g/ha. 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.
		6 months*	
		24 months*	
Diuron	5	Refer to label	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. Do not use on light sandy soils low in organic matter.
Flumetsulam	2	2 years	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.
Flumioxazin	14	0 months	For zero plant-back for knockdown spike rates of 45 g/ha or below.
		2 months	For residual rates above 210 g/ha.
Imazamox	2	10 months	Must have 800 mm of rainfall or irrigation.
Imazamox + imazapyr	2	34 months	Registered for use in Clearfield® (or imidazolinone herbicide tolerant) crops – refer to label for varietal constraints.
Imazethapyr	2	22 months	Dryland cotton.
		18 months	Irrigated only (providing rainfall and irrigation exceeds 2000 mm).
Isoxaflutole	27	7 months	350 mm rainfall (excluding flood/furrow irrigation) between application and planting the subsequent crop.
Mefenpyr-diethyl + iodosulfuron-methyl sodium	2	12 months	Rainfall <500 mm may result in extended re-cropping intervals for summer crops sown in the following season.
Metribuzin	5	6 months	Rates <1.5 L/ha. Could be longer if there have been long dry periods between crops.
		12 months	Rates >1.5 L/ha.
Metsulfuron methyl	2	Unknown	Registered for use in wheat, barley, triticale and as a desiccant in chickpea.
Metsulfuron-methyl + mefenpyr-diethyl	2	12 months	Rainfall of less than 500 mm following application may result in extended re-cropping intervals for summer crops sown in the following year.
Picloram + 2,4-D	4	12 months	(Nth NSW & Qld). Do not use on land to be cultivated for growing susceptible crops within 12 months of application. Based on normal rainfall.
Pyroxasulfone	15	5 months	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.
Simazine	5	9 months	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.
Sulfosulfuron	2	Unknown	Registered for use in wheat and triticale.
Tiafenacil	14	6 weeks	See label for recommendations on compatible herbicides and adjuvant use.
Triasulfuron	2	15 months	Soil pH <7.5; 700 mm rainfall between application and sowing the plant-back crop.
		18 months	Soil pH 7.6-8.5.
Tribenuron methyl	2	Unknown	Registered for use in fallows.
Triclopyr + picloram + aminopyralid	4	4 months*	Rates 0.2 L/ha.
		6 months	Rates 0.4 L/ha.

*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.

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 of rain is required before plant-back period begins.

Refer to the herbicide label for specific information, such as 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.

Check the APVMA website for the most up-to-date information regarding both herbicide registrations at portal.apvma.gov.au/pubcris and off-label permits at 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.

Exclusive use of glyphosate for controlling summer weeds means that these weeds are exposed to a high selection pressure to just one mode of herbicide action.

The Herbicide Resistance Management Strategy (HRMS; pages 91-94) recommends at least two non-glyphosate tactics in summer fallows in addition to two non-glyphosate tactics in the cotton crop. Residual herbicides provide good alternatives in fallows. 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 (see Table 22). In irrigation systems, consider utilising pre-irrigation to cause a flush of weeds to emerge and be controlled using a non-glyphosate tactic before the cotton emerges.

Herbicides from Groups 4, 5, 9, 10, and 14 can be used to target weeds that have emerged in the field (see the HRMS diagram on page 91). This can be made more effective when used as a double knock.

Residual herbicides may remain active in or on the soil for many months and can act on successive weed germinations. They 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 3, 5 or 15.

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 patchy applications. Ash from burnt stubble may inactivate the herbicide, and must be dissipated with a light cultivation or rainfall prior to herbicide application.

TABLE 23: Cotton herbicide plant-backs to rotation crops

Active ingredient (MoA group)	Plant-backs from cotton to rotation crops (months)																			
	Cereal grains								Legumes								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
Diuron (5)	24	24	24	24	24	24	24	24	24	24	24	24	24	24	12	24	24	24	24	24
Halosulfuron-methyl (2)	24	2	24	24	2	24	3	24	24	24	24	24	24	24	24	24	24	24	24	24
Metolachlor (15)	6	0	6	6	0	6	6	6	6	6	6	6	6	6	6	6	0	6	6	0
Pendimethalin (3)	6	0 ²	12	12	12	—	—	—	—	—	—	—	—	—	6	—	—	—	6	—
Prometryn (5)	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
S-Metolachlor (15)	6	0	6	6	0 ¹	6	6	6	6	6	6	6	6	6	6	6	0	6	6	0
Trifloxysulfuron sodium (2)	6	22	22	6	22	22	6	22	18	22	7	22	22	22	22	9	15	15	22	22
Trifluralin (3)	12	12	12	12	12	12	12	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH

¹ Concep® II or III treated seed only.

² Maize can be resown immediately post-use in a failed crop provided it is sown below treated band of soil.

FH = following cotton harvest

— = no information

For further information see Weed control section in Summer and Winter Crop Publications from NSW DPIRD.

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 product's ability to bind to the soil and organic matter content, and the volume and timing of rainfall/irrigation, as well as the method of applying irrigation. Growers can influence crop safety by herbicide choice, application timing and rate, planting depth, planting date (to promote rapid crop establishment) and moisture management. Always follow label directions, and if you are inexperienced in using residuals in cotton you should discuss your circumstances with your consultant, chemical supplier or the manufacturer.

Consider residual herbicide persistence in order to avoid impacts on rotation crops (Table 23). Persistence is complex – determined by factors including application rate, soil texture, organic matter levels, soil pH, rainfall/irrigation, temperature and the herbicide's characteristics. 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 herbicides primarily live near the soil surface and require warm, 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 more 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) can be applied over the top of cotton, however repeated use is likely to lead to the development of Group 1 resistance (already present in several species). It is important not to over-use alternative modes of action in an effort to manage glyphosate resistance, as over-use (particularly if there are survivors) will lead to additional resistance to the alternative herbicides. Use Group 1 herbicides sparingly and ensure any survivors are controlled before they set seed, using another tactic, such as manual chipping to control survivors.

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 3, 5, 14, and 15. Check the label to confirm usage is allowed for each product in your situation and for crop safety directions.

HHP restrictions

Under the Better Cotton™ initiative (certification is available through the *myBMP* Program), several herbicide actives classified as highly hazardous pesticides (HHPs) and cannot be used by Better Cotton growers. Herbicides in this list include bromoxynil (Group 5; may be used in fallow applications only), diquat (Group 22; dibromide and ion forms), and paraquat dichloride (Group 22).

Cotton Australia is negotiating with Better Cotton to allow restricted paraquat use in Australian cotton over the next few years.

For more information on banned and restricted products under this program, contact Cotton Australia or the *myBMP* team.



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 crop damage. Be aware 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. While these weeds will normally produce few seeds in a competitive cotton crop, they can be very problematic in skip-row configurations or 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' later in this chapter.



Maintaining strict weed hygiene in and around field is essential to managing herbicide resistance and drive weed numbers down. No Survivors. This is especially true for glyphosate-resistant weeds such as this feathertop Rhodes.

 Graham Charles, CottonInfo

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.



Eric Koetz, NSW DPIRD



Jeff Werth, Qld DPI



Jeff Werth, Qld DPI

IMPORTANT – avoid spray drift

Cotton crops are particularly sensitive to spray drift from Group 4 herbicides (phenoxy herbicides including 2,4-D), and every year there are reports of damage.

Take every precaution to minimise the risk of causing or suffering spray drift damage from ANY herbicide application:

- When planning field layout, note the crop's proximity to areas where spray drift is most likely to have an adverse impact. Sensitive areas include human residential, workplace or recreational spaces, native vegetation, other non-target vegetation (including other crops or pastures), and riparian zones and aquatic areas (including wetlands).
- 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.
- Ensure the droplets produced by the spray rig are within the required size range, and be aware that some adjuvants can influence drift risk.
- Pay particular attention to weather conditions before application (and use the WAND tower network to identify potential hazardous inversion conditions).
- Be prepared to halt spraying operations if weather conditions become unsuitable.
- Use buffer zones to reduce the impact of spray drift or over-spray.
- Keep detailed records.

See the 'Spray application' chapter for more details.

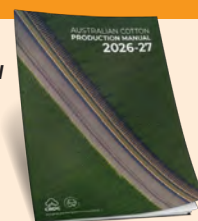
Notes on herbicide use

Note that registration of a herbicide does not constitute a recommendation for its use in a particular situation. The information in this publication is presented as a guide only to assist growers in planning their herbicide programs. Satisfy yourself that the product(s) used is the best choice for the crop and weed, and is registered for use at your location. Carefully study the container label before using any herbicide, noting any specific instructions relating to mixing, rates, timing, application and safety. |||

USEFUL RESOURCES:

The **Australian Cotton Production Manual** also includes information on weed control tactics (including calculations for band spraying).

cottoninfo.com.au/publications-and-resources/202627-ACPM



A range of weed-related videos can be found on the CottonInfo YouTube channel.

www.youtube.com/@CottonInfoAust



The WeedSmart website contains a wide range of resources articles, podcasts, case studies and webinar recordings on various aspects of weed management.

www.weedsmart.org.au



Key weeds

These common weeds of cotton have a high risk of and/or have already developed resistance within Australia to one or more herbicide mode of actions (Tables 25 and 26 list weed species with confirmed resistance to glyphosate, paraquat and 2,4-D).

Note the weed species present in your fields (take into account the likely composition of the weed seed bank) and make herbicide decisions early. Many weeds in cotton are prolific seed producers, although dormancy in grasses is often less than that of broadleaf species. Learn how to recognise weed species at the seedling stage so you can target young plants and prevent seed set.

Terms and symbols used in the specific management suggestions in this section include:

fb	followed by (as a herbicide double knock)
IBS	incorporation by sowing
OSST	optical spot spray technology
PPI	pre-plant incorporated
POST	post-emergent to crop and weeds (spraying live plants)
PRE	pre-emergent to crop and weeds
PSPE	post sowing pre-emergent application
⇒	indicates following crop or situation

Always consult herbicide label for plant backs, state registrations and application/incorporation requirements. Tradenames are provided as examples only and do not constitute an endorsement of the product. Note that different formulations (even within the same trade name) can have different amounts of active and application recommendations.

Broadleaf weeds

The Asteraceae or 'daisy' family includes several key weed species, including fleabanes, sowthistle, and tridax daisy.

Fleabanes (*Conyza* spp.)

Often seen as roadside weeds, fleabanes are prolific wind-dispersed seeders. Seeds have relatively low dormancy, so while they can germinate quickly from the soil surface in favourable conditions, preventing plants from setting seed set is likely to minimise fleabane species in the soil seed bank. **Flaxleaf fleabane** (*Conyza bonariensis*) is often the species of most concern within cotton production from a herbicide resistance management perspective. Plants are generally less than 1 metre tall with multiple erect branches.

Two related species also found in cotton regions are **tall fleabane** (*Conyza sumatrensis*), and **Canadian fleabane** (*Conyza canadensis*), both of which usually grow more than 1 metre high on a single stem.

Flaxleaf fleabane is an annual or short-lived perennial that can germinate from seeds on the soil surface. It can emerge in late autumn or early winter, growing very slowly above ground while developing an extensive root system, allowing it to grow quickly when spring temperatures increase. A combination of poor control by glyphosate and prolific fecundity (up to 100 000 seeds/plant) has contributed to its success. Flaxleaf fleabane is very small seeded, and very susceptible to cultivation, and it has become a difficult weed to control with the move to reduced or zero tillage.



Flaxleaf fleabane lifestyles.

 Graham Charles, CottonInfo and Eric Koetz, NSW DPIRD

For effective control of flaxleaf fleabane, a long term integrated farming system approach is needed (over at least 2–3 years), using a combination of pre- and post-emergent herbicides, crop competition, spot spraying and cultivation.

Fleabane should also be managed in non-crop areas, such as roads, irrigation channels and fence lines, to prevent re-infestation into the cropping area.

Key pre-emergent herbicides:

- Isoxaflutole (Balance®) at 100 g/ha ⇒ Fallow
- Terbutylazine (Terbyn Xtreme®) at 0.86–1.2 kg/ha PSPE or lay-by ⇒ Cotton
- Flumioxazin (Valor®) at 210 to 280 g/ha ⇒ Fallow; 180 g/ha IBS ⇒ Chickpea
- Saflufenacil (Sharpen®) at 34 g/ha ⇒ late application in Wheat
- Saflufenacil + trifludimoxazin (Voraxor®) at 200 mL/ha PRE ⇒ Wheat and Barley.

Key post-emergent herbicides:

- Xtendimax® 2 at 1.17 L/ha + Roundup Ready® PL at 1.9 L/ha + 1% v/v VapourGrip® Xtra ⇒ Xtendflex® cotton varieties (see label for application restrictions)
- Glufosinate (Biffo®) at 3.75 L/ha ⇒ Fallow and Xtendflex® cotton varieties, or at 10 L/100 L OSST ⇒ Fallow (less than 30% weed cover)
- Research has shown the Xtendimax® + Roundup Ready® PL fb Biffo® provides consistent control
- Clopyralid (Lontrel® Advanced) at 150 mL/ha ⇒ Winter cereals.

Red pigweed (*Portulaca oleracea*)

A prostrate, succulent annual herb germinating in spring and summer that often forms dense mats. It has the potential to produce up to 240 000 seeds/plant. Seeds are very small, but also very hard and can persist in the soil for extended periods.

Weed fragments created by cultivation can regrow if not fully desiccated. The succulent nature of the plant means that a combination of tactics is needed to ensure control of plants beyond the seedling stage. Consider using a double knock approach combined with cultivation if possible. Monitor the field to ensure adequate control has been achieved. The use of pre-emergent herbicides with post-emergent follow-up will likely achieve satisfactory control. Due to red pigweeds high fecundity and persistence in the seed bank, it is critical to prevent seed production.

Key pre-emergent herbicides:

- Fluometuron at 2-4 kg/ha PSPE ⇒ Cotton
- Prometryn (Gesagard®) 3.3-4.5 L/ha ⇒ Cotton
- Diuron at 1-2 kg/ha PSPE or lay-by ⇒ Cotton
- Pendimethalin (Stomp® Xtra) at 2.2 L/ha PPI or 3.3 L/ha PSPE ⇒ Cotton
- Terbutylazine (Terbyne Xtreme®) at 0.86-1.2 kg/ha PSPE or lay-by ⇒ Cotton; 1.2 kg/ha PRE or PSPE ⇒ Sorghum
- Trifluralin (TriflurX®) at 1.2-2.3 L/ha PPI ⇒ Cotton
- Flumioxazin (Valor® WG) at 210 to 280 g/ha ⇒ Fallow; 90 g/ha lay-by ⇒ Cotton.

Key post-emergent herbicides:

- Aminopyralid + fluroxypyr (Hotshot®) at 500 ml/ha + glyphosate ⇒ Fallow
- Roundup Ready® PL at 660 mL to 1.9 L/ha ⇒ Cotton
- Fluroxypyr (Starane® Advanced) at 300-450 mL/ha ⇒ Sorghum/ Maize/Millet
- Xtendimax® 2 at 335 mL to 1.17 L/ha + 1% v/v VapourGrip® Xtra ⇒ Xtendflex® cotton varieties (see label for application restrictions)
- Glufosinate (Biffo®) at 3.75 L/ha ⇒ Fallow and Xtendflex® cotton varieties.



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Sowthistle (*Sonchus oleraceus*)

A surface germinating, prolific (up to 25 000 seeds/plant), wind-dispersed weed that can emerge all year round. Seed have no innate dormancy and are able to germinate straight away. Sowthistle is somewhat susceptible to seed burial with 30-50% of seed buried below 2 cm persisting and remaining viable. Seed left on the surface for six months resulted in less than 5% being viable. Seed buried at depths of 5 to 10 cm can remain viable for over 30 months.

A long term (2-3 years), whole farm, integrated approach is needed for its effective control. It can be controlled using a combination of pre- and post-emergent herbicides, crop competition, spot spraying and cultivation. Sowthistle should also be managed in non-crop areas, such as roads, irrigation channels and fence lines, to prevent re-infestation into the cropping area.

Key pre-emergent herbicides:

- Isoxaflutole (Balance®) at 100 g/ha ⇒ Fallow; PSPE Chickpea
- Terbutylazine (Terbyne Xtreme®) at 0.86-1.2 kg/ha PSPE or lay-by ⇒ Cotton; 1.2 kg/ha PRE or PSPE ⇒ Sorghum; 0.86-1.2 kg/ha PRE or PSPE ⇒ Chickpea
- Flumioxazin (Valor® WG) at 210 to 280 g/ha ⇒ Fallow; 120 g/ha IBS ⇒ Wheat (not Durum)
- Fluometuron at 2-4 kg/ha PSPE ⇒ Cotton
- Prometryn (Gesagard®) 3.3-4.5 L/ha ⇒ Cotton
- Saflufenacil (Sharpen®) at 34 g/ha ⇒ late application in Wheat
- Saflufenacil + trifludimoxazin (Voraxor®) at 200 mL/ha PRE ⇒ Wheat and Barley.

Key post-emergent herbicides:

- Xtendimax® 2 at 1.17 L/ha + Roundup Ready® PL 1.9 L/ha + 1% v/v VapourGrip® Xtra ⇒ Xtendflex® cotton varieties (see label for application restrictions)
- Glufosinate (Biffo®) at 3.75 L/ha ⇒ Fallow and Xtendflex® cotton varieties
- Research has shown the Xtendimax® + Roundup Ready® PL fb Biffo provides consistent control
- 2,4-D (Colex-D®) at 430 mL/ha to 1.25 L/ha ⇒ Fallow; 6.16 L/ha OSST ⇒ Fallow (less than 30% weed cover)



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Tridax daisy (*Tridax procumbens*)

Also known as 'coat buttons', tridax daisy is a perennial, semi-prostrate herb with 'toothed' leaves and small daisy-like flowers on hairy stems about 30 cm long. It is a common environmental weed in the tropics and sub-tropics and is particularly hard to control once a taproot establishes. Glyphosate resistance was first reported in the Ord region in 2016.

It produces at least 1500 wind-bourne seeds per plant, and is becoming a dominant species in many northern cotton production areas. Feathery bristles on the seed allow it to attach to people and vehicles as a hitchhiker. It can also develop roots where stem nodes touch the ground.

Tridax daisy is also a potential host for cotton aphid, silverleaf whitefly, two spotted mites and charcoal rot.



Grasses

Annual ryegrass (*Lolium rigidum*)

A cool season annual grass with high seed production (up to 45 000 seeds per plant) that is increasingly becoming an issue, particularly in northern Australia. Seed typically germinates in autumn to spring and forms a persistent soil seed bank with seeds viable for several years. This species is notorious for herbicide resistance, with resistance to a number of modes of action. Management tactics:

- Use tillage to bury seed at depth to minimise emergence
- Use double knocks to ensure clean fields prior to planting a crop
- Use a combination of pre- and post-emergence herbicides to reduce emergences and control escapes
- Ensure no plants are able to set seed
- Undertake resistance testing of control failures.

Key pre-emergent herbicides:

- Prosulfocarb + S-Metolachlor (Boxer Gold®) at 2.5 L/ha PRE/IBS or 1.75 L/ha PRE/IBS fb 0.75 L/ha POST or 2.5–3 L/ha POST ⇒ Wheat and Barley, or 2.5 L/ha PRE/IBS ⇒ Chickpea
- Diuron at 1–2 kg/ha PSPE or lay-by ⇒ Cotton
- Aclonifen + pyroxasulfone + diflufenican (Mateno® Complete) at 0.75–1.0 L/ha PRE/IBS ⇒ Wheat (not durum)
- Trifluralin (TriflurX®) at 1.2–2.3 L/ha PPI ⇒ Cotton
- Pyroxasulfone (Sakura®) at 118 g/ha PRE/IBS ⇒ Chickpea, Wheat (not durum)
- Cinmethylin (Luximax®) at 500 mL/ha PRE/IBS ⇒ Wheat (not durum)
- Tri-allate (Avadex® Xtra) at 3.2 L/ha PRE or PRE/IBS ⇒ Wheat, Barley.

Key post-emergent herbicides:

- Clethodim (Platinum® Xtra 360) at 165–330 mL/ha ⇒ Cotton
- Butroxydim (Encode® 500 WG) at 40–90 g/ha ⇒ Chickpea, Faba beans
- Haloxyfop at 75–100 mL/ha ⇒ Chickpea, Faba beans
- Roundup Ready® PL at 660 mL to 1.9 L/ha ⇒ Cotton



Awnless barnyard grass (*Echinochloa colona*)

A small seeded, fast growing annual grass that can produce up to 40,000 seeds per plant and is a strong competitor in no-till cropping and fallow systems.

The key to its management lies in managing the seed bank and preventing new seed from entering the soil:

- Use tillage to bury seed, and pre-emergent herbicides to reduce numbers of seedlings emerging
- Monitor emergence and control weeds when small
- Use double knocks to control plants and prevent seed set.

Awnless barnyard grass can last in the seed bank for up to 4 – 5 years. Targeted management for this period of time will have a major impact on driving down the seed bank.

Key pre-emergent herbicides for reducing emergences:

- S-Metolachlor (Dual Gold®) at 1 L/ha PRE/PSPE or OTT/directed @ 4-8 nodes ⇒ Cotton, or 1-2 L/ha ⇒ Fallow
- Pendimethalin (Stomp® Xtra) at 2.2 L/ha PPI or 3.3 L/ha PSPE ⇒ Cotton
- Fluometuron at 2.4-4 kg/ha PSPE ⇒ Cotton
- Prometryn (Gesagard®) at 3.3-4.5 L/ha ⇒ Cotton
- Flumioxazin (Valor® WG) at 210-280 g/ha ⇒ Fallow
- Diuron at 1-2 kg/ha PSPE or lay-by ⇒ Cotton
- Isoxaflutole (Balance®) at 100 g/ha ⇒ Fallow (suppression).

Key post-emergent herbicides:

- Clethodim (Platinum® Xtra 360) at 165-330 mL/ha ⇒ Cotton
- Glufosinate (Biffo®) at 10 L/100 L OSST ⇒ Fallow (less than 30% weed cover)
- Research has shown that the combination of clethodim (330 ml/ha) fb glufosinate (3.75 L/ha) at a 7-10 day interval provides control.
- Roundup Ready® PL at 660 mL to 1.9 L/ha ⇒ Cotton.



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Feathertop Rhodes grass (*Chloris virgata*)

A small-seed annual that can produce >40,000 seeds per plant. It can germinate after rainfall events as small as 5 mm, and is capable of producing seed 6 weeks after germination. Often recruiting more than one cohort per year, this weed can germinate across a wide range of temperatures. It can establish quickly on lighter textured soils, but rapidly becomes stressed under dry conditions.

The key to its management lies in managing the seed bank and preventing new seed from entering the soil by:

- Using strategic deep tillage to bury seed, and pre-emergent herbicides to reduce numbers of seedlings emerging
- Monitoring emergences and controlling seeds when they are small
- Utilising the double knock tactic to control plants and prevent seed set.

Target all stages of the lifecycle and ensure control of plants in non-crop areas. Its seed bank life is relatively short (approximately 2 years), so intensive management for up to two years will have a major impact.

Key pre-emergent herbicides for reducing emergences:

- Isoxaflutole (Balance®) at 100 g/ha ⇒ Fallow
- S-Metolachlor (Dual Gold®) at 1 L/ha ⇒ Cotton – PRE/PSPE or OTT/directed @ 4-8 nodes, or 1-2 L/ha ⇒ Fallow
- Flumioxazin (Valor® WG) at 210-280 g/ha ⇒ Fallow.

Key post-emergent herbicides:

- Clethodim (Platinum® Xtra 360) at 165-330 mL/ha ⇒ Cotton
- Research has shown that the combination of clethodim (330 ml/ha) fb glufosinate (3.75 L/ha) at a 7-10 day interval provides control.



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Liverseed grass (*Urochloa panacoides*)

A prolific seeding annual summer grass favoured by reduced tillage systems. Seedlings have much broader leaves than most grass weeds. Fresh seed has a strong dormancy and therefore most seed germinates in the following season, with emergence usually occurring in one large mid-spring to early summer flush. Seed viability on the surface is short but persistence increases with seed burial.

- Shallow tillage can be effective on seedlings as the majority of seedlings emerge from the top 5 cm
- Avoid burying seed as this will increase their persistence in the soil seedbank (20% survival at 20 cm after 2 years)
- Double knock tactics at robust rates can reduce grass seed production on survivors from several thousand seeds per square metre to zero.

Target small weeds (2-3 leaves) when using knockdown herbicides. Effective management over 2-3 years in zero tilled systems can therefore reduce the seed-bank to minimal levels.

Seed production on surviving weeds can be markedly reduced by increasing crop competition. Rotating to sorghum in solid 1 m rows with a high planting rate can reduce seed bank replenishment by more than half.

Key pre-emergent herbicides:

- S-Metolachlor (Dual Gold®) at 1 L/ha ⇒ Cotton – PRE/PSPE or OTT/directed @ 4–8 nodes, or 1–2 L/ha ⇒ Fallow
- Pendimethalin (Stomp® Xtra) at 2.2 L/ha PPI or 3.3 L/ha PSPE ⇒ Cotton
- Fluometuron at 2–4 kg/ha PSPE ⇒ Cotton
- Flumioxazin (Valor® WG) at 210–280 g/ha ⇒ Fallow
- Diuron at 1–2 kg/ha PSPE or lay-by ⇒ Cotton.

Key post-emergent herbicides:

- Clethodim (Platinum® Xtra 360) at 165–330 mL/ha ⇒ Cotton
- Glufosinate (Biffo®) at 3.75 L/100 L ⇒ Fallow
- Roundup Ready® PL at 660 mL to 1.9 L/ha ⇒ Cotton.



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Windmill grass (*Chloris truncata*)

A short-lived perennial species that has recently been identified as resistant to glyphosate. Summer dominant and a prolific seeder (>20,000 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 seed is dispersed by wind onto the soil surface. Management tactics include:

- Use tillage to bury seed
- Monitor emergences and control weeds when they are small
- Use double knocks to control plants and prevent seed set.

Seed persistence in the soil is short lived and seeds struggle to emerge from deeper than 3 cm. Stopping seed-set for up to two years will deplete the soil seed bank. The double knock tactic is most effective on windmill grass when applied before early tillering.

No pre-emergent herbicides are registered for control of windmill grass, however herbicides used for feathertop Rhodes grass may provide some control. Key post-emergent herbicides include:

- Butroxydim (Encode® 500 WG) at 60–90 g/ha ⇒ Cotton
- Research has shown that the combination of clethodim (330 mL/ha) fb glufosinate (3.75 L/ha) at a 7–10 day interval provides control.

III



 Eric Koetz, NSW DPIRD

Herbicide resistance management

The Australian herbicide mode of action (MoA) classification system changed in 2021 from letters to numbers. Search for MoA classifications 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 herbicide MoA will result in an ever-increasing proportion of the population being able to survive those herbicide applications. In Australia, herbicides are grouped according to their MoA which is represented by a number code on the label 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, repeated mowing of annual bluegrass (*Poa annua*) on golf courses has favoured plants with fewer, lower seed heads that escape mowing, effectively developing resistance to mechanical control.

By mid-2026, there were 546 unique cases (species x mode of action) of herbicide resistant weeds recorded globally across 274 species. Weeds have evolved resistance to 21 of the 31 known herbicide sites of action and to 168 different herbicides, and herbicide-resistant weeds have been reported in 102 crops in 76 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.

TABLE 24: Glyphosate-resistant weeds in Australia

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

*Resistance documented at more than 100 sites within Australia.

More than half of the confirmed glyphosate-resistant weed species in Australia listed in Table 24 occur widely in cotton farming systems. Reports of resistance to other MoA groups that have been commonly used in agricultural systems are shown in Table 25.

An industry-wide strategy

Experience with insecticide resistance has encouraged a proactive culture to resistance issues within the Australian cotton industry. The Herbicide Resistance Management Strategy (HRMS) draws together available information, enabling growers and agronomists to understand and manage the risks of herbicide resistance in Australian cotton farming systems. The HRMS helps you determine which other weed control tactics can be incorporated into your management system by offering guidance on the 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.

TABLE 25: Species that have developed resistance in Australia to paraquat or 2,4-D

Weed	Herbicide (MoA group)	First documented	Also reports of resistance to MoAs
Northern barley grass (<i>Hordeum glaucum</i>)	Paraquat (22)	1983	9, 22 (diquat)
Capeweed (<i>Arctotheca calendula</i>)	Paraquat (22)	1984	9, 22 (diquat)
	2,4-D (4)	2015	22
Barley grass (<i>Hordeum leporinum</i>)	Paraquat (22)	1988	22 (diquat)
Silver grass (<i>Vulpia bromoides</i>)	Paraquat (22)	1990	22 (diquat)
Wild radish (<i>Raphanus raphanistrum</i>)	2,4-D (4)	1999	2, 4 (MCPA), 9, 12, 27
Indian hedge mustard (<i>Sisymbrium orientale</i>)	2,4-D (4)	2005	2, 4 (MCPA), 12
Small square weed (<i>Mitracarpus hirtus</i>)	Paraquat (22)	2007	
Annual ryegrass (<i>Lolium rigidum</i>)	Paraquat (22)	2010	1, 9
Crowsfoot grass (<i>Eleusine indica</i>)	Paraquat (22)	2015	
Cudweed (<i>Gamochaeta pensylvanica</i>)	Paraquat (22)	2015	
Blackberry nightshade (<i>Solanum nigrum</i>)	Paraquat (22)	2015	
Sowthistle (<i>Sonchus oleraceus</i>)	2,4-D (4), dicamba (4), clopyralid (4)	2015	9
Flaxleaf fleabane (<i>Conyza bonariensis</i>)	Paraquat (22)	2016	9
Tall fleabane (<i>Conyza sumatrensis</i>)	Paraquat (22)	2018	9

WeedSmart BIG 6

SCAN QR 

Rotate crops and pastures

Rotation equals diversity

- Build in more diversity using cotton, alternative summer crops, winter cover crops and fallows.
- Use crop rotation to manage high-pressure situations (e.g. spray out weedy patches, alternative herbicides, crop-topping, swathing, hay-making).

Increase crop competition

Optimise crop growth

- Aim for optimal planting time and even seed distribution in cotton.
- Even crop establishment in cotton suppresses weeds. Avoid gaps of 50 cm or more along the rows.
- Improve soil health and crop nutrition.
- Focus on early weed control until canopy closure.
- Maximise crop competition in rotational crops.

Mix and rotate herbicides

Rotating buys you time, mixing buys you shots

- In cotton systems, apply six different herbicide modes of action on grass and broadleaf weeds every two years.
- Rotate between herbicide modes of action.
- Incorporate multiple modes of action where possible (e.g. in double-knock applications).
- Test weeds for resistance to know what herbicides will and won't work for you.

Optimise spray efficacy

Make every droplet count

- To maximise efficacy and reduce spray drift, follow spray application guidelines and ensure the correct speed, nozzles, water volume, boom height, and adjuvants are used.

Stop weed seed set

Take no prisoners

- Aim for 100 per cent weed control and remove weeds that survive, before they set seed.
- In cotton, consider shielded spraying, optical spot spraying, targeted tillage, inter-row cultivation or chipping.
- Use effective tactics to stop weed seed set around irrigation infrastructure and along crop borders.

Implement harvest weed seed control

Capture weed seed survivors

- In rotational crops, capture and destroy weed seed present at harvest using any of the harvest weed seed control tools.



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

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 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.

Strategies should be aimed at driving down the seed bank and preventing seed bank replenishment. See tables B and C in the HRMS for information on seedbank levels and management options.

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 combinations of tactics, to allow growers and consultants to make their own informed decisions.

Without careful management, the majority of herbicides commonly used in cotton have an estimated time of less than 15 years before resistance potentially develops (see Table 26).

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 facilitate maximum spray efficacy.

Resistant weed seeds can also be transported into fields and other farm areas 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.

Why should I get weeds tested?

Testing plant populations for the presence of herbicide resistant individuals is an important tool for growers and advisors, as the results 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). It can take several months to receive results from seed samples as it is the subsequent seedlings grown from the collected seed that will be tested. Results are usually available by the end of April when samples are received before January.

An alternative 'quick test' method uses actual plants from the field. The quick test 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. When plants are sent for Quick Tests, results are usually available within 4-8 weeks.

It is recommended to take seed samples from surviving plants in summer and mark the sites to enable seedling collections the following autumn or spring if required.

Collecting samples (seed test):

- Collect 2000-3000 seeds from plants you suspect are resistant (e.g. for barnyard grass this is about 1 cup full).
- If testing for more than 3 modes of action, collect additional seed.
- Shake seed heads into a bucket to ensure only ripe seed is collected.
- 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.



An annual ryegrass survivor. © Eric Koetz, NSW DPIRD

- 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 per 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 post over the weekend. If plants cannot be posted on the same day, store overnight in the fridge.

Sending samples to testing services

Contact one of the testing services below so they know to expect the sample. Follow the collecting instructions above and send samples together with a sample registration form (noting testing required), field and weed management history, and your contact details to:

RESISTANCE TESTING:

 **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

How do I manage resistant weeds?

The strategy to **manage** weeds resistant to glyphosate (or other herbicide products) is similar to the strategy to **prevent** 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, June 2026. The latest information on reported cases of resistance is available from the international herbicide-resistant weed database:

 www.weedscience.org

III

USEFUL RESOURCES:



A demonstration of
weed resistance
youtu.be/y7Jj1laiSLk



Weedsmart

 www.weedsmart.org.au



Minimising glyphosate
resistance
youtu.be/cke-mamGe2o



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TABLE 26: Resistance risk for herbicides most commonly used in cotton

Herbicide active ingredient	Pre plant	At plant	Post plant	Mode of action group	Years to resistance	Resistance status
Amitrole + ammonium thiocyanate	Y	N	N	34	>15	Rare
S-Metolachlor or Metolachlor	Y	Y	Y ¹	15	>15	Rare
Saflufenacil	Y	N	N	14	>15	Rare
Glufosinate-ammonium	Y	N	N ²	10	10-15	Rare
Dicamba ³	Y	N	N ²	4	10-15	Rare
Fluroxypyr	Y	N	N	4	10-15	Rare
Fluroxypyr+ aminopyralid	Y	N	N	4	10-15	Rare
Diuron	Y	Y	Y	5	10-15	Rare
Fluometuron	Y	Y	Y	5	10-15	Rare
Prometryn	Y	Y	Y	5	10-15	Rare
Terbuthylazine	N	N	Y	5	10-15	Rare
Triclopyr	Y	N	N	4	10+	Rare
Triclopyr + picloram	Y	N	N	4	10+	Rare
Triclopyr + picloram + aminopyralid	Y	N	N	4	10+	Rare
Carfentrazone-ethyl	Y	N	N	14	10	Rare
Flumioxazin ⁴	Y	N	Y	14	10	Rare
Oxyfluorfen	Y	N	N	14	10	Rare
Tiafenacil	Y	N	N	14	10	Rare
Isoxaflutole ³	Y	N	N	27	10	Rare
*Paraquat	Y	Y	Y	22	>15	Occasional
2,4-D ³	Y	N	N	4	10-15	Occasional
Pendimethalin	Y	Y	Y ⁵	3	10-15	Occasional
Trifluralin	Y	Y	N	3	10-15	Occasional
*Bromoxynil	Y	N	N	5	10-15	Occasional
Glyphosate ⁶	Y	Y	Y	9	>12	Widespread
Butroxydim	N	N	Y	1	6-8	Widespread
Clethodim	N	N	Y	1	6-8	Widespread
Fluazifop-p	N	N	Y	1	6-8	Widespread
Haloxyfop	N	N	Y	1	6-8	Widespread
Propaquizafop	N	N	Y	1	6-8	Widespread
Halosulfuron-methyl	N	N	Y	2	4	Widespread
Trifloxysulfuron sodium	N	N	Y	2	4	Widespread
Lowest resistance risk	Note that Group 1 and 2 herbicides already exhibit widespread resistance in multiple species. Controlling survivors is essential.					
Moderate resistance risk						
Highest resistance risk						

Always read the label for detailed use patterns and application rates.
^{*}Actives classified as HHP under the Better Cotton™ initiative.

¹ Dual Gold® formulation.

² XtendFlex® varieties only, using specific formulation registrations.

³ See label for rainfall required before plant-back period begins.

⁴ Valor® formulation only.

⁵ Rifle® formulations.

⁶ Roundup Ready Flex® varieties only.

Refer to Tables 21, 22 and 23 for plant-back periods.

Herbicide Resistance Management Strategy 2026/27

An integrated weed management system relies on a large number of complementary components, including chemical and non-chemical control tactics combined with cultural practices such as crop competition, rotation, farm hygiene and crop scouting. Effective strategies to delay herbicide resistance and manage resistant populations are essential for long-term sustainability of cotton farming.



Apply 6 different modes of action on grasses and broadleaves every 2 years, and allow NO SURVIVORS to set seed

CHOOSE 6 TACTICS

Fallow

Strategic cultivation
Double knock
Optical sprayers¹
Patch management
Cover crops

Fallow herbicides

Group 9
glyphosate

Group 5
bromoxynil, terbutylazine

Group 14
flumioxazin, pyraflufen, saflufenacil, tiafenacil

Group 27
isoxaflutole

Group 10
glufosinate

Group 4
2,4-D, dicamba, fluroxypyr

Rotation Crops³

Crop competition
Rotate modes of action
Plant back restrictions
Cover crops

Pre/at plant

Cultivation
Double knock

Knockdowns

Group 5
bromoxynil

Group 14
pyraflufen, flumioxazin, saflufenacil, oxyfluorfen, carfentrazone, tiafenacil

Group 4
dicamba, fluroxypyr

Group 10
glufosinate

Group 9
glyphosate

Residuals³

Group 5
prometryn, terbutylazine, diuron, fluometuron

Group 3
pendimethalin, trifluralin

Group 15
S-metolachlor, metolachlor

Post-emergent

In-crop cultivation
Manual chipping
Rogueing
Spot spraying

Post-emergent OTT

Group 1²
sethoxydim, clethodim, butoxydim, haloxyfop, propaquizafop

Group 15⁴
S-metolachlor

Lay-by, directed or shielded spray

Group 5
prometryn, terbutylazine, diuron, fluometuron

Group 3
pendimethalin

Group 14⁴
flumioxazin

Group 15⁴
S-metolachlor

Maturing crops

Cultivation
Chipping
Rogueing
Spot spraying

Aim for 100% control of survivors

NO SURVIVORS

Target survivors — aim for 100% control

In fallow survivor control

Cultivation, chipping or spot spraying (refer above for options)
Optical sprayers¹

Pre-plant survivor control

Cultivation, chipping or spot spraying
flumioxazin
pyraflufen-ethyl (added to complementary product)
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 with a different MOA prior to seed set.
- Read and follow all label directions.
- Rotate herbicide mode of action (MoA).
- Come Clean. Go Clean. to avoid importing weed seeds.
- Scout fields regularly for weeds and monitor after spraying for survivors.
- Keep accurate field records.
- Ensure volunteers/ratoons are controlled.
- DO NOT rely solely on glyphosate or any other in-crop herbicide for non-field weed control.
- Take a farming systems approach to weed management, considering winter, summer and non-field area weed control.

Footnotes:

- APVMA permit 90223 for OSST in fallows.
- Group 1 herbicides already exhibit widespread resistance. Controlling survivors is essential.
- Refer to label for plant-back restrictions to following crop.
- Limited formulations are registered for this use. Please check label.

Revised Herbicide Resistance Management Strategy (HRMS) explained

The HRMS is designed as a tool to manage the risk of herbicide resistance in irrigated and dryland farming systems incorporating herbicide tolerant cotton. The strategy has been developed in response to the escalating problem of herbicide resistance across multiple weed species to a number of herbicide modes of action (MoA). This is the second version of the HRMS, following on from the original 2+2+0 strategy that saw the cotton industry adopt world's best, and most effective, glyphosate resistance management. This version of the HRMS focuses on a glyphosate, glufosinate and dicamba tolerant cotton system (XtendFlex® cotton); however, we are constantly alert to the fact that other herbicides could become at-risk for resistance if used more than once every year. Many herbicides, including the ones listed, already have a history of use in cotton fields, indicating that some selection for resistance for any registered herbicide could already have occurred.

A sustainable system requires a high level of diversity and zero tolerance for survivors of herbicide sprays. Using 6 different methods/modes of action across every 2 years (such as 3 in fallow plus 3 in crop, for a dryland situation), plus additional actions if required to prevent seed set on survivors, provides a sustainably low risk (but not zero risk) system.

The formula to delay or manage resistance

The most effective way to delay the evolution of herbicide resistance is to target weed control across the whole farming system with a diversity of tactics. A focus on reducing weed numbers in fallows or rotation crops will reduce the reliance on in-crop weed control. Aim to drive down weed numbers and ensure no weeds set seed after herbicide applications, and use a diverse program of 6 modes of action every 2 years. This can be done by:

- using a minimum of 3 different weed control tactics effective on the weeds being controlled in-crop, and 3 more in summer fallows (or non-cotton crops). If more controls are needed, make use of fallow periods to get access to a range of products that can be used where no crop is present needing protection. Note: where both grasses and broadleaves are present, 'three different modes of action' must apply to both types of weed species, meaning more than three in total may need to be applied. Check the tables in this guide for the wide range of available tactics at different crop stages.
- AND ensuring that no survivors set seed. Effective post-spray monitoring (with follow-up action) is critical for ensuring control of survivors.

Examples of the influence of various weed management tactics on herbicide resistance risk are provided in Table A.

Table A: Risk reducers and risk promoters for herbicide resistance

Effect on resistance risk	Tactic	Notes
Strongly reduces risk	Spot-spray glyphosate at high rates through optical detection system	Glyphosate at the highest allowable rate, applied to small proportions of the field, remains very effective for seedbank and resistance management, including protecting other herbicide groups under pressure of resistance.
Strongly reduces risk	Apply glyphosate as part of double knock	Whenever there is the opportunity to follow glyphosate with a fast-acting knockdown herbicide, it should be taken. In the absence of paraquat, glufosinate or cultivation can be useful double knock partners. Other suitable sequences of tactics may be used.
Reduces risk	Late season survivor control	Additional tactics used specifically to control survivors in crop prior to seed set are fundamentally important.
Reduces risk	Apply glufosinate as part of double knock	Glufosinate is a moderately at risk herbicide for resistance. Preserve its susceptibility by attempting to use it as part of mixed strategies with other modes of action.
Reduces risk	Apply key herbicides in mixtures	Glufosinate and dicamba are at risk for resistance. Using them in mixtures with compatible products can help reduce resistance risk.
Increases risk	Weed species known for evolving resistance (annual ryegrass, barnyard grass, feathertop Rhodes grass, flaxleaf fleabane)	Several such species are present in various regions. Currently susceptible biotypes of key species should be treated as being at risk of resistance in the short to medium term. Consult your agronomist about the herbicide resistance history of your weed species.
Highly increases risk	Cross-seasonal species (often germinates out of expected season)	Adaptable species such as annual ryegrass can generate large seedbanks by appearing out of their expected season, and going uncontrolled.
Highly increases risk	Multiple generations per year	These highly fecund species can evolve very rapidly, and must be controlled with multiple modes of action.
Highly increases risk	Relying on 1-2 herbicides	

Increased time to resistance

Research into glyphosate resistance has indicated that typically glyphosate failure may appear in grass weeds after approximately 13 years (dryland) and 19 years (irrigated) in a glyphosate only system. Resistance to glyphosate in broadleaf weeds can be slower to emerge and usually takes around 18 years in both irrigated and dryland systems. Some non-glyphosate modes of action share similar or slightly longer timeframes (e.g. Group 4 herbicides, glufosinate), while others have substantially shorter timeframes (Group 1, Group 2 herbicides). However, it is important to remember that the most reliable herbicides in our system, including but not limited to glyphosate, have now been in frequent use for one to two decades in nearly all cropping situations in Australia. This means that time frames to resistance for populations on farm could appear to be much shorter, since we are unlikely to be starting with a truly wild type, unselected population. It is helpful to know your herbicide use history on weeds that have been on farm for many years. Assume that resistance could appear much more quickly than these indicative timeframes, if the system begins to favour a particular herbicide.

Herbicide resistance can be delayed by 4-6 years with good survivor control and product rotations and mixtures, and the same strategies are very effective for managing resistant populations that do occur. To drive down weed numbers and eradicate resistant biotypes, additional tactics such as intensive patch management are required.

Other management considerations

Any rotation or cover crop should be managed similarly to a fallow, with at least 3 modes of action recommended. Rotation and cover crops provide an opportunity to incorporate other tactics, rotate to herbicide groups not used in cotton, vary the time of year crop competition suppresses weeds, and produce stubble loads or mulch that can reduce subsequent weed germinations.

Aim for 100% control of survivors after each herbicide application. Effective post-spray monitoring to detect survivors is critical. The use of cultivation to control any survivors after a herbicide application is predicted to achieve 80% survivor control, whereas cultivation plus follow-up chipping is predicted to achieve close to 100% survivor control. Other tactics for survivor control can be equally effective, such as shielded or spot-spraying with an effective knockdown herbicide. Even very small mature weeds may produce viable seeds, and if those carry resistance genes, a long-term problem can begin to emerge. Get suspect weed survivors tested for resistance.

Residual herbicides need back up, such as tillage, chipping and knockdown herbicide applications to control survivors. When using residual herbicides, consider plant-back periods and crop safety. Be aware that prolonged dry periods may extend plant-back periods.

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 solely 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 the introduction and transport of resistant seeds.

Use patch management strategies – control any weeds in and around problem patches with a different mode of action from ones that the patch may have recently survived. Be ready for the tendency of patches to spread if not controlled well.

Use IWM best practice when employing tactics, including:

- Optical Spot Spray Technology, particularly where spot spraying allows for high herbicide rates on a small proportion of the paddock.
- Regular scouting and ensuring correct weed identification. Check with an agronomist if you are unsure of a weed's identification. Be on the lookout for any new weeds and eradicate problematic new weeds before they become an issue.
- Frequent post-spray monitoring.
- Good record keeping.
- Timely implementation of tactics – hitting weeds when they're small and vulnerable.
- Rotate and mix herbicide mode of action groups.
- Always follow label recommendations.
- Consider other aspects of crop agronomy.

Poor seedbank control over 5-10 years strongly correlates with increased herbicide resistance risk.

The medium-term success of moderate-high resistance risk strategies depends greatly on the history of exposure to the MOAs used in crop. If a weed population is already at 1-10% resistance due to historical practice, full-blown resistance can appear within 3-4 years of even a moderate risk strategy.

The success of moderate risk strategies is highly responsive to summer fallow actions in dryland cotton. Crops grown 1 year in 3 with a very low-risk, robust summer fallow program can sustain somewhat less diverse in-crop strategies. Back-to-back irrigated crops, where summer fallow control is not available, should stick with low risk strategies in crop.

Assessing your own risk

Refer to pages 86-89 of this publication for information on recognising potential herbicide resistance how to get weeds tested.

More information and tools related to herbicide resistance and weed management in cotton is available from:

 cottoninfo.com.au or  www.weedsmart.org.au

The HRMS in practice

Implementing the HRMS in cotton requires fitting a range weed control tactics into real situations with lots of variables. Finding room for 6 different tactics every two years is feasible but can be challenging. A few of the important considerations are:

- What weed species are you actually dealing with?
- What's your crop rotation?
- When, and how often, can you include soil disturbance for weed management?

Tables B and C include some example IWM strategies in-crop and during fallows, rated for resistance risk and seedbank control. The most diverse strategies (at the top of each table) maximise seedbank control and minimise resistance risk, but potentially have the highest input costs.

In order to fit the HRMS requirements of 6 different tactics every 2 years, aim for a strategy similar to those in the green rows (low or low-moderate risk). Avoid high or very high risk strategies where possible, and remember that if high risk strategies are used in one part of your rotation (e.g. in-crop), you'll need an even greater focus on reducing risk in the following year to reach the HRMS target.

Table B: Example IWM strategies for in-crop weed management

Resistance risk level	Strategy	#MoA/season	Seedbank control*	Comments
Low	2-3 OTT glyphosate + double knock prior to planting + 2 different residuals (at/near planting, layby) + OTT dicamba + double knock glyphosate/glufosinate OTT + tillage/spot spraying late season for survivor control	5-6	Very high	Fallow choices for broadleaf control are important (avoid 2,4-D). In the absence of paraquat, double knock with glyphosate fb glufosinate or other suitable sequences.
Low-moderate	2-3 OTT glyphosate + 2 different residuals at planting and layby + double knock glyphosate/glufosinate OTT + inter-row cultivation + spot spraying for survivor control	5	High	Glufosinate is best used as part of double knocks, from the point of view of overall resistance management.
Low-Moderate	2 OTT glyphosate + double knock prior to planting + residual at planting + up to 2 dicamba and glufosinate OTT	4	High-moderate	Not ideal for cross-season species or species producing multiple generations per year. Can be very successful when supplemented with best practice summer fallows.
Moderate-high	2 OTT glyphosate + residual at planting + up to 2 dicamba and glufosinate OTT	4	Moderate	Requires very aggressive summer fallow program for sustainability.
High	2-3 OTT glyphosate 2-3 OTT dicamba and glufosinate	3	Moderate-low	Especially susceptible to dicamba resistance if 2,4-D or similar products used in fallow.
Very high	Glyphosate alone or with occasional clean-up tactics	1-2	Moderate-low	History demonstrates glyphosate alone is too high risk for resistance to be recommended in any situation.

Table C: Example IWM strategies for summer fallows

Resistance risk level	Strategy	#MoA/season	Seedbank control*	Comments
Low	Glyphosate (applied in double knocks or at high rates via optical sprayer wherever possible) x2-3 + 2 different residual MoAs, early and mid-fallow + broadleaf herbicide ¹ + consistent survivor control + includes cultivation ²	5-6	High	In the absence of paraquat, use glufosinate as a double knock partner – but preferably only as part of double knocks in fallow. Aim to use double knocks for half of all glyphosate applications.
Low-moderate	Glyphosate (broadacre) x2-3 + early season residual + grass selective + glufosinate + late survivor control with spot spraying	4-5	Generally high	
Moderate	Glyphosate (mostly applied in double knock/optical sprayer) x3 + 2 different residuals	3	Moderate-high	Seedbank control is variable, depending on residual choice and existing glyphosate resistance. Choose residuals not used in crop if possible. Be aware of plantback restrictions.
Moderate	Glyphosate x2-3 always applied as double knocks + early residual		Variable	
High	Glyphosate x2-3 + 2,4-D or other group 4 + glufosinate used alone		Moderate	Seedbank control depends on resistance level and can be lost quickly.
High	Glyphosate alone, with occasional cleanup tactics		Moderate-low	Seedbank control depends on resistance level – generally good for various susceptible species and very poor for any resistant ones.

¹ It is preferable to avoid, or carefully manage, broadleaf herbicides with known cross-resistance effects to dicamba, including 2,4-D, clopyralid and fluroxypyr in fallow. Follow any applications from this group with monitoring and robust survivor control.

² Incorporating cultivation somewhere in fallow can be beneficial for seedbank control of surface germinating species. Consider residuals incorporated by tillage.

*Seed bank control key (seeds/m²): Very high <10; High 10-100; Moderate 100-500; Low 500-1500; Very low >1500.

Herbicide tolerance technology:

XtendFlex® cotton Bayer Crop Science

Cotton varieties containing the XtendFlex® herbicide tolerance trait (XtendFlex® cotton) are tolerant to glyphosate, dicamba, and glufosinate-ammonium herbicides. This provides growers with multiple modes of action to target glyphosate-resistant and hard-to-kill weed species.

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. Designed to support the longevity and effectiveness of the trait and herbicides, these requirements include:

- Successful completion of the Bayer XtendFlex® spray applicator training is required prior to use of XtendiMax® 2 herbicide in XtendFlex® cotton.
- Reporting any suspected glyphosate, dicamba or glufosinate-ammonium resistant weed species to a Bayer representative or Nufarm where Nufarm Biffo® has been used or other registered glufosinate-ammonium herbicide providers.
- Completion of the Bayer supplied spray logbook when using XtendiMax® 2 in XtendFlex® cotton.
- Implementing an integrated weed management (IWM) strategy.
- Completion of the XtendFlex® cotton spray applicator training when applying XtendiMax® 2 herbicide in XtendFlex® cotton.

Registered products are: Roundup Ready® herbicide with PLANTSHIELD®, Roundup Ultra® MAX with PLANTSHIELD®, Roundup Ready PL herbicide with PLANTSHIELD® Technology, XtendiMax® 2 herbicide with VapourGrip® Technology (XtendiMax 2) and Nufarm BIFFO® herbicide or other registered glufosinate-ammonium herbicides.

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 over the top (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 your 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 alternative herbicides 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 alternate 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.



This infestation 'blow-out' of glyphosate resistant barnyard grass was due to an extremely wet summer that prevented access to the paddock and hence there was no effective treatment at an early growth stage. © T. Cook, NSW DPIRD

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 27 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 www.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 for further investigation. For suspected glufosinate-ammonium herbicide resistance, report to Nufarm (or relevant registered provider).

Growing Roundup Ready Flex® cotton?

If you are planning to grow Roundup Ready Flex® cotton in the 2026/27 cotton season, please refer to the Roundup Ready Flex® Weed Resistance Management Plan (see link below) or refer to the 2026/27 Bayer Technology User Agreement document.

Roundup Ready Flex® Weed RMP:

www.crop.bayer.com.au/products/biotechnology-traits/roundup-ready-flex-cotton?id=biotechnology-trait-bcs-roundup-ready-flex-cotton-en-au

XtendiMax® 2 Herbicide record keeping requirements

As a condition of the XtendiMax® 2 Herbicide with VapourGrip® Technology registration, Bayer is required to collect the following application information from users of XtendiMax® 2 Herbicide with VapourGrip® Technology in XtendFlex® cotton:

1. Date of application.
2. Farm address where spray application occurred.
3. Rate of application.
4. Total amount of product applied.
5. Air temperature at the start and end of application



Use the QR code to access the online logbook:

Note: this information is being collected to provide spray application data to the APVMA as a registration requirement, and will not be used for any other purpose.

III

USEFUL RESOURCES:



XtendFlex® guides are downloadable from crop.bayer.com.au/products/biotechnology-traits/xtendflex-cotton



For stewardship and resistance management information regarding these technology traits and related products visit crop.bayer.com.au



Other resources on weed management and minimising the risk of resistance can be found at www.weedsmart.org.au



TABLE 27: 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 products containing ammonium e.g. ammonium sulfate, glufosinate-ammonium or glyphosate ammonium salts).
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 XtendiMax® 2 product label for use patterns and application timing restrictions 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 1.8 L/ha for Roundup Ultra®MAX with PLANTSHIELD® Technology. • This application can be used to control late season weeds and improve harvest efficiency. • Compatible with commonly used defoliant (see Roundup Ready® Herbicide with PLANTSHIELD® and Roundup Ultra®MAX with PLANTSHIELD® Technology labels). • Do not use on crops intended for planting seed production.

XtendFlex®, Roundup Ready®, Roundup Ultra®MAX, XtendiMax®, PLANTSHIELD® and VapourGrip® are Registered Trademarks of the Bayer Group; BIFFO® is a Registered Trademark of Nufarm Australia Ltd.

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) 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 (mealybug hotspots are often associated with ratoon cotton plants)
- 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.

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 accidentally spilled on route to or within fields.

Volunteers that emerge pre-planting may allow the early establishment of in-field pests populations and promote disease incidence. Volunteers are also more likely to be impacted by seedling diseases and cool conditions, and rarely contribute to crop yield.

Reduce the amount of viable cotton seed left in fields (via clean pick and stubble management) and around the farm (cleaning up after module removal and spillages) to minimise the volunteers germinating next season.

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

Cultivation and herbicides are the most common methods of volunteer cotton control. Both require the plants to have germinated and emerged (following pre-irrigation or sufficient rainfall). Cultivating is a good IWM fit, as it readily controls seedlings (and also manages other weeds). 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 dryland 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.

Table 28 provides 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 of contact herbicides is essential. 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 modes of action 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). Where isolated plants establish in fallows or non-field areas such as along roadsides and fences, physical removal by chipping can be very effective.

TABLE 28: Herbicides for control of volunteer cotton

Active ingredient	MoA group	Comments (always refer to product labels)
Bromoxynil	5	Apply in minimum of 80 L/ha water for Roundup Ready® cotton. See label for rain-fastness and restrictions on spray quality & condition.
Carfentrazone-ethyl	14	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. See label for adjuvant recommendation.
Flumetsulam	2	May be banded (>40%) over the row or broadcast. Minimum spray volume 150 L/ha for optimum results.
Flumioxazin	14	Apply not later than 1 hour prior to sowing or post sowing up to 2 days before first crop emergence. Can be tank mixed with glyphosate to control other weeds that may be present. See label for adjuvant details.
Fluroxypyr	4	Summer fallow.
Glufosinate-ammonium*	10	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	Registered for control of volunteer cotton in pigeon pea. See label for critical comments.
Pyraflufen-ethyl	14	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.
Saflufenacil	14	Use prior to establishing crops or starting a fallow on small, actively growing volunteers up to the 6 leaf stage. Always apply with adjuvant or high quality methylated seed oil. See label for mandatory no-spray zone and spraying rates.
Tiafenacil	14	Apply at 40 g/ha with 0.5 L/100L CanDo™ adjuvant. Suitable for OSST.

*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

Ratoon cotton

Ratoon cotton (also called regrowth or stub cotton) usually results from ineffective crop destruction – 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.

In theory, ratoons 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 minimum-till situations, and care must be taken to ensure regrowth is prevented. Crop destruction also provides an opportunity to destroy overwintering helicoverpa pupae (a mandatory strategy for Bollgard 3 crops where the first defoliation occurs after March 31) to manage insecticide resistance.



Inadequate end of season crop destruction can lead to ratoon cotton. © Murray Sharman, Qld DPI

Ratoon cotton plants that have survived crop destruction can be difficult to control, having developed a relatively large root system in comparison to their leaf surface area. Volunteer plants in non field areas that have persisted for multiple seasons will also have developed large root systems.

There are currently no herbicide options specifically registered for control of large cotton plants. The best option is physical removal. **III**

USEFUL RESOURCES:

The Australian Cotton Production Manual also includes information on post-harvest pest and stubble management.

cottoninfo.com.au/publications-and-resources/202627-ACPM



Effective end of season crop destruction

youtu.be/rO-JAX7s7jg



WEEDpak

cottoninfo.com.au/publications-and-resources/weedpak



Rogue cotton plants in the farming community

youtu.be/CJP14_swggE



Integrated Disease Management (IDM)

A plant disease occurs when there is an interaction between a plant host, a pathogen, and the environment. IDM should be implemented as part of your farm routine, as the absence of visible symptoms does not necessarily indicate an absence of disease. IDM strategies can also delay the establishment of diseases in a cropping system.

In cotton, disease management focuses on improving the resilience of the farming system and preventing pathogen spread as complete eradication is usually not possible. There are many strategies that may help 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 the field history for disease issues. Avoid back-to-back cotton and rotations that promote cotton diseases.
- Prepare firm, high beds to optimise establishment and seedling vigour.
- Avoid root damage by not placing fertiliser and herbicides too close to 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 where possible, delay planting until soil temperatures are at least 16°C and no cold shocks are forecast. The *Australian Cotton Production Manual* (ACPM) includes information on crop establishment.

Soil temperatures in cotton production regions are available from the Cotton Seed Distributors **Faststart Cotton Soil Temperature Network** (CSD membership required)

csd.net.au/soil-temperature

Variety selection

Consider the disease status of each field when selecting varieties, along with 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

Some varieties have partial resistance to verticillium or fusarium wilts (indicated by higher V rank and F rank respectively). If black root rot is present, select indeterminate varieties as they have more capacity to catch up later in the season.

Best practice...

- Monitor in-crop for disease symptoms and record disease incidence and severity over time. 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 farm hygiene and biosecurity practices.

Dryland cotton...

Disease incidence of wilt pathogens tends to be lower in dryland cotton because consistent moisture from irrigation can create a more favourable environment, while the variable moisture in dryland production conditions can limit their spread.

Incidence of foliar diseases that require high humidity (such as ramularia and target spot) is also likely to be lower in dryland crops, although leaf spot diseases that are associated with potassium deficiency can be exacerbated by dry conditions that restrict the plant's ability to access sufficient nutrients.

The fungus that causes charcoal rot in cotton thrives in dry, hot conditions and can cause significant wilting, defoliation, and root rot. It survives in the soil as microsclerotia that can persist for years, and thrives under dry, hot conditions. Charcoal rot is an emerging issue of concern in rain-fed crops in the Northern Territory.

Replanting

If stand loss has been caused by disease, carefully consider what risk is still present for a replanted crop. 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. Seed treatment options can be selected when seed is ordered. Contact CSD for more information.

Two Group 14 fungicides are registered for use at planting for seedling disease caused by *Rhizoctonia* sp.

Currently, Sero-X® (that targets verticillium wilt microsclerotia) is the only foliar product registered in cotton, although there are also some products with off-label permits. Table 30 (at the end of this chapter) contains a list of fungicides currently registered for use (or available under permit) in cotton. Always read the label/permit carefully to ensure the product can be used in your state.

Where possible rotate fungicide mode of action groups.



Aerial photo of fusarium wilt damage.

Monitoring for disease

In addition to regular monitoring, conducting formal disease surveys each season is strongly recommended.

Always keep an eye out for signs of disease whenever you are in a field (look for plants that show unusual symptoms, have poor vigour, or have died). Conducting additional formal disease surveys that record the incidence and severity of disease allows you to make a comparison over time and adjust your management strategies accordingly.

This chapter includes examples of the key diseases in cotton and their common symptoms, however nutrient deficiency/toxicity, herbicide residues or environmental impacts can sometimes be misinterpreted for disease (see Table 1 for more information).

If disease is suspected, sample plants both with and without symptoms and send to cotton pathologists. Be aware that plants infected with verticillium or fusarium wilt may display minimal or no external symptoms (particularly in varieties with high disease rankings), so you need to cut plants in several places along the stem to look for discolouration. If unsure, contact your nearest CottonInfo REO for more information.

Implement your own in-season surveys

Conduct formal disease surveys both early (within 3 to 4 weeks of planting), and late (between final irrigation and defoliation). Survey two transects per field, located well apart to capture variability. Within each transect, assess 10 consecutive plants at each of 10 evenly spaced sampling points (a total of 200 plants per field per survey). At each sampling point, record disease incidence by counting the number of affected versus healthy plants, and estimate disease severity. In early season surveys, also measure plant establishment at each point by counting the number of plants in one metre of row and compare with number of seeds planted per metre.

To avoid edge effects, stay at least 50 meters from field edges, head ditches, and tail drains, using GPS to mark the start and end of each transect for consistency across seasons. Use a step-point sampling method (10 meters along the row plus 10 rows across between points). Assess plants directly in front of you, regardless of condition, so that the sample remains unbiased and representative. Ensure that information on environmental conditions (such as temperatures, humidity, rainfall, and stubble loads) is included, and that your recording system allows easy comparison within and between seasons. If collecting samples for diagnosis, record the GPS location of each sample.

Collecting and submitting a sample

Send well-prepared plant samples and corresponding information about the sample to enable industry pathologists to accurately identify the pathogen or disease affecting your crops. Poorly collected samples may arrive mouldy or deteriorated, leading to inconclusive results. Missing or incomplete submission forms can also leave pathologists without critical information, such as disease symptom details or your contact information. Submitting quality samples increases the chances of receiving a clear diagnosis, helping you to effectively manage the disease sooner.



Sample collection

A CottonInfo video on *Collecting samples for disease testing* looks at the process of taking plant samples and the appropriate packaging to send them for diagnosis. youtu.be/UruGsqUnr08

Please note: When collecting leaves for foliar disease identification, place individual leaves between paper towel to absorb moisture, before placing into a paper bag. If possible, before posting, dry the leaves in an air conditioned room before placing them between fresh paper towel to help reduce the risk of leaves becoming mouldy during transit. If leaves arrive mouldy it becomes too difficult to isolate pathogens. Contact your local REO or pathologist for more information.

Sample submission

Find a factsheet on collecting plant samples, the appropriate *Disease diagnostic submission form* for your region (NSW/QLD or NT/WA) needed for sending samples to your state pathologist, and pathologist contact details on the 'Disease management' page of the CottonInfo website: cottoninfo.com.au/disease-management

Background information on the crop and its environment assists with diagnosis. Please provide as much detail as you can, using the prompts provided in the form.

Please contact your local pathologist BEFORE sending the sample to ensure there is someone available to receive it while it is still fresh.




CottonInfo HELPING YOU GROW
DISEASE DIAGNOSTIC SUBMISSION FORM (NSW/QLD)

Read the instructions carefully and complete this form to assist with diagnosis. Please contact your local REO for more information. This form is to be completed by the grower or a nominated person. It is not to be completed by the pathologist.

PLEASE NOTE: For the most accurate results, please ensure that the sample is fresh and that the leaves are not damaged or diseased. Please ensure that the sample is not contaminated by any other material.

Sample submitted by: Full name: _____ Contact details: _____
Phone: _____ Email: _____
Field name: _____ GPS location: _____

REGION
Queensland: ☐ Far North QLD ☐ Central QLD ☐ Darling Downs ☐ Southern Downs
New South Wales: ☐ Sydney ☐ Hunter ☐ Murrumbidgee ☐ Riverina ☐ South Coast

Other region not included in this list: _____

Symptoms
☐ Plant emergence or seedling death
☐ Leaves yellow, dead or dying
☐ Leaves damaged
☐ Leaves distorted or curled
☐ Leaves wilting
☐ Plant stunted
☐ Premature leaf drop
☐ Root rot or die
☐ Premature defoliation

INCIDENCE
☐ 1-10% of plants
☐ 11-20% of plants
☐ 21-30% of plants
☐ 31-40% of plants
☐ 41-50% of plants
☐ 51-60% of plants
☐ 61-70% of plants
☐ 71-80% of plants
☐ 81-90% of plants
☐ 91-100% of plants

SEVERITY
☐ 1-10% of plants
☐ 11-20% of plants
☐ 21-30% of plants
☐ 31-40% of plants
☐ 41-50% of plants
☐ 51-60% of plants
☐ 61-70% of plants
☐ 71-80% of plants
☐ 81-90% of plants
☐ 91-100% of plants

Other information
What you observed first (symptoms) in this field? ☐ Yes ☐ No ☐ Not sure
If yes, how long previously did you observe this first? ☐ 1-2 weeks ☐ 3-4 weeks ☐ 5-6 weeks ☐ 7-8 weeks ☐ 9-10 weeks ☐ 11-12 weeks ☐ 13-14 weeks ☐ 15-16 weeks ☐ 17-18 weeks ☐ 19-20 weeks ☐ 21-22 weeks ☐ 23-24 weeks ☐ 25-26 weeks ☐ 27-28 weeks ☐ 29-30 weeks ☐ 31-32 weeks ☐ 33-34 weeks ☐ 35-36 weeks ☐ 37-38 weeks ☐ 39-40 weeks ☐ 41-42 weeks ☐ 43-44 weeks ☐ 45-46 weeks ☐ 47-48 weeks ☐ 49-50 weeks ☐ 51-52 weeks ☐ 53-54 weeks ☐ 55-56 weeks ☐ 57-58 weeks ☐ 59-60 weeks ☐ 61-62 weeks ☐ 63-64 weeks ☐ 65-66 weeks ☐ 67-68 weeks ☐ 69-70 weeks ☐ 71-72 weeks ☐ 73-74 weeks ☐ 75-76 weeks ☐ 77-78 weeks ☐ 79-80 weeks ☐ 81-82 weeks ☐ 83-84 weeks ☐ 85-86 weeks ☐ 87-88 weeks ☐ 89-90 weeks ☐ 91-92 weeks ☐ 93-94 weeks ☐ 95-96 weeks ☐ 97-98 weeks ☐ 99-100 weeks

Irrigation and 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. Late season irrigations to extend plant maturity can result in a higher incidence of verticillium wilt.

Irrigation cools the soil, enhancing pathogen survival and increasing infection rates. Moisture can also be an important component of pathogen dispersal, root infection and colonisation.

Irrigate as required if disease has weakened the root system and there are signs of water stress, but avoid waterlogging, particularly when temperatures are cool. Plants are also more susceptible to water stress if infected by pathogens that enter the xylem and inhibit water flow.

Heavy irrigation or periods of prolonged wet weather can cause potassium to leach from the soil and/or inhibit root development. The resulting potassium deficiency in the canopy can lead to a higher incidence of leaf spot diseases, with the potential for defoliation in severe cases.

Manage tail water to minimise the risk of spreading pathogens; if possible water the least infected fields first. General traffic, sprays, and picking should 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 irrigation 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).

Balanced crop nutrition

A healthy crop is more able to express its natural resistance to disease. Excessive nitrogen favours fusarium and verticillium wilts, and also greatly increases 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, particularly of leaf spots. Refer to NUTRIpak, the 'Crop Nutrition' page of the CottonInfo website or the *Australian Cotton Production Manual* for more information on managing cotton nutrition.



Cotton trash bleached grey by 140 days of UV solarisation. © Scott Brimblecombe

IDM post harvest

Control alternative hosts and volunteers

A host free period prevents build-up of pathogen inoculum and carryover of disease from one season to the next. Many pathogens that cause disease in cotton can also infect common weeds found in cotton growing areas (see examples in Table 29). Host-free periods are particularly important for diseases (such as cotton bunchy top) that require living plants to survive.

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 mode of actions and explore alternate mechanical means of weed control. See the 'Weeds' chapter for more information.

Manage crop residues

The pathogens that cause verticillium wilt, fusarium wilt, black root rot, boll rots, seedling disease and alternaria leaf spot can 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, slash residues and retain them 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. Bleaching of stems from pale brown to grey is a good indication of adequate UV exposure.

Otherwise, incorporate crop residues as soon as possible after harvest to promote faster decomposition.

Use crop rotations to help manage disease

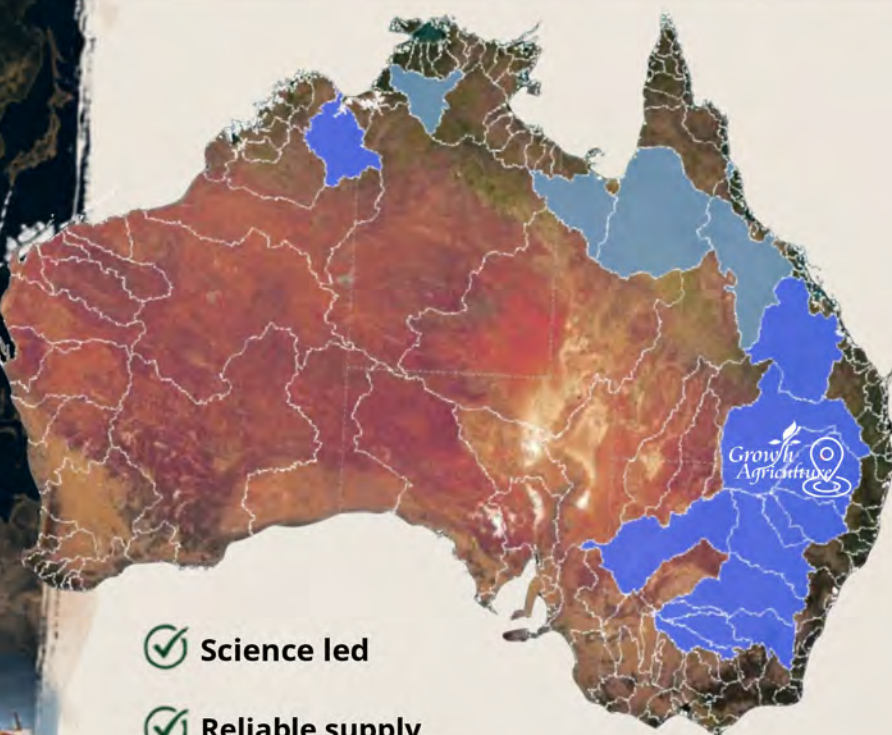
Successive crops of cotton (or other host species) can contribute to a rapid increase in disease incidence, particularly if susceptible varieties are used. Employ a sound crop rotation strategy using crops that are not hosts for the pathogens present.



Volunteer and ratoon cotton can allow diseases such as cotton bunchy top to persist between seasons. © Linda Scheikowski, Qld DPI

SOME FERTILISERS
TRAVEL THROUGH
**GLOBAL
UNCERTAINTY...**

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TABLE 29: Broadleaf weeds as hosts of cotton pathogens

Family	Scientific Name	Common Name	Cotton disease					
			Alternaria leaf spot	Black root rot	Cotton bunched top	Fusarium wilt	Tobacco streak virus	Verticillium wilt
Malvaceae	<i>Abutilon theophrasti</i>	Velvetleaf	✓	✓	✓			✓
	<i>Anoda cristata</i>	Anoda weed	✓		✓			✓
	<i>Gossypium hirsutum</i>	Cotton volunteers/ratoons	✓	✓	✓	✓	✓	✓
	<i>Hibiscus trionum</i>	Bladder ketmia	✓		✓	✓		✓
	<i>Malva parviflora</i>	Small flowered mallow			✓			✓
	<i>Malvastrum americanum</i>	Spiked malvastrum			✓			
	<i>Sida rhombifolia</i>	Paddy's lucerne			✓			
Aizoaceae	<i>Trianthema portulacastrum</i>	Black pigweed			✓			
Amaranthaceae	<i>Alternanthera nodiflora</i>	Common joyweed						*
	<i>Amaranthus macrocarpus</i>	Dwarf amaranth				✓		✓
	<i>Amaranthus retroflexus</i>	Redroot amaranth		✓				✓
	<i>Gomphrena celosioides</i>	Gomphrena weed						✓
Asteraceae	<i>Bidens pilosa</i>	Cobler's pegs					✓	*
	<i>Carthamus lanatus</i>	Saffron thistle						✓
	<i>Centaurea solstitialis</i>	St Barnaby's thistle						✓
	<i>Helianthis annuus</i>	Sunflower volunteers					✓	✓
	<i>Parthenium hysterophorus</i>	Parthenium weed					✓	
	<i>Silybum marianum</i>	Variegated thistle						✓
	<i>Sonchus oleraceus</i>	Common sowthistle		✓			✓	✓
	<i>Verbesina encelioides</i>	Golden crownbeard		✓			✓	✓
	<i>Xanthium spinosum</i>	Bathurst burr						✓
	<i>Xanthium occidentale</i>	Noogoora burr					✓	✓
Brassicaceae	<i>Brassica</i> spp.	Wild turnip						✓
	<i>Capsella bursa-pastoris</i>	Shepherd's purse		✓				✓
	<i>Rapistrum rugosum</i>	Turnip weed						✓
Chenopodiaceae	<i>Rhagodia nutans</i>	Climbing saltbush						✓
Convolvulaceae	<i>Convolvulus erubescens</i>	Australian bindweed						✓
	<i>Ipomoea lonchophylla</i>	Cowvine, peach vine						✓
	<i>Ipomoea plebeia</i>	Bellvine		✓		✓		✓
Cucurbitaceae	<i>Citrullus lanatus</i>	Wild melon				✓		
Euphorbiaceae	<i>Chamaesyce hirta</i>	Asthma plant			✓			
	<i>Euphorbia drummondii</i>	Caper spurge						✓
Fabaceae	<i>Medicago polymorpha</i>	Burr medic		✓	✓			✓
	<i>Medicago sativa</i>	Lucerne volunteers		✓				✓
	<i>Medicago</i> spp.	Medic		✓				✓
	<i>Neptunia gracilis</i>	Native sensitive weed						✓
	<i>Sesbania cannabina</i>	Sesbania pea				✓		
Lamiaceae	<i>Lamium amplexicaule</i>	Dead nettle		✓	✓			✓
	<i>Salvia reflexa</i>	Mintweed						✓
Martyniaceae	<i>Proboscidea louisianica</i>	Devil's claw						✓
Polygonaceae	<i>Fallopia convolvulus</i>	Black bindweed						✓
	<i>Rumex crispus</i>	Curled dock						✓
Portulacaceae	<i>Portulaca oleracea</i>	Red pigweed						✓
Solanaceae	<i>Datura ferox</i>	Fierce thornapple		✓			✓	✓
	<i>Datura stramonium</i>	Common thornapple		✓			✓	✓
	<i>Nicotiana glauca</i>	Wild tobacco		✓				✓
	<i>Physalis ixocarpa</i>	Groundcherry						✓
	<i>Physalis minima</i>	Chinese lantern					✓	*
	<i>Physalis virginiana</i>	Perennial groundcherry						*
	<i>Solanum nigrum</i>	Blackberry nightshade					✓	✓
Verbenaceae	<i>Verbena bonariensis</i>	Purpletop						✓
	<i>Verbena officinalis</i>	Common verbena						✓

* other species of the same genera are a known host
 blank = unknown



The *Australian Cotton Production Manual's* 'Post-harvest pest and stubble management' chapter includes a table detailing the potential disease implications for cotton of various rotation crop options. This information can assist in developing a rotation strategy.

The pathogen that causes verticillium wilt has a very large host range (see Table 29), 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; 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 >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 assist in restoring mycorrhizal fungi.

IDM all year round

Manage insect vectors

The risk and severity of diseases caused by viruses can be minimised by managing the vector. Cotton bunchy top can be transmitted by aphids feeding on infected plants before migrating to healthy plants. Transmission of tobacco streak virus 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). Apply integrated pest management principles and consider resistance risks when managing vectors.

Viruses can only survive in living plants. Control of cotton rats 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 by considering vehicle and machinery movements within and between farms. 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.

For more information on exotic diseases and farm biosecurity, see the 'Biosecurity' chapter. III



The Australian Cotton Disease Collaboration (the ACDC) is a partnership between the Cotton Research and Development Corporation, the University of Southern Queensland and the Queensland Department of Primary Industries.

Its mission is to reduce the impact of diseases in cotton to less than 5 per cent of the cost of production through research on key areas, such as systems-based disease control, understanding pathogen behaviour, spatial data analytics, fungicides and plant defense mediators. Find out more at www.unisq.edu.au/research/the-acdc

USEFUL RESOURCES:

Further information on cotton diseases and their management can be found at

cottoninfo.com.au/disease-management

and mybmp.com.au

'Come Clean. Go Clean.' is based on the premise that prevention is better than cure, and is an essential component of disease management in cotton.

This 4-step poster is included in the 'Biosecurity' chapter and can be downloaded from the Biosecurity page of the CottonInfo website.

CottonInfo also have a video demonstrating Come Clean. Go Clean. principles.



Come Clean. Go Clean.
youtu.be/gR8hf8-hYQA



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. Note that visual symptoms can be highly variable and 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 101).

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Severe black root rot infection on a mid-November planted crop in a Murrumbidgee field. © Duy Le, NSW DPIRD

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 appear stunted, especially early season. Destruction of the root cortex (outer layer), is seen as blackening of the roots, and some roots may die. The fungus does not kill seedlings by itself, but severe black root rot can increase the susceptibility of plants to *Pythium* or *Rhizoctonia* spp. Dead cells are shed when growth resumes in warmer weather, so the root blackening may not be visible later in the season, even on plants that were badly affected as seedlings.

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.

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.
- Base replanting decisions 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.
- Minimise tailwater.
- Practice good farm hygiene – Come Clean. Go Clean.
- Most conventional crop rotations will not reduce black root rot inoculum levels (apart from a rice rotation, where prolonged flooding can reduce inoculum levels).
- Flooding of fields for 30 days when maximum temperatures are above 30°C significantly reduces the population of *B. rouxiae*. Even better results are seen in fields flooded for 60 days.
- Consider using 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 rotating to other host species (such as legumes).
- Control weeds, cotton volunteers, and cotton ratoons.

Boll rot, tight lock and seed rot

Boll rots are caused by a number of fungal and bacterial pathogens. Tight lock is 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.

Several fungi can also cause secondary boll rots in cotton, taking advantage of injury or wounds in the boll wall, such as those caused by insect pests.

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).
- The exposure of opening bolls to wet weather (boll rots and tight locks).

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, while sclerotinia hosts include sunflower, safflower, soybeans and most pasture legumes. Consider disease host range when planning rotations – more detailed information for several boll rots is available in the 'Post-harvest pest and stubble management' chapter of the *Australian Cotton Production Manual*.

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 that might lead 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.

Types and causes of boll rot

Alternaria leaf spot

Alternaria spp. causes leaf spot in cotton, and several 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, creating circular dry brown lesions. 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, turn a dull to dark brown and not open properly.



Anthracnose boll rot showing orange spore masses.

© Duy Le, NSW DPIRD



Bolls affected by *Diplodia* spp. are covered in 'sooty' black spores. © Linda Smith, Qld DPI

Anthracnose boll rot

Anthracnose boll rot (caused by *Colletotrichum* spp.) is only occasionally seen in Queensland cotton crops and is characterised by large, spreading lesions on bolls, often with an associated pink or orange spore mass. While the pathogen is able to infect all parts of the cotton plant and at any stage of growth, it is more commonly found on higher bolls. Seedling stems may be girdled at or near the base of the stem.

Bacterial blight

Bacterial boll rot symptoms (caused by *Xanthomonas citri* pv. *malvacearum*) include dark water-soaked lesions. are currently rare due to varietal resistance. However, hyper-virulent strains currently exist overseas (see the 'Biosecurity' chapter for images).

Diplodia boll rot

Diplodia boll rot starts as dark brown lesions that rapidly expand to cover the whole boll as the rot progresses. Bolls become covered with a black smut-like fungal growth which can easily be rubbed off the boll surface.

Fusarium boll rot

Fusarium boll rot is not an advanced symptom of fusarium wilt, but a different disease. It often appears on the boll as a covering of 'furry' orange or pink spore masses.



Advanced infestation of fusarium boll rot.

© Linda Scheikowski, Qld DPI

Phytophthora boll rot

Phytophthora boll rot (caused by *Phytophthora nicotianae* var. *parasitica*) can occur from rain-splash of soil onto low bolls that are beginning to crack open or inundation by backed-up tail water or flooding. Infected bolls quickly turn brown and become tight locked (sometimes with areas of white mould on the surface), before opening prematurely.



Bolls with seed rot caused by pale cotton stainers.

© Stephen Allen

Sclerotinia boll rot

Sclerotinia sclerotiorum 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. See the section on sclerotinia rots later in this chapter for images of infected bolls.

Seed rots

Seed rot is a 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 boll's surface. Seeds within the maturing green bolls are swollen and discoloured yellow or brown. When affected bolls open, locks with infected seed fail to fluff out, remaining compact and discoloured. Seed rots may be limited to one or two locks rather than affecting the whole boll.

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 play a role in the development of tight lock. The tight consistency of the seed cotton mass means 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.



Tight locked boll (top). Healthy, fluffy locules (left) and fully affected, severe tight lock locules (right).

© Linda Smith, Qld DPI

Collar rot

Agroathelia rolfsii (formerly *Sclerotium rolfsii*) is a soil-borne fungal pathogen that causes blights and stem rots in a range of crops.

The reproductive phase of the fungus (spherical resting structures known as 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

The 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, and white or brown sclerotia the size of mustard seeds (0.5–2.0 mm) form around the infection site.

Favoured by

The pathogen 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 DPI



Girdling of cotton stem © Dinesh Kafle, Qld DPI



Sclerotia and hyphae © Tegan Brownie, Nutrien Ag Solutions



Sclerotia on agar media © Dinesh Kafle, Qld DPI

Cotton bunchy top (CBT)

A viral disease spread by cotton aphids, CBT can only survive in living plants.

Ratoon plants affected by CBT that survive from the previous season often harbour aphids which can then move to adjacent plants, creating patches of infection.

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 can be 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.



Identifying CBT disease
youtu.be/xrp1420cjlk



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.



CBT infection leads to a distinctive leaf mottling. © Stephen Allen



Pale green angular patterns around the margins and darker green centres is typical of CBT. © Linda Smith, Qld DPI

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 29). 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 – the most effective way to minimise CBT risk is to eliminate hosts, particularly over winter. Break the green bridge and Step 2 should not be required.

- CBT virus can only survive in living plants. A break in host presence between cotton seasons reduces 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



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 have 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.
- Crop stress – e.g. waterlogging, root damage from 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.



Dark brown discolouration observed in cross sections of cotton stems infected with Fov. © Janelle Montgomery, CottonInfo



Fusarium wilt: Wilting and dying plants are often observed at the tail drain. © Linda Smith, Qld DPI

- Regularly inspect fields for early detection and containment of isolated outbreaks. See page 101 for information on how to sample and send 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 102) 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.

USEFUL RESOURCES:



Managing fusarium wilt
youtu.be/Cygy6XiRDcw



Fusarium wilt fact sheet

 [cottoninfo.com.au/
publications-and-resources/
fusarium-wilt](https://cottoninfo.com.au/publications-and-resources/fusarium-wilt)



Post-harvest management
of fusarium wilt
youtu.be/NGeQ4FTH7IM



Leaf spots and blights

Alternaria leaf spot (ALS): *Alternaria alternata* and other minor spp.

Cercospora leaf spot: *Cercospora* spp.

Stemphylium leaf spot: *Stemphylium* spp.

Target spot: *Corynespora* spp.

Ramularia: *Ramulariopsis* spp.

Leaf blights

ALS is the most common cause of leaf spot in cotton in cooler regions. 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.

Alternaria spores can only germinate when there is several hours of free moisture on the leaf surface, meaning the disease is favoured by either repeated heavy dews or extended periods of wet weather and suppressed by periods of very hot weather. Symptoms are also more prevalent in stressed crops (e.g. with heavy fruit load or premature senescence), and back-to-back fields are at greater risk of developing the disease.

In northern Australia, leaf blights may occur either independently or as part of a leaf spot complex involving *Alternaria*, *Cercospora* and *Stemphylium* spp. Disease development is favoured by cooler temperature and is generally slow and mild, with no cases of severe defoliation reported in modern commercial varieties. Leaf blights may be associated with potassium deficiency during periods of high demand, such as boll filling. In dryland crops, disease severity may also increase during prolonged dry conditions where reduced soil moisture limits potassium uptake by the plant. Because of the nutrition link, symptoms of K deficiency, premature senescence, and leaf blight lesions often appear together, and fungicides are generally ineffective for managing these symptoms.



Leaf blights in northern Australia. Left: potassium deficiency and premature senescence. Right: close-up of *Stemphylium* leaf spot lesions. © Samuel Krekeler, Qld DPI



Initial target spot symptoms. Left: characteristic brown concentric lesions. Right: early symptoms on lower canopy leaves. © Samuel Krekeler, Qld DPI



Canopy closure over the row is a key phenological stage for target spot. Solid-row configuration (left) versus skip-row configuration (right). © Samuel Krekeler, Qld DPI



Images from a field trial. Untreated control (left) versus two Merivon® sprays 15 days apart (right). © Samuel Krekeler, Qld DPI

Target spot

Target spot can be easily identified by the brown concentric rings on the upper leaf surface in the lower canopy. As the disease progresses, symptoms spread upwards through the mid-canopy, often resulting in premature defoliation.

Prolonged periods of leaf wetness are a key aspect for disease development. As such, the disease is usually confined to northern Australia with recent reports in grown-on crops in Central Queensland (CQ). Target spot is strongly linked to crop phenology and environmental conditions. Canopy closure over the row is essential for disease development, as it creates a dense, humid microclimate in the lower and middle canopy that can trap moisture and lead to prolonged periods of leaf wetness – the key driver of infection and disease build-up.

The disease is therefore most likely to occur in vigorous, well-growing cotton that experiences regular leaf moisture after canopy closure from frequent rainfall, drizzle, dew or overhead irrigation. Crops with restricted growth due to soil constraints (e.g. waterlogging or acidity) or other limitations rarely develop target spot and generally require no specific management.

- In northern Australia, scout for target spot symptoms from the third week of flowering onwards, when the canopy progressively closes over the inter-row. Field trials have shown strong fungicide efficacy against target spot, however the impact of the disease on yield in Australia remains unknown and is likely to vary depending on disease severity and the crop's ability to compensate. Fungicides are most effective when applied prior to row closure to ensure good coverage in the mid-canopy
- In Central Queensland, target spot has mainly been reported in grown-on cotton (where crops are retained through the January-March rainfall period rather than harvested beforehand), but disease development is generally mild, as prolonged periods of leaf wetness are less common than in northern coastal environments. Management is also difficult in these crops because canopy closure may occur well before target spot symptoms appear, limiting the opportunity to apply fungicides at the optimal time.

Ramularia

Ramularia has been confirmed across northern Australia and in grown-on crops in CQ. Although associated with tropical environments, it typically appears later in the season as temperatures begin to cool during late autumn and early winter (as crops approach defoliation and harvest). Severe disease development resulting in premature defoliation is uncommon, probably because the cooler temperatures coincide with the transition into drier seasonal conditions, reducing prolonged humidity and leaf wetness.

Ramularia causes fine yellow to chlorotic spotting on the upper leaf surface, together with grey to white fungal growth on the underside of infected leaves (sporulation may also occur on the upper leaf surface under favourable conditions). 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 the margin and cup inward before turning yellowish brown and falling off prematurely. This disease can have ongoing cycles throughout a season.



Initial ramularia symptoms. Left: yellowish lesions on the upper leaf surface. Right: white/greyish powdery mildew on the underside of the leaf. © Samuel Krekeler, Qld DPI

Host range

Foliar pathogens are widely distributed and often have a broad plant host range, although some strains may show host specificity. Ratoon and volunteer cotton plants can harbour these pathogens between seasons. Infection generally occurs through spores originating from infected crop residues or self-sown cotton, with spread occurring via wind, rain splash, irrigation water and farm equipment.

Infected leaves and crop debris are an important source of inoculum for both survival and disease spread. As infected leaves become necrotic, they can continue producing spores that drive repeated cycles of infection under favourable environmental conditions.

IDM tactics

- Ensure complete crop destruction at season's end. Prioritise incorporating post-harvest crop residues and removing volunteers as soon as possible.
- Provide balanced crop nutrition (especially potassium for leaf blights) and avoid excessive application of nitrogen.
- Wider row spacing and skip row configurations can reduce or largely eliminate target spot.
- For target spot, use mepiquat chloride according to the Tropical Canopy Management Tool to avoid excessive canopy expansion (see the *Cotton Production in Northern Australia* publication)
- If disease is persistent, avoid back-to-back cotton (plant a break crop) in the same fields.

Only consider fungicides when favourable environmental and crop growth conditions align.

Two minor use permits (PER95141 for mefentrifluconazole and PER95142 pyraclostrobin + fluxapyroxad; both valid until 31 December 2029) have been issued to control target spot in cotton. Other foliar fungicides such as tebuconazole (permitted for ALS) have shown no efficacy on target spot in cotton.

Emergency use permits for ramularia in cotton have now expired. Although overseas studies have shown strong fungicide efficacy against this disease (including for fungicides currently under permit for target spot control), severe disease pressure requiring fungicide intervention has been inconsistent in Australia. Crop managers are encouraged to report suspected cases of ramularia to assist our knowledge of this disease under Australian conditions.

USEFUL RESOURCES:



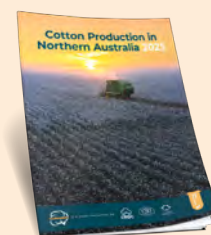
Foliar diseases of cotton
youtu.be/x5lhJEiB8vw



Further information on foliar cotton diseases is available at the CottonInfo website:
cottoninfo.com.au/disease-management



Cotton Production in Northern Australia
cottoninfo.com.au/publications-and-resources/cotton-production-northern-australia



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 dihystra*), 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.

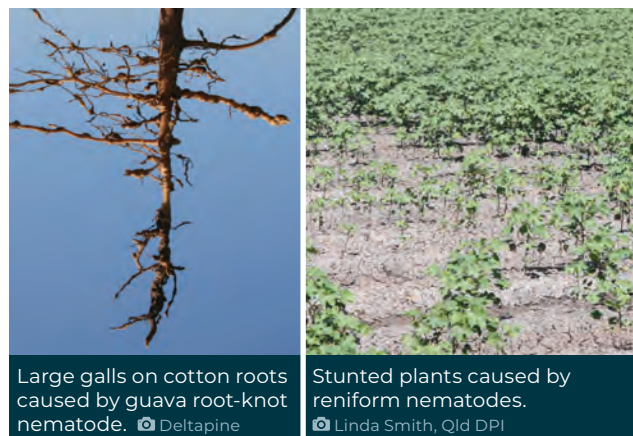
Root-knot nematodes thrive in sandy and sandy loam soils and causes little damage in soils with clay content greater than about 15%. However, the reniform nematode has been associated with soil types having higher silt and (or) clay contents compared with most plant-parasitic nematodes

Host range

Many nematodes have a wide host range, including weed species. Reniform nematode hosts include 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. Root-knot nematode hosts include field crops such as maize, soybean, grain sorghum, wheat, rye, oats, barley, and many vegetables, fruit and ornamentals. Guava root-knot nematode hosts include soybean, banana and many vegetable crops.

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.

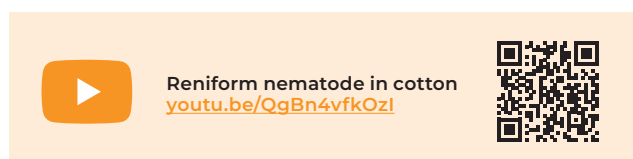


- Plant into good conditions, including optimum soil temperature, no water stress and well-formed beds.
- Monitor crops for patches of stunted plants and submit suspicious root samples for testing to Queensland DPI.
- Manage cotton stubble. Cut cotton stalks and till soil through the stubble zone as 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 101 for more information on sending plant samples for diagnosis).



Reoccurring wilt

Pathogen: Novel *Eutypella* species

Reoccurring wilt was first observed in the 2017/18 season, the first known detection of a species of *Eutypella* 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

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

The host range of the pathogen that causes reoccurring wilt is currently unknown.



IDM tactics

Glasshouse trials indicate 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 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 and send samples for pathogen confirmation. Your samples will also assist the industry's understanding of the genetic diversity of this pathogen.

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:



Identifying reoccurring wilt

link.springer.com/article/10.1007/s13313-021-00843-8



Contact your nearest REO or cotton pathologist if you suspect the disease on your farm. For information on collecting and submitting disease samples, see page 101.



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.

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 black irregularly shaped resting structures (sclerotia). These large (2–10 mm diameter) sclerotia 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.

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 populations).



Sclerotinia boll rot has black irregularly shaped sclerotia within and/or on the surface of the rotted bolls (L) and a white cottony fungal growth. © Linda Smith, Qld DPI

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.
- Sclerotia can survive in the soil for up to 10 years, so while five or more years of rotations with non-host crops (such as small grains, cereals, and maize) can reduce the number of sclerotia in the soil by loss of viability over time, one-to-three-year rotations are unlikely to have a significant impact on disease incidence.



In vitro production of apothecia on sterile sand and ascospore discharge of *Sclerotinia sclerotiorum*.
© H.R. Dillard, Cornell University



Sclerotinia in cotton
youtu.be/yt_542Kj3_0



Seedling diseases

Seedling diseases are caused by numerous pathogens (either acting alone or in combination) that cause slowed growth, 'damping off' and reduced plant stands. The main pathogens infecting cotton seedlings are *Rhizoctonia solani*, *Pythium ultimum*, *Fusarium* spp. (not the same pathogen that causes fusarium wilt) and black root rot.

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, or planting depth have had an effect.

Favoured by

Anything that slows down germination and/or seedling growth, including cool and/or wet weather, poorly formed beds, compaction, waterlogging, incorrect planting depth, poor fertiliser placement, excessive herbicide rates at planting, herbicide movement into the root zone, establishment pests, or 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.

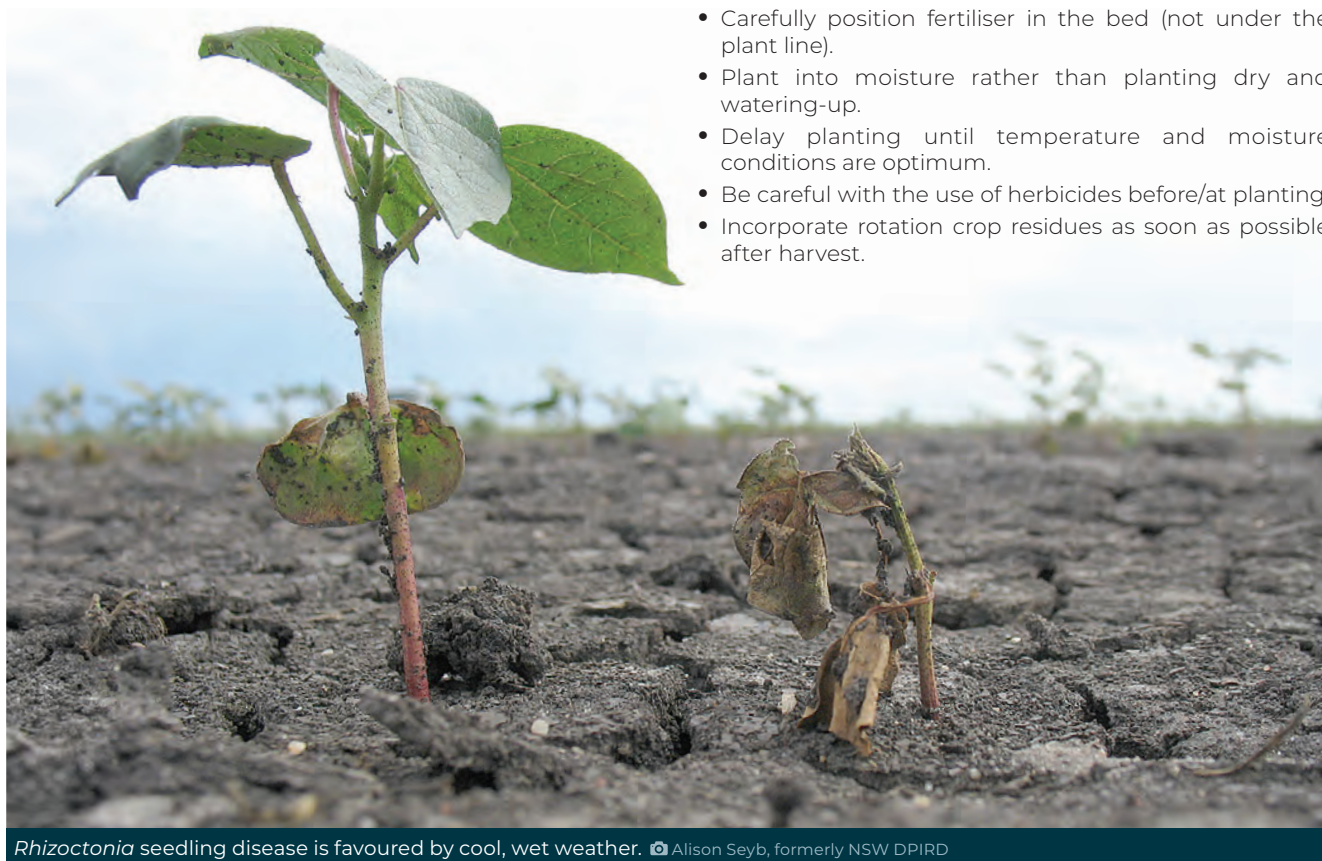


Rhizoctonia lesions on cotton seedlings. © Duy Le, NSW DPIRD

Seedling disease 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 before/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 DPIRD

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*, however virulence varies greatly within strains. All incidences of verticillium wilt are potentially serious regardless of the strain as yield losses can still be severe (even if defoliation does not occur).

Symptoms

Verticillium wilt has streaks/flecking through the centre of the stem (compared to the more solid discolouration of fusarium wilt). However, as symptoms of verticillium wilt and fusarium wilt are difficult to tell apart, plant/s suspected of being infected should 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 can be 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 and 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, oats, triticale, canary grass, lablab, black gram and vetch are hosts.



Typical leaf symptoms of verticillium wilt. © Stephen Allen

Microsclerotia have recently been detected on commercially grown barley, confirming barley as a host when grown under Australian field conditions. The pathogen also has a wide range of weed hosts (see Table 29 for examples). There is some host specificity between strains.

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 (see page 101 for full details).
- If your farm is free of *V. dahliae*, try to keep it that way. Ensure all farm staff and contractors practice good farm hygiene and Come Clean. Go Clean.



Characteristic symptoms of verticillium wilt include wilted plants, leaf mottle and necrosis. As disease progresses, defoliation and plant death may occur. © Linda Smith, Qld DPI

USEFUL RESOURCES:



Verticillium wilt in cotton
youtu.be/hgiatA52nNw



Verticillium wilt fact sheet

 cottoninfo.com.au/publications-and-resources/verticillium-wilt



Dark grey peppery discolouration observed in cross sections of cotton stems infected with *V. dahliae*. © Duy Le, NSW DPIRD

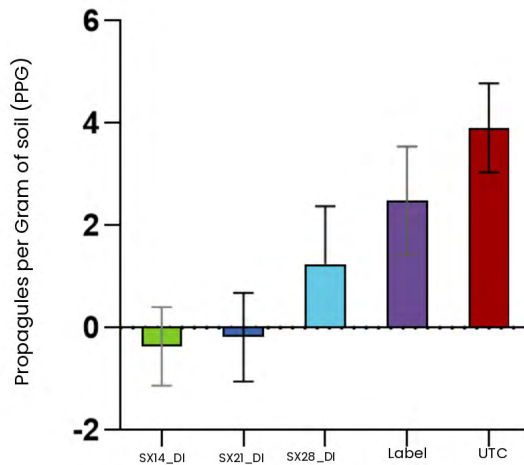
Under the protection of Sero-X and with BMP you CAN manage vert



SERO-
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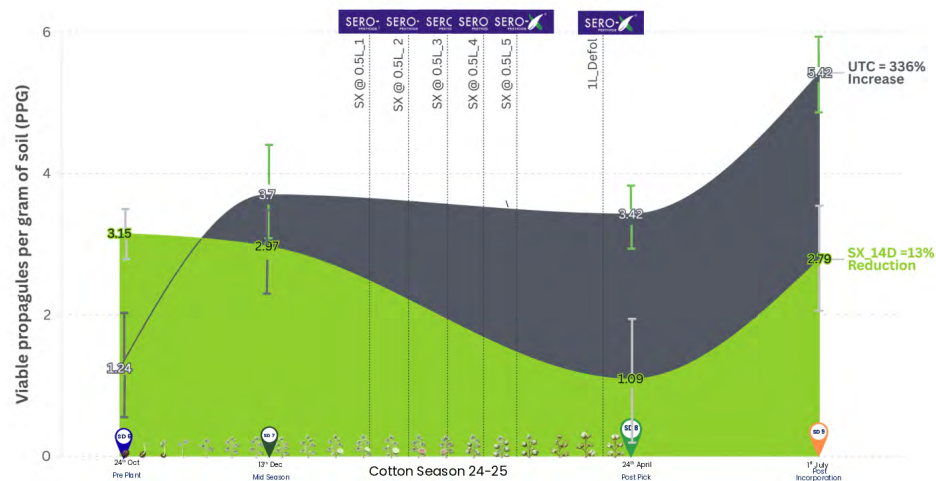


Change in Inoculum of *Verticillium dahliae*
from Pre Plant to Post Incorporation 2024-2025



Treatment Name	Timing (First - Early Flowering Start)	Number of in season Applications	Rate L/Ha	Defol Rate L/Ha	TOTAL
SX_14DI	0.5 L/Ha 14 days apart	5	0.5	1	3.5
SX_21DI	0.5 L/Ha 21 days apart	4	0.5	1	3
Label	Label Rate (3 x 2L/Ha)	2	2	2	6
SC_28DI	0.5 L/Ha 28 days apart	3	0.5	1	2.5
UTC	Untreated	0	0	0	0

Season 24-25: Sero-X Multiple 500ml applications
6 applications 14 days apart



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Agriculture

The Fast Facts: Be wilt aware

	FUSARIUM WILT	VERTICILLIUM WILT	SUDDEN WILT	LIGHTNING STRIKE	REOCCURRING WILT
CAUSAL AGENT	<i>Fusarium oxysporum</i> f.sp. <i>vasinfectum</i>	<i>Verticillium dahliae</i>	Potentially caused by <i>Fusarium</i> spp./physiological effect of environmental conditions	Lightning (thunderstorm)	Novel <i>Eutypella</i> 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.

Other diseases

A range of other diseases can also affect cotton. These are usually much less common and/or have less impact on yield or quality than the key diseases mentioned in this chapter, largely thanks to cotton breeding programs and biosecurity measures.

Bacterial blight

Bacterial blight (*Xanthomonas citri* pv. *malvacearum*) is no longer a problem in Australian cotton due to varietal resistance. However, hyper-virulent strains currently exist overseas (see the 'Biosecurity' chapter), so if you see dark water-soaked lesions on cotyledons, leaves, stems or bolls, collect samples for testing.



Bacterial blight symptoms include dark water-soaked lesions on leaves, stems or bolls.

Bacterial stunt

Bacterial stunt (*Pseudomonas* sp.) often leads to relatively uniform stunting or slow growth early in the season. The severity varies between seasons. Look for rapid root browning in seedlings. Growth will generally improve later in the season.



Bacterial stunt results in slow growth (left) compared with healthy plants (right).

Charcoal rot

Charcoal rot (*Macrophomina phaseolina*) causes wilting and death, and can be distinguished from other wilt-causing pathogens by the small black sclerotia that can be found embedded in infected tissue. It is usually only a problem when plants are stressed by drought or high temperatures.



Charcoal rot caused by *Macrophomina phaseolina*.



Coprinus cinereus is associated with module rot.

Post-harvest rot

Post-harvest rot (*Coprinus* sp.), sometimes known as 'inky cap', is most often found where water enters a module (e.g. through a hole in the plastic, or along rops holding the rectangular module tarp in place). The fungus is favoured by wet picks, excessive trash, or poor storage of modules or bales, along with damage to module covers. Hyphae attack the cellulose in cotton fibres, causing bumps/swellings and can significantly affect fibre quality.



Sudden wilt

Sudden wilt mostly occurs during hot weather following irrigation or rainfall. A 'sudden' wilt (occurring randomly within a field, affecting single plants or small patches of plants) is followed by defoliation and usually plant death, although occasionally it may regrow. Vascular discolouration is only observed in the woody parts of the root and lower stem. It is suspected that the physiological impacts of adverse environmental conditions incidentally allow pathogens such as *Fusarium* sp. to enter the plant's vascular system.



Sudden wilt symptoms usually appear during hot weather after irrigation or rainfall.

Tobacco streak virus

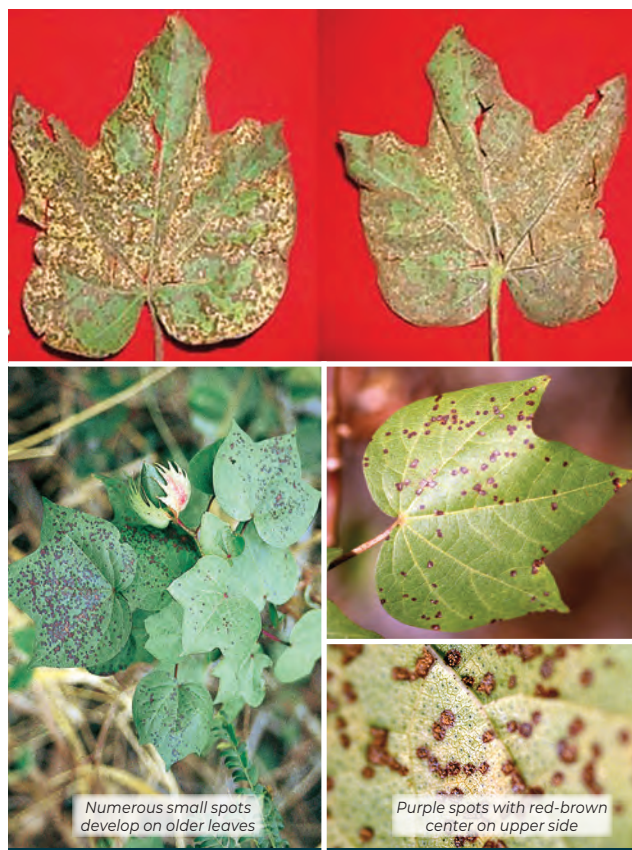
Tobacco streak virus (TSV), found in Central Queensland is transmitted by infected pollen, spread by wind or carried by thrips (thrips damage allows infection by the virus. Symptoms are usually mild, with some leaves developing dark purple diffuse lesions. The major alternative host for this disease is parthenium weed.



Foliar symptoms of TSV may include purplish or brownish-black patches that can be circular or irregular.

Tropical rust

Tropical rust (*Phakopsora gossypii*) is common in feral cotton in parts of Northern Australia. Numerous small purple to reddish spots develop on the upper surface of older leaves, corresponding to brown powdery pustules on the underside. The disease is more prevalent during the dry season.



Tropical rust produces small leaf spots.

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. In some fields, more than one disease may be present so it is important to liaise with your local pathologist (and collect samples in for identification) if you have any concerns.

More information can be found at the CottonInfo website www.cottoninfo.com.au/disease-management, including links to the Cotton Symptoms Guide and various disease factsheets, along with information on how to collect and send a sample in for disease diagnostics.

TABLE 30: 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 <i>Pythium</i> spp. and <i>Rhizoctonia solani</i>	Seed treatment available through CSD when ordering seed.
	Acibenzolar-S-methyl 500 g/L	Bion®		No group	Fusarium wilt, black root rot	Seed treatment available through CSD when ordering seed. Suppression only. Activates the plant's natural resistance mechanisms.
	Metalaxyl-M 350 g/L	Various		4	Damping-off caused by <i>Pythium</i> and <i>Phytophthora</i> . Fusarium wilt disinfection on seed	Seed dressing. Qld & NSW only. Does not protect against damping off by <i>Rhizoctonia</i> , Fusarium or other fungi. 97% R-enantiomer. Much more effective in controlling diseases. Lower rates can be used.
At planting	Quintozone 750 g/kg	Terraclor®		14	Damping-off caused by <i>Rhizoctonia</i> spp.	Qld, NSW & WA only. Soil fungicide. Spray over seed and surrounding soil at planting.
	Tolclofos-methyl 500 g/L	Tolex® Rhizolex® In Furrow		14	<i>Rhizoctonia solani</i>	Qld & NSW only. Mix with seed immediately before planting. Applied as an in-furrow spray or water injection at planting.
Foliar fungicides	<i>Clitoria ternatea</i> 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.
	Mefentrifluconazole 75 g/L	Belanty®		3	Target spot	PER95141. Expires 31 December 2029. NT, QLD and WA only. Check permits for restrictions regarding release height, droplet size and buffer zones. Maximum 3 applications per crop, at least 15 days apart.
	Pyraclostrobin 250 g/L + Fluxapyroxad 250 g/L	Merivon®		7, 11	Target spot	PER95142. Expires 31 December 2029. QLD, NT & WA only. Check permit regarding ground rig and aircraft buffer zones. Maximum of 3 applications per crop, at least 7 days apart.
	Tebuconazole 430 g/L	various		3	Alternaria leaf spot	PER82660. Extended to 31 August 2028. Southern cotton regions only. Apply as a preventative when conditions favour disease development. Maximum 2 sprays 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.

For more information on cotton diseases, including contact details for industry pathologists, visit cottoninfo.com.au/disease-management

Biosecurity – we all have a responsibility

Biosecurity aims to protect your property and the entire industry from the entry, spread and establishment of exotic (and endemic) pests, including insects, weeds and diseases. These pests can affect everyone – farmers, agronomists and the community, so it is important that we all play a part in preparing for and minimising biosecurity risks. Australia's national quarantine system helps prevent the introduction of harmful exotic pests, but the threat they pose is still very real. Our ongoing reliance on imported goods, as well as existing natural entry pathways (e.g. island hopping or winds), makes future incursions of exotic pests and diseases almost inevitable.

Biosecurity – a legal responsibility

All Australian states and territories have biosecurity legislation to minimise the risk of the entry and spread of pests, pathogens and weed seeds. In some states (such as Queensland and NSW), legislation is based on the principle of a 'shared responsibility' where **everyone** must contribute to biosecurity by ensuring they minimise the risk of spreading 'biosecurity matter' that could impact the environment, economy and the broader community.

It is your responsibility to meet the specific requirements of your state or territory. For further information contact your State or Territory Agriculture Department.

Anyone working on or visiting farms has a biosecurity responsibility

Biosecurity should be an integral part of both farm planning and all day-to-day operations.

- **Come Clean. Go Clean.** Vehicles, farm equipment and people can carry biosecurity matter. Clean down between farms, including vehicles and footwear. Use an on-farm rather than visitor vehicle where possible.
- **Monitor frequently for 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, and early reporting improves the chance of effective control and eradication.
- **Communicate your biosecurity requirements** using clear signage (particularly at farm and field entry points) 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 insects, 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 clothing 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, refugees and other commercial crops. Keep detailed records of all farm inputs.
- **Maintain zero tolerance of volunteer cotton plants** and other weeds at all times throughout the year.

Come Clean. Go Clean.

Effective decontamination of vehicles, machinery and other items involves two separate steps:

1. Cleaning with detergent, followed by
2. Disinfection.

Agricultural detergents

To work properly, disinfectants need to be applied to a cleaned surface (all soil and trash removed). Agricultural detergents (e.g. Bio-Cleanse™ or most industrial and domestic brands of soaps and detergents) provide optimal soil removal.

Agricultural disinfectants

Disinfectants that are specifically marketed for agricultural situations (such as Path-X™, Sporekill®, Steri-maX®) and disinfectant products containing quaternary ammonium compounds are usually 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.

Wash-down facilities

A dedicated wash-down area is highly recommended for both convenience and containment. Ensure that it is:

- easily accessible from your main farm entry point
- engineered so that dirty water is contained on-site
- regularly monitored for pests not killed by the disinfection stage (e.g. germinating weeds).

Step-by-step procedures in the Come Clean. Go Clean. process are detailed in the poster on page 127.

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 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.

More information on biosecurity stewardship, including the cotton biosecurity plan, is available from Cotton Australia. cottonaustralia.com.au/biosecurity

The biosecurity module within the cotton industry's myBMP program provides growers with the latest resources and support to meet best practice standards for farm biosecurity. www.mybmp.com.au

USEFUL RESOURCES:



On-farm biosecurity – prevent endemic and exotic pests entering and establishing on farm

farmbiosecurity.com.au



Biosecurity Contacts



Visit CottonInfo's Biosecurity page for the contact details for the Biosecurity authority in your state or territory.

cottoninfo.com.au/biosecurity

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



REMEMBER

To wash all equipment, floor mats, tools and footwear kept in the vehicle as well



Image: NSW DPI

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

Farm biosecurity management plans

A farm biosecurity management plan is a practical way of showing how you are preventing insects, weeds and diseases from:

- Being introduced to your property
- Spreading around your property (or spreading from your property to others).

Developing a 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 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 them. 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. |||

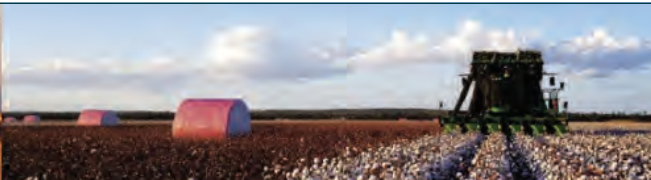
Biosecurity Top Tips:

Practices you implement to mitigate a biosecurity risk; 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.

www.youtube.com/@CottonInfoAust







Biosecurity Management Plan

Biosecurity Management Plan for broadacre industries

Property Name:	Property Address:
Owner or Manager:	Contact number:
Review date: Review every 12 months.	
Biosecurity Management Plan completed by:	Exotic Plant Pest Hotline 1800 084 881
(Name, signature and date)	



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Action Plan for implementing biosecurity practices	14

This is a Biosecurity Management Plan in accordance with Section 94G(4) of the Queensland Biosecurity Regulation 2016 and clause 44B 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 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.




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. For more information on the current high priority exotic pest list, contact Cotton Australia or Plant Health Australia.

Some species included in this section 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.

High priority pests

Cotton blue disease

Cotton leafroll dwarf virus (Polerovirus)

Spread by cotton aphids, with reports from Brazil of an up to 80% reduction in productivity of susceptible varieties. The disease has similarities to cotton bunchy top (CBT). Affected leaves tend to be smaller, thicker, more leathery and brittle and are intense green with yellow veins (while CBT-affected leaves have an angular pattern of pale green margins and darker green centres). Symptoms and stunting are more obvious in plants infected early on.

Reddening of stem petioles and leaf veins may occur. Leaf edges tend to roll downwards and under and plants become stunted and produce many branches, giving a bunchy zig-zag stem habit. 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 DPI



Boll weevil. © Alton N. Sparks, Jr., University of Georgia, Bugwood.org

Cotton boll weevil

Anthonomus 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 successful, but has cost hundreds of millions of dollars.

Cotton leaf curl disease (CLCuD)

Cotton leaf curl viruses (Begomovirus)

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. Disease development requires the presence of at least one begomovirus and one satellite. 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 (from a few millimetres diameter to almost the size of a normal leaf, but cup-shaped) are common.

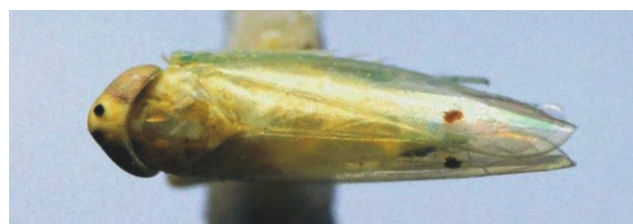
Indian cotton jassid

Amrasca biguttula

A sap-sucking leafhopper that can cause yield losses of up to 25%. Indian cotton jassids inject a toxin as they feed that causes leaves and bolls to drop and can stunt plant growth. While several leafhopper species are currently present in Australian cotton (see page 57) the damage they cause is usually relatively minor, rarely if ever affecting yield.



Leaf curl disease. © Cherie Gambley, Qld DPI



Indian green jassid. © NSW DPIRD



2026 Product Range



Ground Up Protection for the Australian Cotton Industry



100% Australian
Owned Company



Australian Products for
Australian Conditions



Longstanding relationship
with the highest quality
manufacturers



Fully QA Tested



Committed to
Australian Cotton Growers

eChem PRODUCTS

PGR'S & DEFOLIANTS

- e e-Tron Defoliation Oil
- e Ethephon 900
- e Mepiquat 38
- e Parasol Insecticide & Defoliant Oil
- e Thidiazuron 500 SC
- e Thi-Ultra SC

SEED TREATMENTS

- e Genero 600 SC
- e Methoxam 600

HERBICIDES

- e Amitrole T
- e Clethodim 360
- e Dicamba 500
- e Diuron 900
- e Glufosinate 200
- e Glyphosate 450 & 540 K
- e Halox 520
- e Paraquat 250 & 360
- e Pendimethalin 440
- e S-Metol 960
- e Staroxy 200 EC & 400 EC
- e Triclopyr 600

INSECTICIDES

- e Abamectin
- e AceTam 225
- e Alpha-Cyp 100 Duo.
- e Bifenthrin 100 EC
- e Difen 500
- e Fipronil 200 SC
- e Indox 150
- e Lambda 250 CS
- e Pyrip 100



Tarnished plant bug (left). © Scott Bauer, USDA Agricultural Research Service, Bugwood.org
Western tarnished plant bug (right). © Whitney Cranshaw, Colorado State University, Bugwood.org

Lygus bugs

Lygus lineolaris and *L. hesperus*

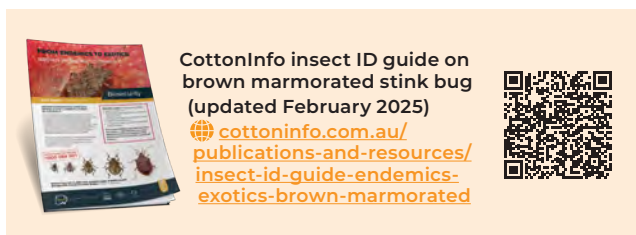
Tarnished plant bug and western tarnished plant bug occur predominantly in Northern America and have a wide host range. In cotton, feeding causes seed abortion, stem or leaf wilting and poor seed germination. It is likely that if an incursion occurred, control of these bugs would be very disruptive to the current Australian IPM system.

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 on the legs of nymphs). BMSB have been reported to be capable of damaging more advanced bolls than the current stink bug species found in Australia.



Brown marmorated stink bug. © Susan Ellis, Bugwood.org

Cotton stainer

Dysdercus spp.

Related to the already endemic pale cotton stainers (see page 45), 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.
Read more about this pest at ask.ifas.ufl.edu/publication/IN606

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

Phymatotrichopsis omnivora

Texas root rot is a 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* spp. 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 *H. zea* (American cotton bollworm) may hybridise with *H. armigera*.

Fall armyworm

Spodoptera frugiperda (exotic strains)

Fall armyworm was first detected in northern Australia in early 2020 and has since been declared endemic.

Although there are FAW strains overseas that have the capacity to feed on cotton, in Australia it has so far preferred cereal crops with whorls (such as maize and sorghum), and to date no impact on cotton crops has been reported.

Cotton aphid

Aphis gossypii (exotic strains)

Cotton aphids are potential vectors for exotic pathogens such as cotton blue disease.

As well as the risk of an aphid incursion carrying exotic disease, there is a risk that new aphid strains entering the country could have different insecticide resistance profiles, making control more difficult.

Bacterial blight

Xanthomonas citri subsp. *mavacearum* (exotic strains)

Although strains of bacterial blight are already present in Australia, they are no longer a problem due to host plant resistance in currently used varietal lines. Exotic strains (races) occur, however, that are 'hypervirulent' and, if established in Australia, could cause significant 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 the 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 also potentially introduce viruses (such as CLCuD) that they vector. **III**

**IF YOU SEE ANYTHING UNUSUAL,
CALL THE EXOTIC PLANT PEST HOTLINE**

1800 084 881

Applying pesticides

Pesticides are chemical products or mixtures, usually applied as a spray, that control pest species (e.g. insecticides, herbicides, fungicides, or nematicides). Products influencing plant growth and development and harvest aids (e.g. plant growth regulators, defoliants, or desiccants) are also applied using farm spray equipment.

Pesticides are an important component of cotton farming systems, but their short and long term efficacy largely relies on appropriate product choice and effective handling and application. Many 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 crop phytotoxicity in certain situations. Always read the entire label before applying any product.

Plan ahead

Developing a comprehensive spray plan (e.g. a Pesticide Application Management Plan or PAMP) prior to the season is an important part of the Best Management Practice (*myBMP*) program for cotton. Having a spray plan in place helps to ensure that everyone involved has a clear understanding of their responsibilities. Discuss cropping intentions and communication processes with spray applicators. The plan should consider farm layout, weather monitoring and record keeping, identification of sensitive areas and potential hazards, and procedures for communication with staff, contractors and neighbours. More information on spray plans can be found at cottoninfo.com.au/effective-spray-application

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 tool for mapping the location of crops (including cotton), allowing growers and applicators to be better informed of the proximity of potentially sensitive crops before spraying satacrop.com.au

Be aware of both federal and state regulations regarding 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 product labels and safety data sheets. For more information, see the 'Pesticides and regulation' section later in this chapter.

Best practice...

Product and application technique must be matched to the target, tank mix and weather conditions. You also 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.

Understanding product labels

Always read and follow the label when handling and applying chemicals. Product labels are legal documents, and include the sticker attached to the container along with any associated booklets or leaflets containing additional information). Labels typically include:

1. **Warnings and product description** (signal heading, trade name, chemical type, active ingredient, mode of action group, product summary, manufacturer details).
2. **Directions for use** (registered hosts, pests, states, rates, withholding periods, and restraints on use).
3. **General instructions** (direct or cross resistance warnings, compatibilities, mixing instructions).
4. **Precautions** (re-entry, plant backs, protection of other crops, livestock and the environment)
5. **Storage, disposal and batch information** (storage and handling instructions, recycling /disposal options, safety and first aid information, APVMA approval and product batch numbers, dates of manufacture and expiry).

Read the label carefully for any specific application instructions or conditions. Common examples include:

- **Spray quality** (the droplet sizes produced). Influenced by nozzle design, operating pressure, spray pattern angle, 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 nozzles and ensure that equipment is set up and used appropriately to achieve the required spray quality.
- **Wind speeds.** 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.** A specified distance downwind that must not include a sensitive area (e.g. a residence, school, public area, water body, pasture, terrestrial vegetation or crop). The distance required may differ depending on the type of sensitive area and application method (e.g. no-spray zones for aerial applications can be larger than those required for ground application).
- **Record keeping.** Maintain detailed records of the application. Specific requirements are included on the label or permit conditions for many products, and are in addition to any state-based record-keeping requirements.

ALWAYS follow label instructions. Users are not absolved from compliance with the label directions/permit conditions or other legal requirements by reason of any statement made or not made in this publication.



This poster and accompanying booklet can be downloaded from the APVMA website apvma.gov.au/node/11041



Monitor and record conditions

It is 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.

A network of spray hazard identification towers that can quickly detect hazardous conditions was initiated with CRDC and GRDC funding. The network can be accessed for free (single tower only) or by paid subscription (goannaag.com.au/wand-network).

Spray records can be kept in a hardcopy or electronic format. See page 143 for an example of a pesticide application record sheet.

Know what's in your tank

Both water quality and the choice of products can have a significant impact on spray efficacy. Incompatible products, pH or other issues may produce unwanted chemical reactions, including the formation of solids that can block spray lines or nozzles. Always check the product label for incompatible products or water quality restrictions, and follow mixing order instructions carefully.



Several videos demonstrating incompatible tank mixes and highlighting water quality issues are available at www.youtube.com/@CottonInfoAust

Optimise 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. Multi nozzle fittings allow quick nozzle changes without needing to replace all nozzles along a boom.
- 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 suitable timing for mobile targets (insects).
- Calculating actual field rates for product/water.
- Ensuring the water used is of suitable quality.
- Considering potential incompatibilities during mixing.
- Regular calibration and rig maintenance (including decontamination).

Decontaminate equipment

Thoroughly decontaminate application equipment after use (take particular care when herbicides have been used) by following decontamination instructions on pesticide and cleaning product labels.



Decontaminating a spray rig
youtu.be/-zDQwoIEcB0



Top tips for agronomists...

1. Run through a pre-season spray plan with your growers (see module 5 of GRDC's 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 spray coverage and performance (nozzle selection, pressures, speed, adjuvants, water quality, tank mix compatibilities etc).
6. Recommend a nozzle that complies with the product label and delivers the coarsest spray quality without compromising efficacy.
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(s). For example, you can search to see if a ground or aerial contractor is licensed in NSW at apps.epa.nsw.gov.au/prdlapp/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 per sprayed hectare, but 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 calculating 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.

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 lifting 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/agronomists work closely with their aerial operator in planning, executing and following up on their spray applications.

Some key points that should be considered are:

- **Target** – pest location within crop canopy or field, or potential time constraints related to pest 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 centimetre on the target. Aerial operators can 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 for various conditions. Many aerial operators do regular pattern testing as well to optimise the swath width used for each aircraft. Review with your aerial operator to ensure everyone is satisfied with the spray parameters being used.

Select an aerial applicator with Aerial Application Association of Australia (AAAA) membership, Spraysafe or AIMS accreditations to ensure that you 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. aaaa.org.au



For more information on best practice for aerial and ground spray application go to www.mybmp.com.au

© Jack Hawkins, Cotton Australia

Reducing drift

Spray application needs to maximise efficacy against the target pest, while minimising any off-target movement or adverse effect. Movement of spray beyond the target area is undesirable as it represents both 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.

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.

A spray operator must decide whether to stop spraying or to continue spraying using a larger droplet size and higher water rate when Delta T exceeds 8.

GRDC's factsheet on weather monitoring equipment is available from their Spray Drift Hub at grdc.com.au/spray-drift

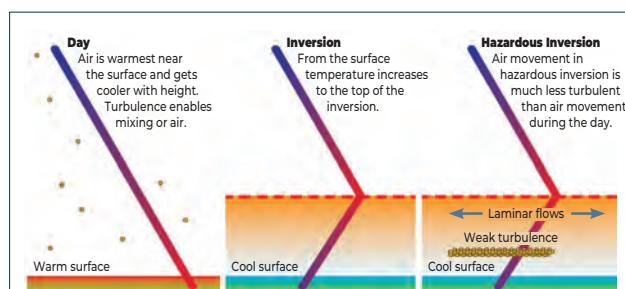
Avoid hazardous surface temperature inversions

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 sunset and persist until one to two hours after sunrise.

GRDC and CRDC, in partnership with Goanna Ag, 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

More information is available in the 'Effective spray application' chapter of the *Australian Cotton Production Manual* or GRDC's *Weather essentials for pesticide application* (see GRDC's Spray Drift hub).



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

G4 Crop Cruiser

SERIES 2

Introducing the latest
G4 Crop Cruiser Series 2,
boasting enhanced comfort,
increased power & superior
spraying performance.

- ▶ **4000L tank capacity.** TriTech boom sizes up to 36m.
- ▶ **More comfort - less noise.** Claas cabin combined with mechanical driveline provides the quietest spraying environment on the market. 65.5 Db
- ▶ **More spraying - less time filling.** G-Hub - Goldacres integrated intuitive system and Fast Fill for more time spraying and less time filling.
- ▶ **More power - less fuel usage.** Cummins B Series engine producing 200 hp, 6 speed Allison auto with mechanical drive for unmatched efficiency.
- ▶ **More adaptable - less crop damage.** Multiple wheel track options available, lightest mid-sized self-propelled sprayer on the market.



TightTurn
5m turning radius*



Fast Fill
Liquid induction & distribution



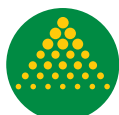
G-Hub
Goldacres integrated systems



Dynamic Drive
Mechanical direct drive



Adjustable Axle
2-3m hydraulic track adjust

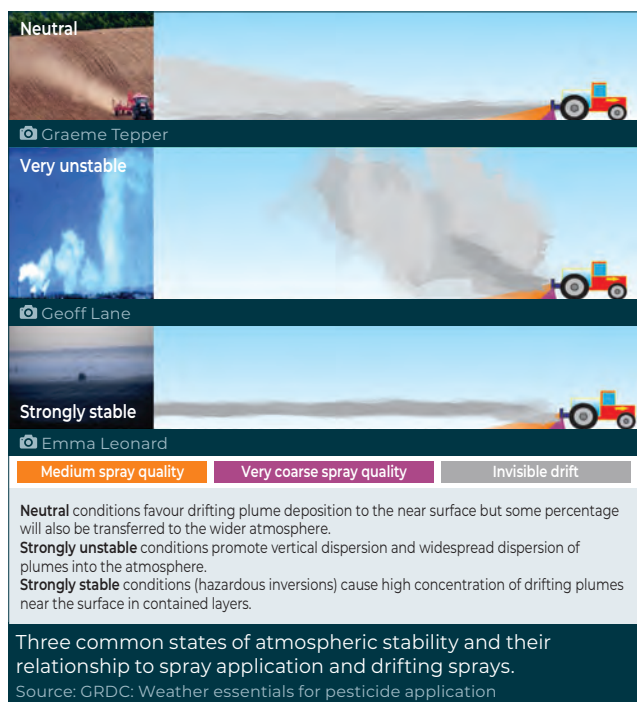


GOLDACRES



goldacres g4

*Depending on options fitted.



Plant spray drift barriers

Dedicated field borders of vegetation can be used to 'catch' spray drift, but do not utilise remnant native vegetation or environmental corridors for this purpose. Identify habitat vegetation as 'sensitive' and protect it from spray drift, along with riparian areas and waterways.

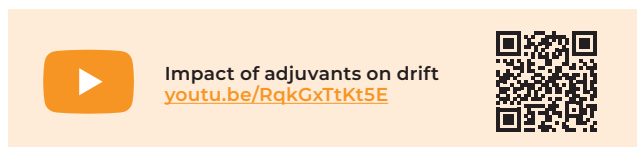
Effective planted vegetative barriers (a mixture of tree and shrub species with foliage all the way to the ground) can reduce drift by up to 90%. The optimum barrier is 20 m wide with a 10 m maintenance strip on either side. Don't plant barriers where adjacent objects such as turkey's nests, water storages 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.

Long thin or needle-like leaves or hairy leaf surfaces are the most effective traps for airborne droplets. Choose hardy and drought tolerant species with thick cuticles to help them survive small doses of pesticide. |||

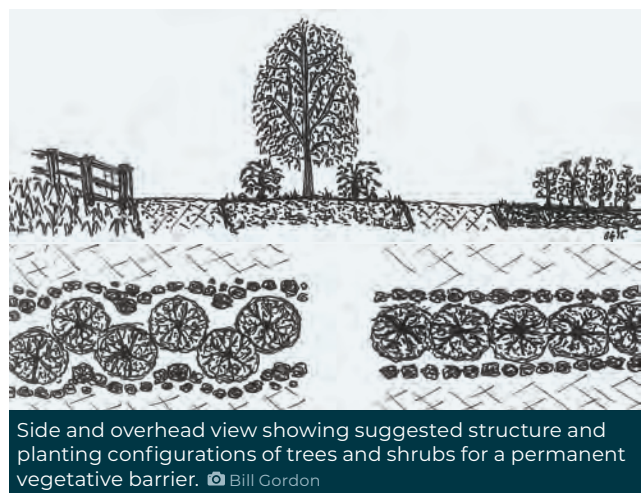
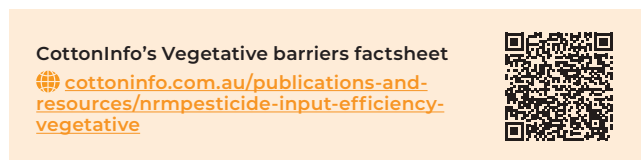
Optimise spray rig operation

Nozzle types, operating pressures, boom height, delivery speed and the characteristics of the product or products used will all influence the risk of droplets moving away from the target area. Some adjuvants will influence the droplet range exiting the nozzle and increase drift risk.



Always check the product label(s) for operation requirements/restrictions, regularly calibrate your equipment and avoid excessive travel speed during application.

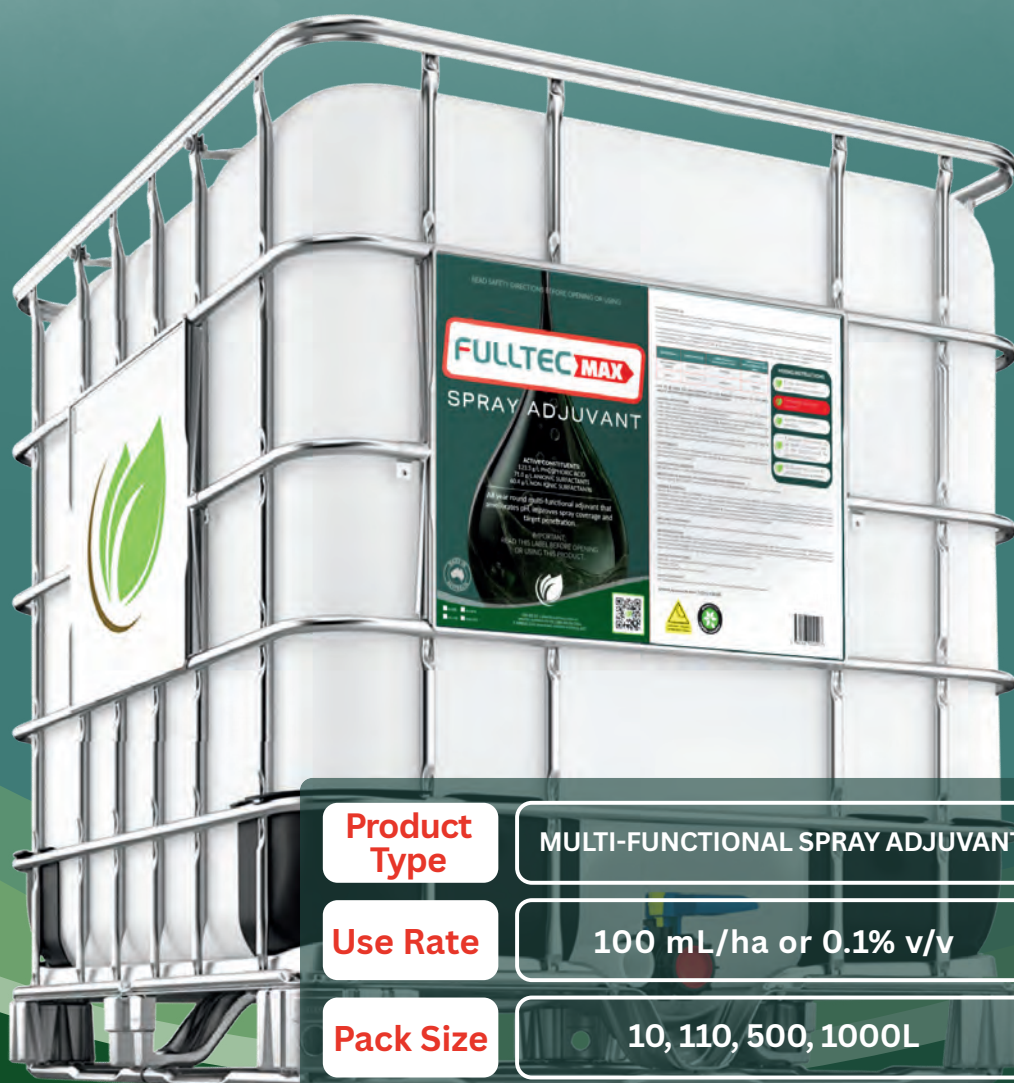
GRDC's GrowNotes™ Manual on Spray Application (see Useful resources on page 138) includes a section on sprayer set-up.



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SPRAY ADJUVANT

**SPRAY SMARTER, NOT HARDER WITH
THE YEAR-ROUND HYBRID ADJUVANT.**



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**Product
Type**

MULTI-FUNCTIONAL SPRAY ADJUVANT

Use Rate

100 mL/ha or 0.1% v/v

Pack Size

10, 110, 500, 1000L



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USEFUL RESOURCES (COTTONINFO):



Chapter 18 in the *Australian Cotton Production Manual*
cottoninfo.com.au/publications-and-resources/202627-ACPM



View the Pesticides and application video playlist at the CottonInfo YouTube channel
www.youtube.com/@CottonInfoAust



CottonInfo's Effective spray application page
cottoninfo.com.au/effective-spray-application



myBMP's Pesticide application module
mybmp.com.au



USEFUL RESOURCES (OTHERS):

Links to a range of factsheets, publications, posters and videos are available from GRDC's Spray Drift hub
grdc.com.au/spray-drift



Much of GRDC's GrowNotes™ *Spray Application Manual for Grain Growers* is also applicable to cotton.
grdc.com.au/resources-and-publications/grownotes/technical-manuals/spray-application-manual



Download a copy of the *Agronomist Guide to Aerial Application* from the AAAA website
aaaa.org.au/news-and-resources

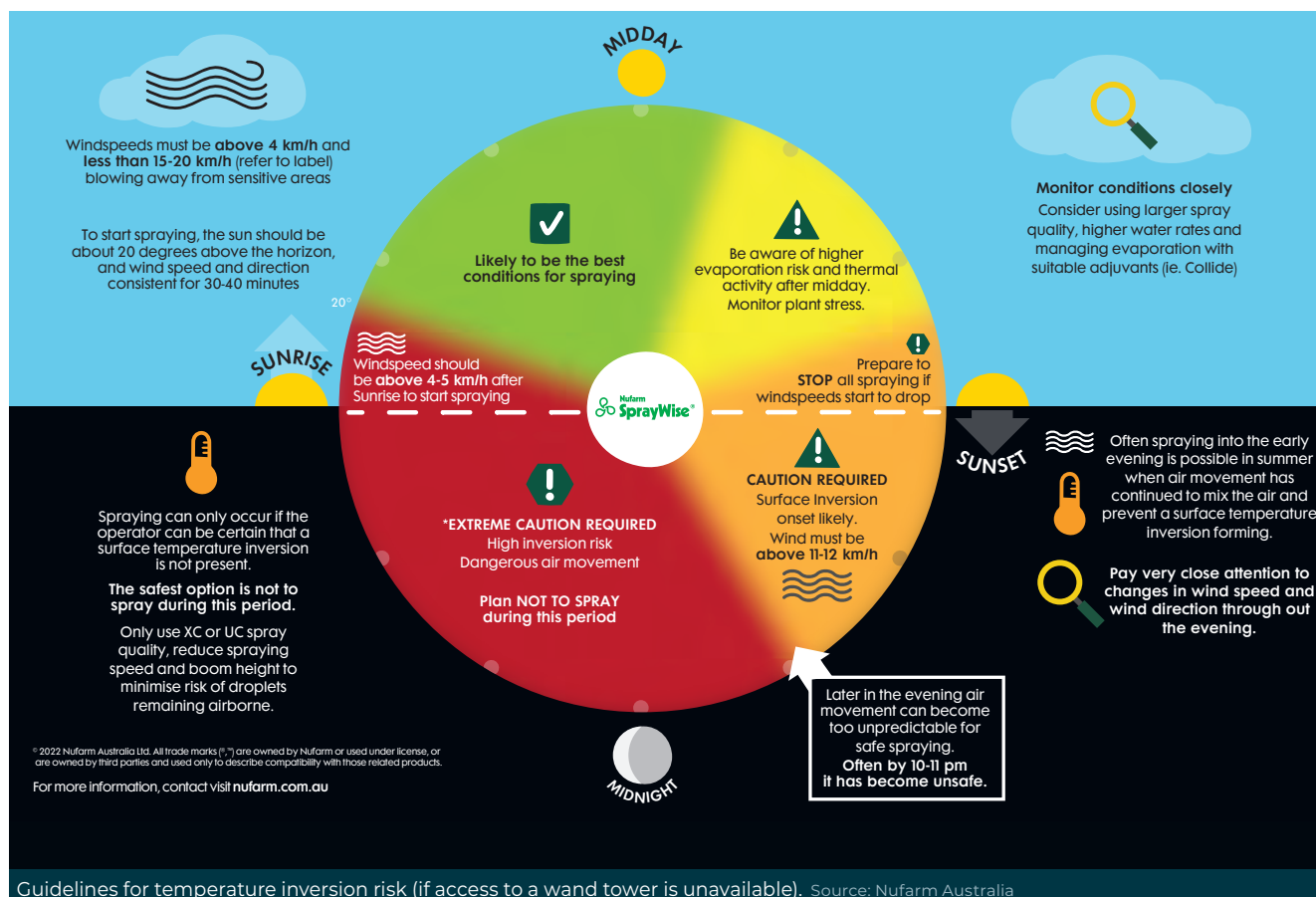
A number of spray-related mobile apps are also available for weather forecasting, nozzle selection, calibration and/or tank mixing. Research them carefully (including the reviews) before installing to ensure they will meet your needs.

24 HOUR RISK PROFILE FOR SPRAYING

Always follow label instructions



AUSTRALIAN
THROUGH
& THROUGH



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.gov.au for the most up to date information on product registrations and permits, active ingredients, residue issues, regulatory operations and chemical use.

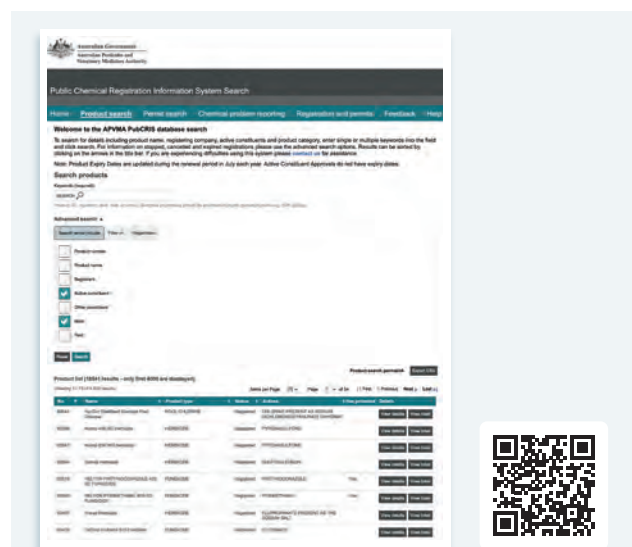
Check the site regularly as registrations can be amended or revoked at any time. Formal reviews are undertaken to scientifically reassess the risks and determine whether changes are needed to ensure a chemical can continue to be used safely and effectively. This may include modifying the way chemicals are used or if risks cannot be managed, cancelling registrations or label approvals. A full list of products previously and 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. portal.apvma.gov.au/pubcris

Search by product name, active constituent or other ingredients, host, pest, registrant or registration number. There are also advanced search and filter options, such as product type, the state(s) and territories in which the product is registered and the formulation type. The database also supports Boolean search functionality; read the guide at www.apvma.gov.au/registrations-and-permits/search-registered-chemical-products-and-permits/using-pubcris-boolean-search-guide

Select the type of search term(s) and enter into the search box. A drop-down list will provide suggestions as you type. PubCRIS search results display by product number (with the most recent at the top) and provide links to a summary of registration details and a PDF copy of the label. Search results can also be exported as a CSV file.



Check the APVMA's PubCRIS database regularly as registrations (and off label permits) are subject to change.

Keep in mind that labels usually cover multiple uses and the search engine may provide matches from anywhere on the label, so cross-check the search results carefully. For example, a search for 'cotton' could list products registered for 'cotton aphid' in other crops, that have no registration in cotton at all. Alternatively, a product may be registered for use in cotton, but the target pest may only be registered against a different crop. Sometimes even a pest or host alias may trigger a positive result, therefore do NOT just rely on the search results.

Always read the product label carefully before use to confirm that:

1. The product is registered for your intended use (crop, pest etc.) 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 off-label minor or temporary emergency use) can be searched at portal.apvma.gov.au/permits (or select the 'Permit search' tab if already in 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).

Check the APVMA website regularly as registrations (and off label permits) are subject to change.

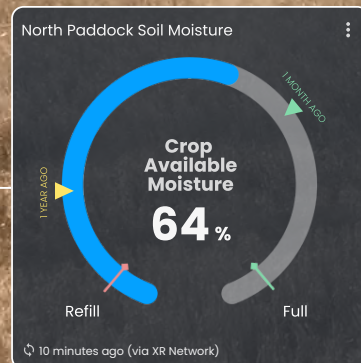
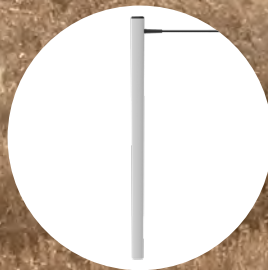
Cancellations or amendments to registrations may occur immediately or with an adjustment period. For example, in October 2024, the registration of all products containing chlorothal dimethyl in Australia was revoked with no phase-out period. In the same month it was announced that the sale, possession, or use of chlorpyrifos in cotton would not be supported beyond 30 September 2025. In Australia, immediate cancellation is rare – products with changed registration status are usually granted a phase out period where existing stock can still be used.

The APVMA website also lists product recalls, usually for specific batches of pesticide that may pose a health hazard or are otherwise compromised (e.g. faulty containers, the presence of contaminants, labelling or packaging issues etc). Find the latest list at www.apvma.gov.au/regulation/recalls/agvet-chemical-recalls

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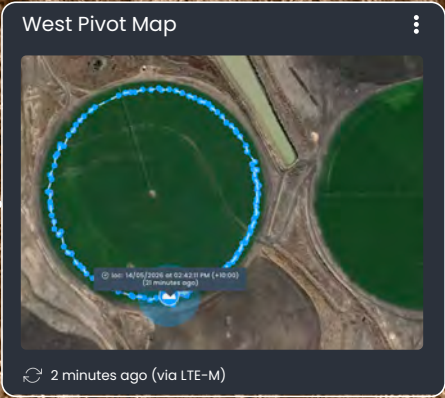
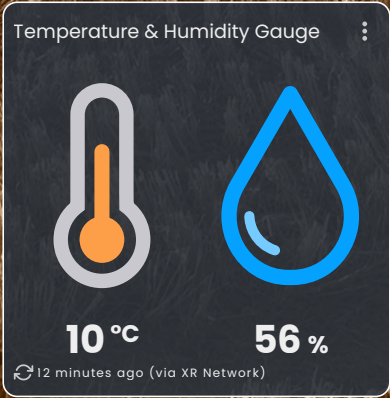
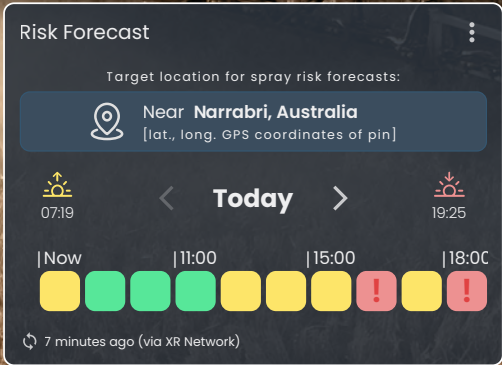
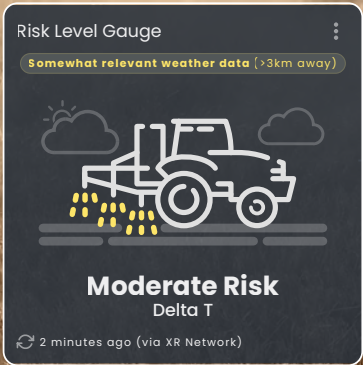
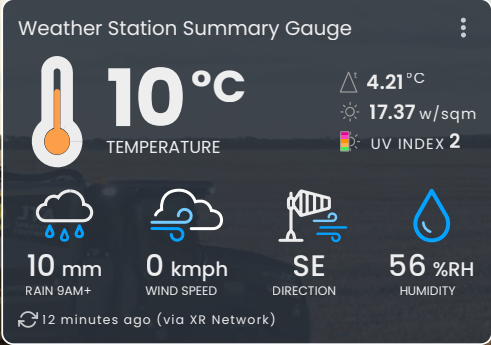
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- ✓ Australian owned & engineered.
- ✓ One platform.
- ✓ Accesible via phone, tablet, or computer.
- ✓ Local support.



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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 that appear on labels. For this reason, it is critical that the directions for use, restraints and all other label instructions are read and understood before each use. Keep in mind that labels can be revised and amended, so ensure you have access to the most current version. You can also subscribe at the APVMA website to receive customised updates and notifications via email.

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 (that 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 (via manned or remotely piloted aircraft) must be licenced. 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.

Exemptions typically exist for growers applying agricultural chemicals with ground equipment on their own land, and cotton growers usually do not need to hold a licence for agricultural chemical application, unless operating under fee-for-service arrangements as a contractor. However, specific training and accreditation may be required in some jurisdictions, and 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 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 or possession of 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 that 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 DPIRD) is provided in this chapter, and is available from dpird.nsw.gov.au/agriculture/chemicals/farm-chemical-management/records

Some commercial farm management software and apps include the ability to record spray details. III

Further information on relevant State regulations and training requirements:

- NSW: dpird.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: www.health.wa.gov.au/Articles/N_R/Pest-industry-licensing-and-registration
www.dpird.wa.gov.au/business/biosecurity/agricultural-standards/chemical-spray-regulations
- NT: nt.gov.au/industry/agriculture/farm-management/using-chemicals-responsibly
- VIC: agriculture.vic.gov.au/farm-management/chemicals

Pesticide Application Record Sheet

**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): <table border="1" style="margin-left: auto; margin-right: auto;"> <tr><td></td><td>N</td><td></td></tr> <tr><td>W</td><td>Treated Area</td><td>E</td></tr> <tr><td></td><td>S</td><td></td></tr> </table>					N		W	Treated Area	E		S		Comments (including risk control measures for sensitive areas):		
					N										
				W	Treated Area	E									
					S										

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 agrichemical labels will usually specify a minimum amount of time after a product has been applied 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 or harvesting a treated field or crop. 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, formulation or application parameters, even if products have the same active ingredient.

Non-compliance with current label restrictions may result in prosecution under relevant state or territory legislation.

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS.

Re-entry period

Re-entry periods and any specific personal protective equipment (PPE; see product labels for specific recommendations) help manage the risk associated with dermal (skin) contact with spray deposits. Include re-entry periods (see Table 31) when developing workplace health and safety procedures and protocols. More information on WH&S is available in the *Australian Cotton Production Manual*.

Adhere to any actions required in the precautions section of the label to protect your health before entering a treated field.

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 early entry is necessary, limit the duration of entry and wear the PPE specified on the label (e.g. *Wear cotton overalls buttoned to the neck and wrist (or equivalent clothing), a washable hat and elbow length chemical resistant gloves. Clothing must be laundered after each day's use.*)

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 31). 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.

Some labels include trade advice and/or export slaughter intervals (ESI) for produce or livestock destined for export markets. Refer to individual labels for more details.

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 will not 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 or failed crops.

Handling and storage

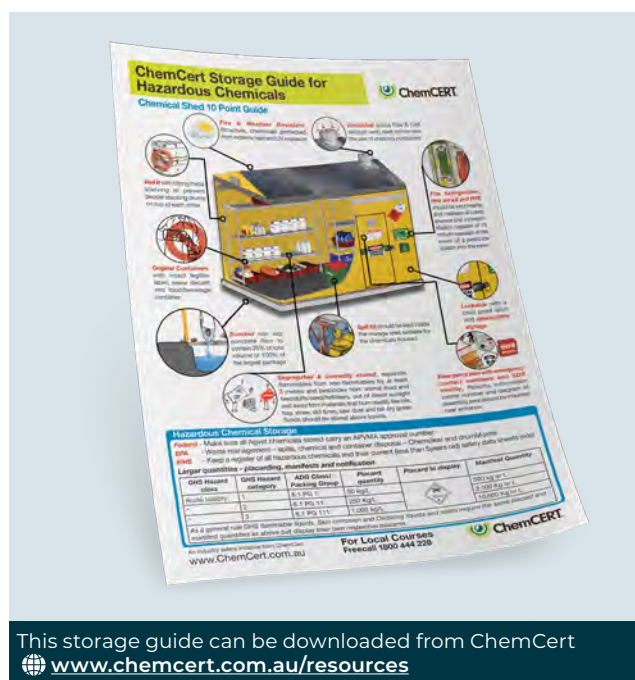
A critical part of responsible use of pesticides is their safe storage, transport and handling, as well as appropriate disposal of product that is no longer wanted or able to be used. Storing, handling and applying pesticides correctly greatly reduces the risk to you, your staff, your business, your 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.

Do not transport pesticides in the passenger cabin space in vehicles, and ensure chemical storage areas have sufficient ventilation and bunding to minimise risk. Appropriate dangerous goods signage for the products present should be clearly visible.

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. myBMP 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 you have the most recent safety code of practice for your location (e.g. SafeWork NSW's 'Safe use and storage of agricultural and veterinary chemicals' was reviewed in March 2026) www.safework.nsw.gov.au/data/assets/pdf_file/0013/1404022/Agricultural_and_veterinary_chemicals-COP.pdf



A not-for-profit subsidiary of CropLife Australia, AgSafe helps promote the safe and responsible management of agricultural chemicals, assisting the Australian AgChem supply chain in upholding the highest standards of safety and product stewardship through training programs, certification, and recycling initiatives such as *drumMUSTER*, ChemClear, and bagMUSTER, to protect both people and the environment.



www.agsafe.org.au

Safe disposal

Disposing of empty containers

Empty chemical containers present a risk to people and the environment. Clean your 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 often 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.
- Return 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** receive site will be inspected to ensure that no product residue (fluid, powder or flakes) is visible on the inside or outside of the container. Some stains (including dirt, dust or mould) are acceptable.



For more information on the program, including collection sites, drum preparation or contact details for the *drumMUSTER* regional consultants, visit

www.agsafe.org.au/dm-program-overview

Disposing of unwanted chemicals

Unwanted agrichemicals may result from discontinued use (due to changes in cropping or animal practices), development of newer/more effective/safer chemicals, changes in registration and/or banning from use, or the result of 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 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 the inappropriate disposal of potentially hazardous chemicals.

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 ChemClear.
2. Register the inventory for the next collection in your area. Freecall ☎ 1800 008 182 or visit www.agsafe.org.au/cc-register-chemicals
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. Group 2 chemicals (no longer registered, do not display the *drumMUSTER* logo, unknown, unlabelled, out of date, or mixed product) attract a disposal fee (a quotation will be provided for their disposal before the collection is scheduled). Individual state EPA funding may be available from time to time to subsidise disposal of Group 2 chemicals.

TABLE 31: 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	UNM	dry	0	0
	<i>Bacillus thuringiensis</i>	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
	<i>Clitoria ternatea</i> 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
	Dimpropridaz	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	—
	<i>Helicoverpa</i> NPV	31	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
Fungicides	<i>Clitoria ternatea</i> extract	UNE	dry	0	—
	Metentrifluconazole (PERMIT)	3	—	30	NG
	Pyraclostrobin + Fluxapytoxad (PERMIT)	7/11	dry	30	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
	Ethephon	conditioner	4 hrs	14	NG
	Mepiquat	PGR	dry	28	NG
	Paraffinic oil & other non-ionic surfactants	adjuvant	—	1	—
	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. **Classified as highly hazardous pesticides (HHPs) under the Better Cotton™ initiative. Growers under this program must adhere to relevant restrictions on HHP use.					



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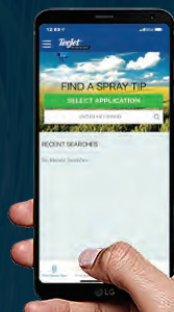
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Cotton growth regulators and harvest aids

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

Excessive vegetative growth can result in poor within-canopy light interception, that can reduce fruit retention, increase boll rot risk, and delay 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). 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.

For more information refer to the 'Managing crop growth' chapter of the *Australian Cotton Production Manual*
cottoninfo.com.au/publications-and-resources/202627-ACPM

For cotton production in the tropics, see NORpak Burdekin
cottoninfo.com.au/publications-and-resources/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. Defoliant activity is HIGHLY temperature dependent.
- **Desiccants** (e.g. sodium chlorate) 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). *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.*

Both the crop senescence process and the plant's response to applied harvest aids are heavily influenced by plant and environmental factors. Old cotton leaves naturally senesce (detach and fall off), but a cotton plant would not normally lose all leaves at once. Applying defoliants to induce senescence is therefore a key component of harvest management.

Artificially-induced defoliation ideally enables leaf separation while the leaf remains green; the fresh 'weight' of the leaf helps it reach the ground, 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 amount of trash in modules. Avoid them unless conditions (e.g. very cold weather) prevent the effective use of defoliants. Desiccants can also be used to reduce leaf regrowth. High rates of some defoliants can act as desiccants.

Boll opening is mostly a mechanical process. Dehydration causes the boll to split and unfurl. Leaf removal exposes bolls to more direct sunlight; the increased temperatures promote maturation, and drying and cracking of the boll walls. Boll conditioning/opener products applied too early may cause bolls to shed, reducing yield. Defoliate when the youngest harvestable boll is physiologically mature (usually when about 60-65% of bolls are open).

Wetting agents and spray adjuvants (e.g. paraffinic oil, non-ionic surfactants or petroleum oil) are often added as cool temperatures, low humidity and water stress can result in increased wax and thickness of the leaf cuticle, reducing chemical uptake efficiency.

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:



Using harvest aids in cotton
youtu.be/8st4yggcCNY



Defoliation booklet
cottoninfo.com.au/publications-and-resources/defoliation-end-season-management



What is pix?
youtu.be/clFpyymWW6Q



Pesticides and the environment

Cotton industry guidelines for minimising risk to the environment are incorporated into the *myBMP* program.

Pesticides, carriers, surfactants, and pesticide metabolites can be inherently hazardous for aquatic organisms, insects (including bees), birds, and other fauna and flora. The risk that a particular product poses to the environment is reflected in statements on the label under headings like 'Protecting wildlife, fish, crustaceans and the environment'.

Pesticide residues may accumulate in animals fed any crop product (including crop residues), that has been sprayed with pesticides. Animals that test positive for chemical residues that 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 www.apvma.gov.au/regulation/adverse-experience-reporting-program or to the pesticide control-of-use agency in your State or Territory.

Australian cotton industry sustainability framework

Pesticide use has come under increasing scrutiny and pressure to eliminate highly hazardous pesticide use and minimise off-target impacts. The Australian cotton industry 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. 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 current indicator 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.

A factsheet on how pesticide use in cotton has changed over time for the better is available at australiancottonsustainability.org.au

Protecting the environment

The best way to manage long term environmental risk is to work with spray applicators to develop a spray plan that identifies environmentally sensitive areas, choose products and equipment with the lowest risk profile without compromising effectiveness, follow 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.



Protect aquatic environments from pesticides; many aquatic birds such as egrets contribute towards natural pest control.
© Stacey Vogel, CottonInfo

Aquatic fauna and flora

Aquatic fauna and flora (and other species that utilise aquatic areas as part of their habitat) are often highly sensitive to agrochemicals. When spraying, always consider the risk of contaminating nearby standing water.

- Prevent drift onto surface waters during application.
- Locate mixing/loading and decontamination facilities away from, and use bunding/sumps to prevent movement of concentrate or rinsate into surface waters.
- Install valves preventing back-flow in equipment used to fill spray tanks and in chemigation system suction lines that draw directly from surface waters.
- Avoid aerial sprays while fields are being irrigated.
- Build sufficient on-farm storage capacity (including storm runoff) to contain pesticide-contaminated tail water from irrigation.
- Spray in an upstream direction (if spraying near water is necessary), to minimise pesticide 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 near surface waters or on flood plains or river catchments.

Birds

Broad-spectrum insecticides can be particularly toxic to birds, especially granular formulations that can be mistaken for food. Insecticidal seed dressings can pose similar risks, and spillages can be very hazardous as birds can easily ingest a toxic dose.

- Ensure complete incorporation, particularly at row ends where spillage may occur.
- Immediately clean up spillage, however small.

Baits (particularly grain-based) for control of rodents or soil insects can also be hazardous to birds and other fauna, either through direct consumption or from feeding on bait-affected animals or pests.

- Only bait when pest pressure is high.
- Ensure even bait distribution.
- Don't bait near bird habitat (e.g. remnant native vegetation).
- Avoid baiting over bare ground, such as near crop perimeters, where birds may see the baits.
- Use bait stations to prevent bird access.
- Bait late in the evening when birds have finished feeding.
- Promptly collect and bury accessible rodent carcasses.



Whistling ducks. © Anne Palfreyman

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 about known sensitive areas (such as nesting sites).
- 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 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 rather than broad-spectrum pesticides (that are more likely to impact on non-target organisms and plants in the environment) and adopt an integrated approach to pest control.
- Spray late in the day when birds have finished feeding.
- Use only low toxicity chemicals when large numbers 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.

🌐 pestsmart.org.au/domestic-animal-safety/the-facts-of-1080-baiting provides information on the impacts of 1080 baits on wildlife.

If targeting feral vertebrate pests:

- 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 improve effectiveness and reduce excess baiting.
- 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 Soil Sustainability Framework to promote soil health in Australian cotton farms is available at australiancottonsustainability.org.au/assets/Australian-cotton-soil-health-framework.pdf

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 soil leaching or leaf absorption.

To minimise the impact of your spray program on remnant vegetation:

- Prevent drift by implementing spray application best practice.
- 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 to manage environmental weeds. III

Native revegetation options

Increase the amount of natural habitat on your farm by planting native species.

The *Native Revegetation Guide for Australian Cotton Growers* is a resource to help cotton farmers plan, prepare, plant, grow, and monitor revegetation efforts, providing practical and cost-effective solutions for restoring habitat connectivity and managing revegetation projects.

🌐 cottoninfo.com.au/publications-and-resources/native-revegetation-guide

Meet 3 different cotton growing family operations that have used the guide's 6 steps for success.

🌐 cottoninfo.com.au/publications-and-resources/6-easy-steps-success-revegetation-cotton



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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 but are less easily seen as they don't have the obvious hives of managed honeybees and social native bees. Remnant vegetation and other bushland should be considered 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
- Carrying of contaminated material back to the hive.

Insecticide contamination can cause individual bee death, diminished productivity or even destruction of the whole hive. Insecticides that are particularly toxic to bees contain a special statement on the label such as: **Dangerous to bees. DO NOT spray any plants in flower while bees are foraging.**

Some fungicide and herbicide actives can also be moderately toxic to honeybees, although it may not be specified on the label. Products categorised as Schedule 6 or 7 ('poison' or 'dangerous poison') for humans are most likely to also be harmful to bees.

The Insecticide Resistance Management Strategy (pages 62-63) highlights insecticides with a label warning about bee safety. The relative toxicity of cotton insecticides to honeybees is included in Table 5 (pages 16-17).

Also consider residual toxicity (how long the product remains toxic to bees post-application). Many insecticides are safer for pollinators and other beneficial species once the spray deposits have dried on the crop. See the label for what action must be taken to avoid impacting bees (note: label recommendations may vary between different formulations containing the same active ingredient).

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS.

Protect bees from fipronil

While bees are susceptible to many of the insecticides used on cotton, and industry best practice is to avoid spraying insecticides on flowering crops where possible, fipronil potentially poses an extended residue risk, 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.

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 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's 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; bees become more active above 12°C with most foraging activity occurring between 19-30°C, and water gathering increasing when temperatures are above the mid-thirties. Honeybees usually forage within 2-4 km of their hive, although they can travel up to 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 both extra-floral nectaries (e.g. under leaves) and cotton flowers, so may be foraging in cotton crops before, during and after flowering, and may visit flowering weeds in and around fields. Damage can also occur if pesticides drift over hives, water surfaces or neighbouring vegetation being foraged by bees.

Eucalypts including coolibah (*Eucalyptus microtheca*), black box (*E. largiflorens*) and river red gums (*E. camaldulensis*) are a primary source of nectar and pollen for honeybees, growing on the black soil plains along many of the river courses in cotton growing areas, and flowering in response to good spring rains. For example, in northern NSW, they flower mid to late December to about the end of January. Beekeepers may move large numbers of hives into these regions when flowering is expected.

Reducing the risk

- Follow the registered label directions.
- Create a spray plan including risk mitigations for pollinators.
- Register with BeeConnected (see next page) and map crops on Satacrop. satacrop.com.au
- If beehives are located near 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.
- Use an IPM framework to minimise pesticide use.
- Favour pesticides that have lower toxicity to bees and other beneficial insects (see Table 5).
- Where possible, use EC or granular formulations that dissolve completely rather than wettable powders or microencapsulated formulations.
- Monitor crop development to identify when flowers will be present.
- Manage weeds to prevent flowering in or near the crop.
- Applying products in the early evening when bees are not foraging will allow spray to dry, reducing risk to bees the following day.

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




Communication between growers and beekeepers is critical to reduce the risk of unintended exposure of bees to products that may negatively impact bee health. BeeConnected is a nation-wide, user-driven smart-phone app and website enabling collaboration between beekeepers, farmers and spray contractors to facilitate best-practice pollinator protection. Properties and present (or future) locations of beehives can be added 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 via a secure internal messaging service. CropLife Australia provide BeeConnected free of charge as part of their Pollinator Protection Initiative. The more growers and beekeepers using the BeeConnected service, the more effective it will be. 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




Insecticide-treated seed

CropLife Australia's Seed Treatment Stewardship Strategy outlines how to reduce risks from dust generated during handling/planting of treated seed, and provides guidance on protecting pollinators.

croplife.org.au/resources/programs/seed-treatment-stewardship-strategy




BeeAware is an information hub for beekeepers and growers about honeybee biosecurity and crop pollination, including how beekeepers and growers can work together to provide and receive best practice pollination services.

BeeAware is supported 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 and bifenthrin. The industry's voluntary IRMS (pages 62-63) includes a best practice recommendation to avoid applying fipronil to flowering crops. The Australian Cotton Sustainability Update 2025 reported that the hazard to bees (from insecticides) has reduced by 91% since 2004.

USEFUL RESOURCES:




Australian Cotton Intergrated Sustainability Report 2025
australiancottonsustainability.org.au/reports

Bees in cotton
youtu.be/LBRUaqZaVoQ



If you suspect a pest or disease affecting bees, call the **Exotic Plant Pest Hotline** on **1800 084 881**, or notify the biosecurity branch of your relevant state or territory.

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 Apiarists' Association
www.nswaa.com.au

Apiaries on public land in NSW (**BPASS** map)
www.dpird.nsw.gov.au/animals-and-livestock/bees/beekeeping-on-public-land/bpass

Queensland

Queensland Beekeepers' Association
qbabees.org.au

Western Australia

Bee Industry Council of Western Australia
www.bicwa.com.au

Northern Territory

honeybee@nt.gov.au
nt.gov.au/bee

Victoria

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.

ACPM. *Australian Cotton Production Manual* (available from CottonInfo).

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. 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.

APVMA. The Agricultural Pesticides and Veterinary Medicines Authority regulates pesticide registrations and issues emergency and off-labels permits.

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. Granule or spray applied in the seed furrow during planting.

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 onto the sheet.

Beneficials. Biological agents that are beneficial to the crop, including natural enemies and pollinators.

Better Cotton™. An international program supported by Cotton Australia (and administered through myBMP) encouraging sustainable cotton production.

Biological insecticides. Insecticides that include (or are 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 pesticide application and downwind sensitive areas, measured from the edge of the sprayer swath closest to the downwind sensitive area. For some products the distance is mandated on the label.

Calendar spray. Application on a timed schedule, regardless of pest density or damage.

Carbamates. Group 1A broad-spectrum insecticides.

CBT. Cotton bunchy top virus (vectored by aphids).

Chipping. Manually digging out weeds with a mattock or chip hoe. Chipping usually cuts through the root. See also '*rogueing*'.

Cold shock. A delay in cotton growth/development caused by low temperatures.

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).

Cotyledon. Seed leaf (part of the embryo within a seed). Functionally similar but look different to the true leaves that form after germination.

Crop compensation. Plant's capacity to 'catch-up' after insect damage without affecting yield or maturity.

Cut-out. The plant's demand for assimilates (photosynthesis products) exceeds supply and no more harvestable fruit is set.

Damage threshold. See '*threshold*'.

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 desiccation.

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 different methods of weed control within a short timeframe.

Dryland. Non-irrigated production system. Also referred to as 'raingrown' or 'rainfed'.

D-vac. Small portable suction sampler or blower/vacuum machine that sucks insects 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. Substance that kills/inhibits microbial pathogens.

GVB. Green vegetable bug.

Herbicide. A substance that kills/inhibits weeds.

Herbicide Resistance Management Strategy (HRMS). Voluntary industry strategy designed to delay resistance to herbicides (predominantly glyphosate).

Highly hazardous pesticide (HHP). Pesticide with significant environmental or health risks relating to acute or chronic toxicity, persistence, bioaccumulation or other properties (e.g. chemically reactive, flammable or explosive). Specific restrictions on HHP use apply to growers in the Better Cotton™ program.

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. Substance that kills/inhibits 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 sustainably minimise pest populations.

Integrated weed management (IWM). Strategy to implement a range of tactics, both chemical and non-chemical, 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.

LD₅₀. Amount of pesticide that will kill half the insects in a tested population (lethal dose, 50%), indicating likely efficacy against a pest or impact on a non-target organisms. Usually expressed as micrograms of active per unit of body mass or individual insect (e.g. µg/bee).

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 that kills mites or inhibits their growth. May also have activity against other arthropods.

Mode of action (MoA). Pesticide classification scheme based on the target site of the active ingredient that aims to prevent the development of cross-resistance to related pesticide compounds.

Monitoring. Checking or sampling crops (for insects, damage, weeds, growth stages etc). Management recommendations are based on interpretation of 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. 4 NAWF is usually an indicator that the crop has cut out.

No-spray zone. See '*buffer zone*'.

NPV (nucleopolyhedrovirus). Entomopathogenic virus. Commercial formulations are available.

Nymph. Wingless immature insect stage that looks similar in shape to the adult (e.g. bugs, thrips, mites). Nymphs develop through a series of moults and do not pass a pupal stage.

Organophosphates (OPs). Broad-spectrum insecticides classified into MoA Group 1B.

OSST. Optical spot sprayer technology. Not all herbicides are registered for use with this equipment – check herbicide labels for compatibility.

OTT. 'Over the top' 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. Issued by the APVMA, permits 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. The minimum period recommended between applying a residual herbicide and planting sensitive crops.

Plant growth regulator (PGR). Chemical 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, for example in the Bollgard 3 RMP.

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 problem (rather than in response to a threshold). These 'insurance' sprays can result in 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 agrochemicals registered for use in Australia (portal. apvma.gov.au/pubcris).

Pupa. Stage where insect larva undergoes transformation into an adult (e.g. from caterpillar to moth).

Pupae busting. Tillage to reduce the survival of overwintering pupae.

Rainfed or raingrown cotton. See 'dryland cotton'.

Rank growth. Excessive vegetative growth; usually managed using mepiquat chloride.

Ratoon cotton. Regrowth from 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 to generate unexposed susceptible individuals that can help dilute resistant populations. Refuges are a requirement of the Bollgard RMP.

Remnant vegetation. Patches of native trees, shrubs and grasses that remain in the landscape post-clearing.

REO (CottonInfo). Regional extension officer.

Resistance (to pesticides). 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 risk of resistance (to Bt toxins) developing. Compliance 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. Systematic removal, usually by hand, of plant off-types (inferior, unhealthy, nontypical etc.), or hand weeding by pulling (to reduce the likelihood of regrowth).

Rotation crops. Other crop types grown before or after the cotton crop.

Sampling (for pests). See 'monitoring'.

Scouting. See 'monitoring'.

Secondary pests. Pests that become a problem when their natural enemies (predators or parasitoids) are reduced in number by insecticides. See also "flaring".

Seed treatment. Insecticide and/or fungicide coating on cotton seeds that offers protection during germination and establishment.

Selection pressure. Multiple pesticide sprays from a particular chemical group leads to greater 'pressure' or chance of selecting a resistant population as susceptible individuals are removed.

Senescence. Biological deterioration associated with aging where plant cells stop growing and dividing, but without dying.

Shedding. Abortion/loss of leaves or reproductive structures (squares, flowers or bolls) caused by environmental factors or pest/disease damage.

Siphunculi. Pair of wax-secreting tubular organs on the abdomen of aphids (also called cornicles).

SLW. Silverleaf whitefly.

'Soft' approach. Managing insect/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. Bollgard 3 has three genes: Cry1Ac, Cry2Ab and Vip3a), or different activities in the same variety (e.g. Bollgard + Roundup Ready®).

Stewardship. Activities (e.g. resistance management strategies) that protect the long-term effectiveness of the chemicals and technology used to control pests.

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 where an action is taken. Action thresholds are based on a level/number of pests/damage. Economic thresholds consider commodity value and treatment costs to identify a 'break even' point.

TIMS. Transgenic & Insect Management Strategy (Committee).

Tipping. Terminal loss, cleaving to multiple stems.

Trap crop. Small area of more attractive host plants that concentrates a pest population to allow easier management. Different to 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. 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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