2025-26 COTTON PEST MANAGEMENT GUIDE





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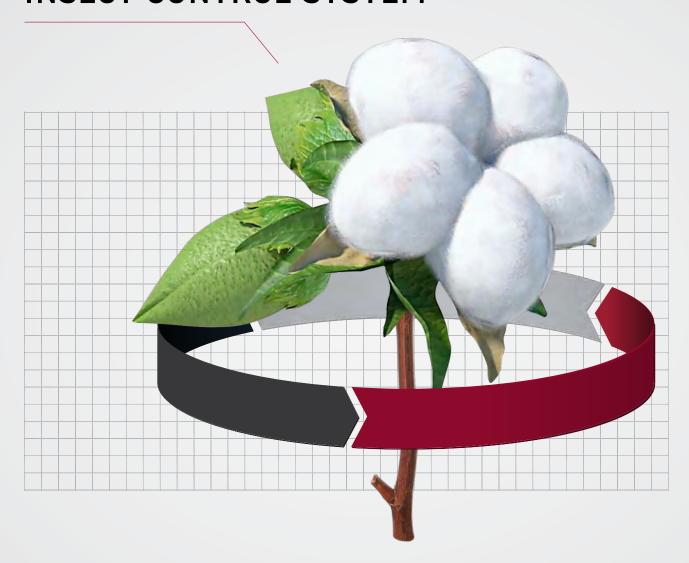
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Cover: Tridax daisy in northern Australia. Taken by Eric Koetz.



Foreword

Megan Woodward (CottonInfo and CRDC)

elcome to the 2025-26 Cotton Pest Management Guide (CPMG). This Guide provides you with a comprehensive summary of the key cotton crop protection issues, and is brought to you by the organisations responsible for cotton industry research, development and extension (RD&E): the Cotton Research and Development Corporation (CRDC) and CottonInfo.

CRDC invests in RD&E for the Australian cotton industry. A partnership between cotton growers and the Australian Government, CRDC exists to deliver impact. CRDC's Strategic RD&E Plan for 2023-28, Clever Cotton, is built on three investment pillars: Paddock, People, and Planet. In 2025-26, CRDC will invest \$33.2 million into RD&E projects via Clever Cotton, on behalf of growers and the government and in collaboration with research partners.

CottonInfo is a joint partnership of the CRDC, Cotton Australia and Cotton Seed Distributors (CSD). CRDC manages the CottonInfo team, Cotton Australia supports the program through myBMP, and CSD is a key investor, providing funding for the Regional Extension Officers. It is designed to connect you - our cotton growers and consultants - with research and provide you with information, when and where you need it. The CottonInfo team takes the research and development invested in by CRDC and 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/publications-and-media or <u>crdc.com.au/publications</u>.

This year's edition of the CPMG features major changes to the Weeds chapter, with an expanded key weeds section and a completely revised Herbicide Resistance Management Strategy (HRMS).

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 (you can find our contact details on the inside back cover). You can also find information from the CottonInfo team online at our website (cottoninfo.com.au, while best practice information for your farm is available at the myBMP website # mybmp.com.au. And you can find information about all of CRDC's investments online at crdc.com.au

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

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Pests and crop protection

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

Pest impact on cotton yield and quality includes both direct damage and indirect influences, 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 pesticde resistance).

What is causing your damage?

Not all crop symptoms are caused by pests. A range of abiotic influences, including soil constraints, environmental/weather factors, herbicide drift, pesticide phytotoxicities, compaction, allelopathy, and nutrient deficiencies/toxicities can also cause crop damage, or exacerbate pest impacts. There can also be significant differences in pest occurence/abundance and their impact(s) on yield between regions.

Before enacting any pest management action, identify the correct cause of the damage and ensure it is:

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

Ideally, management actions should be effective, economically viable, and have minimal off-target impacts.

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

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 deterioriate too much before you have a chance to examine them more closely or send off for diagnosis.

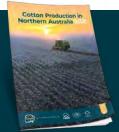
Integrating your pest management approach

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 TEND TO 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. Choose agronomic tactics that disadvantage pests both immediately and in the longer term.
- Effective monitoring. Tailor crop monitoring to the likely pest risks at each crop development stage, and learn when pests are most vulnerable to available control methods. Focus on accurate identification and keep good records to compare pest levels within and between seasons. Utilise industry expertise to identify unusual species or symptoms.
- Consider damage potential. Ensure that the pest(s) are still present and causing damage before enacting a control. Use economic thresholds where possible and monitor the impact of any action taken (ideally, leave a small untreated area for comparison).
- Preserve pesticide usefulness. Target the appropriate pest stage, follow label directions and calibrate equipment to optimise efficacy. Avoid unnecessary prophylactic sprays and adhere to stewardship programs such as resistance management strategies.
- Work with your neighbours. Highly mobile insects or weeds with wind-borne seeds can quickly spread between farms. Improved coordination of agronomic and pest management practices within your local area can provide pest management benefits. Check for nearby beehives or sensitive areas/crops before applying pesticides.

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.

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.



The new 'Cotton Production in Northern Australia' was sent out out in June with the *Australian Cotton Production Manual* to northern subscribers of the Spotlight magazine.

It contains specific information on pest management in northern regions and highlights some considerations related to insect and disease issues in tropical cotton production that are not commonly seen in traditional production areas. To download a copy, visit the CottonInfo website

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

Integrated Pest Management (IPM)

he 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.



What is IPM?

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

IPM - the basics

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

- 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 in regular sampling. Plant monitoring can also assist in decision making where

Dryland cotton...

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

Best practice...

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

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 compensate for early season damage, particularly vegetative plant parts, if growing conditions remain favourable.
 - Ensure you can distinguish between vegetative and fruiting branches when measuring retention during early crop development. View a CottonInfo video that explains the difference between branch types in young crops: youtu.be/7PXIAuinmeY
 - Pests that can contaminate open cotton with honeydew (such as SLW or aphids) become more important as bolls open.
- Know your enemy. 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 liklihood of developing a mite or mealybug problem later in the season. Table 5 (pages 18-19) 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.







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- Consider if a spray is actually required. Scientificallybased action thresholds to help you decide if your pest populations or crop damage might require control action are available for many key pests. Resist the urge to use insecticides prophylactically by combining them with herbicide application operations. 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. When insecticide control is warranted, ensure your selected product appropriately balances effectiveness against the target pest with any potential harm to natural enemies. Actively avoiding the use of broad-spectrum disruptive insecticides (e.g. organophosphates, pyrethroids and some neonicotinoids) wherever possible, especially early to mid-season, will go a long way to reducing mite, SLW and mealybug numbers later in the season. Be aware of the product's mode of action (MoA) group, and of restrictions on the use of certain products as part of the Industry's Insecticide Resistance Management Strategy (IRMS; pages 60-66). If several pesticide options are available, examine their selectivity profiles (see 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, and conserve ladybird beetles, but its impact on the key wasp parasitoids of whitefly is unknown. Population increases of non-target pests such as aphid, mite and whitefly may follow 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.



IPM in action

▶ youtu.be/k5-0XrzBEeq



- Preserve the usefulness of insecticides and Bollgard. The control effectiveness of insecticides or *Bacillis thuringiensis* (Bt) protein-expressing Bollgard crops depends on pest populations being susceptible to the active compounds. Follow label directions and consider both your application technique and environmental conditions to optimise chemical efficacy. Adhere to resistance management programs to ensure that the industry continues to have access to pest control tactics that give good control.
- Look after bees. Bees are particularly susceptible to many of the insecticides used on cotton farms (see Table 5). Hive productivity can be damaged by direct or indirect contact with the applied product by foraging bees, or when insecticide drifts over hives or neighbouring vegetation. Always look for and follow label directions regarding impact on bees and refer to the 'Protecting pollinators' section for more information.

• 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 areawide 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.





Develop an IPM strategy Know your enemy Take a year-round approach Think beyond the crop Have good on-farm hygiene Consider options to avoid or reduce pests Sample crops effectively and regularly Grow a healthy crop Reviappond commander and pormander and poppender and poppe	ly IPM principles to all crops ularly check long and short sider rotation crops (type, loublish and maintain commud spray drift. ve vegetation can harbour amaintaining its health and contolerance of weeds studing volunteer cotton) coss cropping and nonpareas all year round. The amaintaining its health and contolerance of weeds studing volunteer cotton on the pareas all year round. The amaintaining its health and contolerance of weeds studing volunteer cotton on the pareas all year round. The property of the period to make the period to m	and allows end of season a template from cottoning. Participate in IPM training, CottonInfo Regional Exten CottonInfo's e-news mailing. Consider the summer cropping plan and pest risk. ement (AWM) all year round. It is to host cotton. The season was a range of beneficial species diversity, preventing pesticides. Consider pre-irrigation, to allow control of weeds with non-glyphosate options prior to planting. Consider in-crop cultivation where necessary. ractice Come Clean. Go Use a variety suited to your region.	factor them into your mana- pests and disease). your region. (including insects, birds and e drift from reaching it, and Continue to manage volunteer cotton in entire landscape (e.g. fence lines, channels, perennial vegetation and pastures). Consider chipping.	refficiency Intact your nearest be back cover) to join com.au/subscribe season by considering cation. Also consider g rotation decisions. agement planning.							
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Sample crops effectively and regularly Crow a healthy crop	as, pest hosts and neficial habitats. lage vegetation areas to courage beneficials. sider a summer trap crop. less risk of soil pests.	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.	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.							
Grow a Soil req	nain up-to-date with key its, beneficials, sampling hniques and thresholds. itor for soil pests pre- nting.	fruit load and plant damag Consider both current pest	e weekly, checking for pests ge (keep an eye out for weed numbers and population tr esholds and the beneficial t	ls and diseases also). ends.							
risk	sider the best rotation p for your situation. test to determine fertiliser uirements for cotton crop. sider potential disease ss.	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 boll: for defoliation decisions. Manage nutrition and irrigation to avoid or reduce regrowth that may harbour pests.							
	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 spra det or a	thresholds and careful ay selection for all crops. field history and -season sampling to ermine if seed treatments at planting insecticides are propriate.	Consider insecticide selecti beneficials, including bees Do not apply prophylactic s Avoid broad-spectrum prod (particularly early in the se Consider edge or patch spr (aphids, mites, mealybug e	ivity and impact on s. sprays. ducts where possible ason). aying for clumping pests	Defoliation may be a late season alternative to an insecticide.							
Apply good resistance (inc	nplete pupae busting low guidelines). tolerance of weeds cluding volunteer and pon cotton) across the ire landscape.	Adhere to refuge requirements Consider choice of atplanting 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										

A closer look at retention

ne 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.



Fruiting positions and retention levels in cotton

youtu.be/kcN8P9Nf6zo



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





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

to rapidly compensate under good growing conditions declines during flowering as developing bolls compete for resources, so mid-season fruit loss is more likely to impact a crop's yield and maturity. Aim to manage square retention from the initiation of the fifth fruiting branch onwards.

Fruiting vs vegetative branches

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

Fruiting branches during squaring will always have either a square or a scar (from where a square has been lost) directly opposite a subtending leaf.

The 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.



Distinguishing between vegetative and fruiting branches in young crops

youtu.be/7PXIAuinmeY





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



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TABLE 3: Guidelines for	monitoring and ma	anaging retention
Crop stage	Square retention	Pest control action
Up to 5 fruiting branches.	Less than 40%	ONLY take control action if pest insects are still present, at threshold AND the crop has reached 4-5 fruiting branches.
Commence square retention assessment at 3-4 fruiting	40-80%	No action required. Monitor for insects.
branches (9-12 nodes). Count all positions.	More than 80%	No action required. Monitor for insects. Some insect damage to reduce retention may be desirable, particularly in warm areas.
C & it is as la usa a la sa	Less than 40%	Actively manage retention. Control insects if at threshold to allow compensatory fruit production.
5 fruiting branches to first flower. Count all P1 and advanced*	40-60%	Retention levels are adequate. If closer to 40% ensure retention is trending upwards. Continue monitoring for insects.
P2 squares.	More than 60%	No action. Monitor for insects. If retention is very high (greater than 80%), some square loss may be desirable.
	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.
First flower to cut-out (4 to 5 NAWF). Count Pl and advanced* P2 squares between NAWF and terminal.	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	a sized or bigger.	

Environmental stress

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

Guidelines for monitoring and managing retention

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

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

USEFUL RESOURCES:

Qld DPI, Toowoomba Paul Grundy 0427 929 172.



Physiological Fruit Shedding: What are the causes and can it be managed?





When managing for early season retention

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

Protecting beneficials

ot all arthropods found in cotton are pests. Some are just passing through, and some are actively providing benefits, either to the crop directly (e.g. predators or parasitoids of crop pests; often referred to as 'natural enemies') or to the local ecosystem (e.g. pollinators). Any arthropod that provides benefits to the crop or wider ecosystem is referred to as a 'beneficial'.

Building and/or conserving beneficial populations is at the heart of integrated pest management (IPM). Pest management decisions need to be well informed and supported by effective sampling and valid control thresholds. Knowledge of the beneficials present, their activity on pests (see Table 4 for common examples), and the potential impacts of other pest control measures (including insecticides – see Table 5) helps ensure the best management decisions are made for your crop.

Choose insecticides wisely to conserve beneficials

Balance the contribution of beneficials (consider both their general efficacy on pest species, and the time needed for beneficial populations to build to effective numbers) against the need to protect the crop from significant loss. Where insecticide control is warranted (based on industry recommended monitoring and thresholds), select products based on:

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

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

Some insecticides are very selective and have little impact on beneficial insects ('soft'), while others are highly disruptive to beneficial populations ('broad-spectrum or 'hard'). Knowing the selectivity helps you assess the risk of other pests populations 'flaring' (increasing rapidly). The relative selectivity of insecticides available for use in cotton can be found in Tables 5 and 6 (this data has been largely based on industry-funded research).

Table 5 (pages 18-19) lists both general impact and the product's selectivity to specific types of beneficials. For example, if mealybugs are present, look for insecticides that have less effect on parasitic wasps and key mealybug predators such as lacewings and ladybird beetles. When products are registered for a range of rates, using lower rates may provide sufficient efficacy against some target pests, while minimising impact on beneficials. Note that these ratings are based on results after a single application, and multiple applications of a product with a low rank can still have a cumulative disruptive impact.

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



Conserving beneficials in cotton

youtu.be/g3GYrt6QoN8



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



Examples of beneficial species

PREDATORY BUGS



Glossy shield bug. 12 mm. **1** J. Wessels Nymph on right. **1** J. Wessels



Large Australian assassin bug. 25 mm.







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



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



Damsel bug. 8 mm. ② D. McClenaghan Nymph on right. ③ J. Wessels

PREDATORY BEETLES









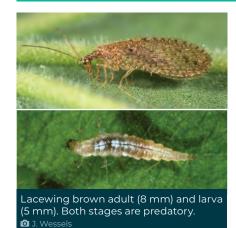
Ladybird species (4–8 mm): Striped 🙆 L. Wilson, Transverse and 3 banded 🙆 P. Grundy and 3 banded larva. 🙆 T. Grundy



Red and blue beetle. 5 mm.

D. McClenaghan

LACEWINGS





Green lacewing adult (12 mm) and larva (6 mm). Only larval stage is predatory.

T. Grundy and M. Miles

SPIDERS



Tangle web spider. 5 mm. 🧧 P. Grundy

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TABLE 5: Impact of foliar insecticides and miticides on pred			dnoyg AoM	۲	33	¥		7C		UNE	10B	91	22A	28	9D	2	12A	9B	22A	36	28	4C	23	53	4C	4 _A	9	9
t of			× c							_																		
pad			Insecticides (in increasing rank order of impact on beneficials)										-/+M	role							ه	<u>></u>			ਰੇ	(wc		Emamectin benzoate
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3LE			Insecticides (in increasing order of impa beneficials)		2	Pirimicarb	BioPest® [⊪]	Pyriproxyfen	Parachute®1	® ×	Etoxazole	Buprofezin	Indoxacarb (low+/-salt, oil)	Chlorantraniliprole	Afidopyropen	Spinetoram	Diafenthiuron	Pymetrozine	Indoxacarb	Dimpropyridaz	Cyantraniliprole	Sulfoxaflor (low)	Spirotetramat	Flonicamid	Sulfoxaflor (mid)	Dinotefuran (low)	Abamectin	mect
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Thiodicarb	≰	750	>					Long	High	=	Σ	¥	NH/	Σ	_ _	_	₹	/	Σ	I	Σ	Σ	T	+ve	+ \ +		Σ
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Pyrethroids ¹⁵	3A		>	>	>		>	Long	Very high	=	ı	ı	l	I F		I	₹	H	<u>></u>	W ×	<u>+</u>	-	-	+ ve	*	+Ve	I

- moderate), 20-40%; H (high), 40-60%; VH (very high), >60%. A Impact rating (% reduction in beneficials following application): VL (very low), less than 10%; L (low), 10-20%; M 'indicates no data available.
- resurgence. Avoid sequential applications of products with a Pest resurgence is +ve if repeated applications of a particular product are likely to increase the risk of pest outbreaks or +ve pest resurgence rating for the same pest species.
- less than 3 days; medium, 3-7 days; long, greater than 10 days. Persistence of pest control: Very short, about 24 hours; short, Total predatory beetles: Includes ladybird beetles, red and 4.
- 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 blue beetle, other predatory beetles.
- rankings for E. mundus (P. De Barro, CSIRO, unpublished) and Rankings for Eretmocerus sp. primarily based on data from laboratory leaf assay experiments, based on % mortality of adult wasps up to 96 hrs after application (highest impact Jamie Hopkinson and Jacob Balzer (Qld DPI) in replicated occurred within the first 48 hours). Also considered are eremicus (Koppert B.V., The Netherlands) <u>ن</u>
 - seedlings (when thrips cause leaf damage) and in mid-late Effects on thrips populations present on leaves (thrips in season crops (when thrips adults and larvae help control flowers are more likely to avoid exposure). Applicable to mites as well as feeding on leaf tissue).

- not available, impacts are based on comments and descriptions. bee; moderate <10 ug/bee; high <1 ug/bee; very high <0.1 ug/bee. following LD50s at 48 hours: very low >100 ug/bee; low <100 ug/ British Crop Protection Council. 2003. The Pesticide Manual: A World Compendium (Thirteenth Edition). Where LD50 data is Bee impact sources: APVMA Public Release Summaries and Where LD50 data is available, impacts are based on the See also the Protecting pollinators section in this guide. Toxin derived from Bacillus thuringiensis. 9. Toxin derived from *Bac* 10. Nucleopolyhedrovirus. ω

 - Selectivity and persistence of key cotton insecticides and miticides Sources: Citrus pests and their natural enemies, edited by Dan Smith; University of California Statewide IPM project, Cotton, Paraffinic oil.
 Sources: Citrus
- 76.3 g ai/ha and 11.4 g ai/ha. Skope may flare mite populations Skope® is a mixture of acetamiprid and emamectin benzoate and 5.7 g ai/ha emamectin benzoate. High rate (350 ml/ha) is Low rate (175 ml/ha) is equivalent to 38.2 g ai/ha acetamiprid where abamectin resistant two-spotted mites are present. 13.
 - Organophosphates, including phorate. Calcualted using other products not currently registered in cotton. 7.
- for mite and silverleaf whitefly control; alpha-cypermethrin, beta-cyfluthrin, bifenthrin, deltamethrin and lambdadeltamethrin, lambda-cyhalothrin. Bifenthrin is registered Pyrethroids: Includes alpha-cypermethrin, cypermethrin, cyfluthrin, bifenthrin, fenvalerate, esfenvalerate, cyhalothrin are registered for control of mirids. 75.
 - Suppression only. 9

- products in the early evening when bees are not foraging will 17. Wet residue of these products is toxic to bees. Applying the allow spray to dry, reducing risk to bees the following day.
 - ladybeetles for wet spray, moderate impact for dried spray 18. high impact on minute two-spotted ladybeetle and other
 - 19. Helicoverpa punctigera only
- 20. Transform is registered for control of greenhouse whitefly at
- 21. Will not control organophosphate resistant pests (e.g. mites, some cotton aphid (Aphis gossypii) populations. the 96 g ai/ha rate.
- represent the highest potential impact on wasps, which may results from laboratory assays (see Footnote 6). New ratings 22. Ratings for total wasps have been revised to consider differ with crop stage and pest status in the field

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

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



Examples of beneficial species (continued)

OTHER PREDATORS







PARASITOIDS











Active	MoA	Data		Targ	et pest(s	5)		Persistence ¹	Impact on I	beneficials ²
Active	group	Rate	Wireworm	Mites	Mirids	Aphids	Thrips	Persistence.	Thrips	Others ³
At planting (r	ate = g a	ai/ha)								
Phorate	1B	600	Υ	Υ	Υ	Υ	Υ	Medium-long	Very high	Very low
Bifenthrin	3A	37.5	Υ					Medium	_	Very low
Seed treatme	nts (rat	e = g ai/100	kg seed) u	sed by	professi	ional see	d treatr	nent companie	S	
Imidacloprid + Thiodicarb + Fipronil	4A + 1A + 2B	350 + 250 + 50	Υ				Υ	Medium long	_	Very low
Imidacloprid	4A	525 or 702	Υ			Υ	Υ	Medium	Very high	Very low
Thiamethoxam	4A	276 or 522	Υ			Υ	Υ	Medium	Very high	Very low

Note: Some regsistrations may be restricted to specific areas (e.g. NSW and QLD only). ALWAYS check the product label.

- 1. Persistence: short, 2-3 weeks; medium, 3-4 weeks; long, 4-6 weeks.
- 2. Impact rating (% reduction in beneficials following application):
- very low, <10%; low, 10-20%; moderate, 20-40%; high, 40-60%; very high, >60%; —, no data.
- 3. Other beneficials include predatory beetles, predatory bugs, spiders, wasps and ants.

Stay a step ahead of pests with

Cotton (1) Info

pest management resources





Managing key insect and mite pests

his 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 yound bolls) may not be due to pests, but other causes, including physiological/environmental stresses.



What is causing my squares to shed?

youtu.be/XMQr2mC25ze



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.



What's on my beat sheet?

youtu.be/3r4uqD5hp-w



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.

KEY INSECT PESTS	Page
Aphids	23
Armyworm (Spodoptera species)	28
Helicopverpa	29
Mealybugs	34
Mirids	36
Mites	40
Soil and establishment pests	44
Stink bugs and stainers	46
Thrips	49
Whitefly	51
Other pests	57





Animals can also damage cotton – these gnawing marks are caused by mice. Regularly check APVMA's PubCRIS database (permits tab) for details of any new permits issued for the management of rodents in cotton.

Roger Lindeman

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 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 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 60-65 for more information). Insecticides can be costly, so follow industry thresholds (when available) to prevent unnecessary spraying.

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

Important - avoid spray drift

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



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 117 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 (see inside back cover) for assistance. If cotton aphid hotspots occur early season, also check these areas for CBT symptoms.



Cowpea aphid. © Tonia Grundy, Qld DPI



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 26).
- 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.



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

Calculate the Cumulative Season Aphid Score (see page 28) to determine an estimate of yield loss

FIRST OPEN BOLL TO HARVEST

50% plants infested OR 10% if trace amounts of honeydew present

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

Other aphids

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

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

Key beneficials

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



Selecting an insecticide

When choosing a pesticide for aphid control, consider aphid resistance status, previous insecticide applications, and rotate chemical groups (see Table 7). If control is required early season, use a selective option (see Table 6) in accordance with the IRMS (pages 64-65) 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 belowthreshold 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 has a broad host range. Winter hosts include marshmallow, capeweed, thistles, and some legume crops such as faba bean. Spring and summer hosts include thornapples, nightshades, paddymelon, bladder ketmia, Bathurst burr and sunflower crops/volunteers. Ratoon or volunteer cotton is a preferred host and can act as a green bridge for CBT.

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

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

USEFUL RESOURCES:

NSW DPIRD. Tamworth 💄 Lisa Bird 줌 (02) 6763 1128 📮 0427 992 466.



Aphid sampling and management in cotton youtu.be/L9N64u1yi8E



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





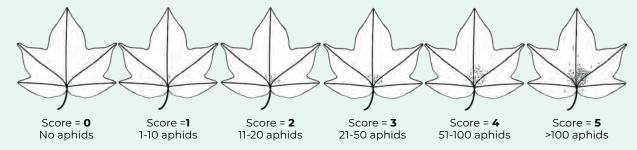
www.sumitomo-chem.com.au



COTTON APHID SAMPLING PROTOCOL - USE UNTIL FIRST OPEN BOLL

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

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



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		Average score this check									
last 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	Day	Days remaining (until 60% open bolls from the time when aphids are first observed)*						red)*		
Aphid Score	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.



		_	Overall	
Active ingredient	MoA group	Cotton aphid resistance	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 wate If populations exceed 20 aphids per terminal shoot, appl as a mixture with another aphicide.
Afidopyropen	9D	Unknown	Low	Disrupts insect behaviour and feeding. Provides a slow knockdown. Maximum 4 applications per season.
Diafenthiuron	12A	Occasional – low	Low	Ensure good coverage. Lower rate for ground rig application only. Maximum 2 applications per season.
Pymetrozine	9B	Unknown	Low	Apply to developing populations prior to row closure on an actively growing crop. Maximum 2 applications per season.
Dimpropyridaz	36	Unknown	Moderate	Do not apply by aircraft. Offers residual control for up to 21 days. Maximum 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 reapply within 14 days. Maximum 2 applications per seasor
Thiamethoxam	4A	Cross-resistance between all the neonicotinoids	Moderate	Use with organosilicone surfactant as per label. Maximum of 2 non-consecutive applications per season.
Sulfoxaflor	4C	No resistance	Moderate	Use higher rate under heavy aphid infestations and/or when water volume is reduced such as aerial application Maximum 4 applications per season.
Flonicamid	9C	Unknown	Moderate	Apply to to developing populations before honeydew is evident or aphid damage occurs. Ensure good coverage. Maximum 2 applications per season.
Emamectin benzoate/ acetamiprid	6/4A	Cross-resistance between all the neonicotinoids	Moderate	Use the high rate under sustained heavy aphid pressure Maximum 2 applications per season (note maximum of 3 applications in total of Group 6 insecticides). Use organosilicone adjuvant as per label.
Acetamiprid	4A	Cross-resistance between all the neonicotinoids	Moderate	Ensure good coverage. Apply with 0.2% Incide® penetrant. Use high rate for sustained heavy pressure. Do not use as first foliar if neonicotinoid seed treatment used. Maximum 2 non-consecutive applications per season.
Clothianidin	4A	Occasional – low. Cross-resistance between all the neonicotinoids	Moderate	Apply when aphid numbers are low and beginning to build. Do not use as first foliar if neonicotinoid seed treatment used. Maximum 2 applications per season.
Imidacloprid	4A	Cross-resistance between all the neonicotinoids	Moderate	Add Pulse® penetrant or equivalent organosilicone surfactant as per label. Do not use as first foliar if neonicotinoid seed treatment was used. Apply early in the establishment of an aphid infestation. Maximum 2 applications per season.
Dimethoate	1В	Widespread resistance in all cotton growing regions. Cross-resistance to pirimicarb/phorate	High	Do not use where resistant strains are present. Maximur 2 applications 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.
*For more details about impact on beneficial insects (including bees), refer to Table 5 in this guide.



Armyworm

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

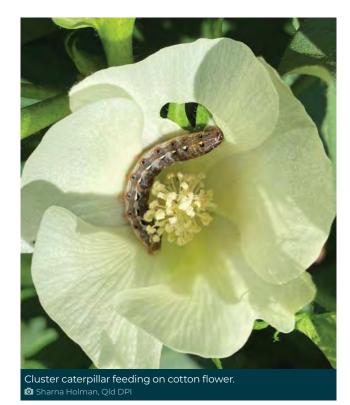
Armyworm species found in cotton have a wide host range. Moths are a mottled grey-brown and lay clusters of eggs that they cover with scales, giving a 'furry' appearance. Individual larvae (particularly up to medium size) are often mistaken for Helicoverpa.

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

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



Lesser armyworm. 🙆 Melina Miles, Qld DPI



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

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

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

Fall armyworm (FAW) is a migratory tropical species. 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.



Fall armyworm. 🙆 Melina Miles, Qld DPI





Helicoverpa

Helicoverpa armigera (cotton bollworm) H. 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	М	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 imapct). Early season eggs are particularly prone to desiccation and being washed/blown from small plants, and parasitism and predation can also dramatically reduce survival of eggs and early larval instars.

In Bt crops, exclude the VS (<3 mm) from your counts. Where small (3-7 mm) larvae are observed on Bt cotton, consecutive checks are essential for decision making.

Helicoverpa must feed in order to ingest the Bt toxin. If the number of small larvae are above threshold, chances are that a large proportion of these will ingest a sufficient dose of the toxin and die before the next check.

Key beneficials

STAGE	PREDATORS	PARASITOIDS
Eggs	red and blue beetle*, damsel bug*, lacewings*, ants, yellow night stalker spiders, ladybird beetles, apple dimpling bugs	Trichogramma spp., Telenomus spp.
Larvae	glossy 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	Microplitis demolitor, 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:

Total key* beneficials	
Helicoverpa (eggs – (% parasitised) + VS + S larvae	(دِ

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.



	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 about 6%, although it has reached much higher in some regions, particularly those with minimal overwintering as indoxacarb resistant *H. armigera* are less likely to survive diapause. Chlorantraniliprole and spinetoram resistance has been detected in some regions but is currently low and there has been no recent detection of emamectin benzoate resistance. Although the industry has ceased monitoring broad-spectrum chemistry for resistance, field failures of synthetic pyrethroids and carbamates are 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 64-65). It is also important to adhere to the resistance management strategy (RMS) for the grains industry.

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

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

Several genes are currently present in field populations of *H. armigera* that confer high-level resistance to the discrete proteins in Bollgard cotton, however none confer cross-resistance to the other proteins. Individuals must carry two copies of these resistance genes to survive





H. armigera larvae (left) have pale hairs compared to darker hairs on H. punctigera larvae (right). Delugh Brier, Qld DPI More detailed information on identifying helicoverpa is available at the the the theorem is available at
consumption of the proteins within Bollgard 3, and the vast majority only carry one copy. However, the continued efficacy of Bt cotton relies on how the industry manages its refuges and implements the other elements of the RMP. For further details, including information about recent changes in the frequency of Bt resistance genes in *H. armigera*, refer to the Bollgard 3 RMP for cotton on pages 67-76.

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 crossresistance to the other proteins. Individuals must carry two copies of these resistance genes to survive consumption of the proteins within Bollgard 3, and the vast majority only carry one copy. However, the continued efficacy of Bt cotton relies on how the industry manages its refuges and implements the other elements of the RMP. For further details refer to the Bollgard 3 RMP for cotton.

Overwintering habit

In colder regions, *H. armigera* over-winters in cotton fields as diapausing pupae (triggered by falling temperatures and shortening day length) that can contribute to carryforward 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.

USEFUL RESOURCES:

CSIRO Agriculture and Food
Amanda Padovan 0400 358 051.

Qld DPI, Toowoomba and CottonInfo Technical Lead for IPM Paul Grundy 0427 929 172.

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



TABLE 8: Contro	ol of Helico	overpa spp. (re	fer to label fo	r target species)
МоА	MoA group	Resistance (H. armigera)	Overall impact on beneficials*	Comments#
Bacillus thuringiensis	11A	None detected	Very low	Restrictions apply (see Bt cotton Resistance Management Plan)
Helicoverpa NPV	31	None detected	Very low	Use alone or with compatible larvicide. Target egg hatching.
Paraffinic oil	UNM	None detected	Very low	Use a minimum of 80 L/ha of water. Apply only by ground rig before crop closure.
Magnet®	Attractant	None detected	Very low	Use with insecticides as per label instructions.
Indoxacarb	22A	Widespread – moderate	Low	Maximum 3 applications per season.
Clitoria ternatea extract	UNE	Unknown	Low	Ensure good coverage. Treatment effects may not be seen for 3 or more days. Target egg hatch and small larvae. Maximum 5 applications per season.
Amorphous silica	_	Unknown	Low	Target egg hatch. Best results are obtained from two sequentia applications 6-7 days apart.
Chlorantraniliprole	28	Occasional – low	Low	Target brown eggs to 2 nd instar larvae (before they become entrenched in squares, flowers and bolls). Use high rate for high pest pressure (>2 larvae/m) or increased residual protection. Maximum 3 applications per season.
Spinetoram	5	Occasional – low	Low	Use high rate for heavy infestations. Larvae >8 mm or feeding within bolls & squares may not be controlled. Maximum 2 applications per season.
Cyantraniliprole	28	Occasional – low	Moderate	Target eggs to 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 pelabel. 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 pelabel. Maximum 2 applications per season.
Methomyl	1A	Widespread – moderate	High	Do not reapply within 14 days. Higher rate may cause reddening of foliage. Do not apply during periods of plant stress. Maximum 2 applications per season.
Thiodicarb	1A	Widespread – moderate	High	Has both ovicidal and larvicidal activity. See label for details. Maximum 2 applications per season.
Alpha- cypermethrin	3A	Widespread – high	Very high	Use low rate for eggs or newly hatched larvae. Use higher rates for higher egg pressure or larger larvae. Maximum 1 application per season.
Bifenthrin	3A	Cross-resistance to all pyrethroids	Very high	Target egg hatch. DO NOT apply to larvae >5 mm. Use high rate for high pest pressure or increased residual protection. Field failures due to resistance are likely for <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 application per season.
Lambda- cyhalothrin	3A	Widespread – high	Very high	Use low rate as ovicide and/or for newly hatched larvae. Maximum 1 application per season.

[#]For all control options always refer to the label for instructions.
*For more details about impact on beneficial insects (including bees), refer to Table 5 in this guide.

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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.





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.

AVOID USE OF BROAD-SPECTRUM PRODUCTS.



End-of-season recommendations for a mealybug infested crop

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

Key beneficials

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

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

Key features that influence survival and pest status

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

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

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



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





The pupal (top) and adult wasp (bottom) lifestages 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

Qld DPI, Toowoomba and CottonInfo Technical Lead for IPM Paul Grundy 0427 929 172.



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





TABLE 9: Control of solenopsis mealybug								
Active ingredient	MoA group	Overall impact on beneficials*	Comments#					
Buprofezin	16	Low	Target early nymph stages. Ensure good coverage. Maximum 2 applications per season.					
Spirotetramat	23	Moderate	Do not re-apply within 14 days. Maximum of 2 applications per season, however note that re-application presents a risk for SLW resistance management.					
Sulfoxaflor	4C	Moderate	Ensure good coverage. Addition of an adjuvant may improve control.					

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

*For more details about impact on beneficial insects (including bees), refer to Table 5 in this guide.



Mirids

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

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

Apple dimpling bugs are around 3 mm long and can damage small squares (at about 1/4 of the rate of adult green mirids), however they are also a predator of mites, silverleaf whitefly (all life stages) and helicoverpa eggs.

Damage symptoms

Mirid adults and nymphs cause blackening and death of plant terminals and mid-season damage to squares and small bolls including blackening of pinhead squares and square shedding. Older (4^{th} and 5^{th}) 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. ② 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 (discussed later in this section). It is also important to distinguish between nymphs and adults. The presence of nymphs can indicate that a mirid population has become entrenched.

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

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



Methods and sample size

Sample throughout the field to gain a reliable estimate of overall mirid density. Visual inspection of whole plants, using a beat sheet or sweep netting, 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. Quickly count the number of adult mirids dislodged onto the beat sheet. Look also for mirid nymphs, which can easily be confused with other small green insects. The easiest way to identify them is by their noticeably long antennae and fast movement across the beat sheet.

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

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

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

Thresholds

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

Mirid thresholds take into account mirid damage in high-yielding Bollgard 3 crops and give the user greater flexibility in determining the relative economics of pest control. They are based on thorough sampling twice weekly, the cost of control (product and application costs 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/m up until flowering aims to prevent an economic yield loss (see Table 10).

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 the control of mirids in cotton in Australia are presented in Table 11. Using more selective insecticide options will help to conserve beneficial insects (see Table 5 on pages 18-19). 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 they are difficult to bioassay. 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.



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Several CottonInfo videos featuring mirids are available on YouTube

youtu.be/cottoninfoaust



Using a beat sheet in cotton

youtu.be/vl-Y8qj_xXs



TABLE 10: Mirid thresholds								
Economi	c factors	Thresholds (adults or nymphs/m)						
Product value	Cost of control (1:1 cost benefit)	Planting to 1 flower/m	Flowering to 1 open boll/m					
\$450		1.5	1					
\$550	\$15	1	0.5					
\$650		1	0.5					
		Alamilana anamana anamahina atau a	/					

Consider reducing the thresholds if:

1

· 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</p>
- ·>10% boll damage

Economi	c factors	Thresholds (adults or nymphs/m)			
Product value	Cost of control (1:1 cost benefit)	Planting to 1 flower/m	Flowering to 1 open boll/m		
\$450		4	2.5		
\$550	\$45	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)

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

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



TABLE 11: Control o	f mirids	ı	
Active ingredient	MoA group	Overall impact on beneficials*	Comments#
Paraffinic oil	UNM	Very low	Use low rate for suppression if <0.5 mirids/m. If population reaches 0.5 mirids/m, use high rate or apply 2 successive low rate sprays not more than 7 days apart.
Clitoria ternatea extract	UNE	Low	Ensure good coverage. Maximum 5 applications per season. Treatment effects may not be seen for 3 or more days. A repeat application may be required at 14-20 days if conditions favour pest development.
Indoxacarb	22A	Low	If populations are high, may only achieve supression. Maximum 3 applications per season. A lower rate with salt can be used for controlling green mirids ONLY. Limited residual activity.
Sulfoxaflor	4C	Moderate	Use lower rate when infestation is predominately nymphs. Maximum 4 applications per season.
Fipronil	2В	Moderate	Ensure thorough coverage. Use higher rate under sustained heavy pressure. May take 3-4 days to reach full effectiveness. Compatible with early season IPM. Avoid repeated use of this insecticide group.
Flonicamid	29	Moderate	Ensure good coverage. Maximum 2 applications per season.
Emamectin benzoate	6	Moderate	Suppression only. Target developing populations (nymphs). Use non-ionic surfactant as per label. Maximum effect may take 5 to 7 days. Maximum 2 applications per season.
Acetamiprid	4A	Moderate	Apply with 0.2% Incide® penetrant. If populations are high, may only achieve supression. Maximum 2 applications per season.
Emamectin benzoate/ acetamiprid	6/4A	Moderate	Use higher rate on heavier populations and for longer residual control. Use non-ionic surfactant as per label. Maximum 2 applications per season.
Clothianidin	4A	Moderate	Maximum 2 applications per season.
Imidacloprid	4A	Moderate	Do not use as first foliar if neonicotinoid seed treatment was used. Maximum 2 applications per season.
Dinotefuran	4A	Moderate	Performance can be reduced in stressed crops, when senescing late season, or when pests are not actively feeding in the upper crop canopy. Maximum 2 applications per season. Do not reapply within 14 days.
Dimethoate	1B	High	Do not use where resistant strains are present. Maximum 2 applications per season.
Gamma-cyhalothrin	3A	Very high	
Lambda-cyhalothrin	3A	Very high	Maximum 1 application per season.
Alpha-cypermethrin	3A	Very high	Use high rate for high pest pressure or increased residual
Bifenthrin	3A	Very high	protection. Maximum 1 application per season.
Deltamethrin	3A	Very high	Suppression only. Maximum 1 application per season.

Phorate (1B) is also registered for mirid suppression when applied at planting (Qld and WA only).
#Target pest is predominantly green mirid (*Creontiades dilutus*). For specific species registrations and all other control options ALWAYS refer to the label for instructions.
*For more details about impact on beneficial insects (including bees), refer to Table 5 in this guide.



Mites

Spider mites:

Two-spotted - Tetranychus urticae Bean – T. ludeni Strawberry – T. lambi

Broad mite – Polyphagotarsonemus latus

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

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

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

Damage symptoms

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

Two-spotted 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

Sampling spider mites

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

Sampling protocol

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

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

Determine the mite species present

Two-spotted spider mite is a pale yellowish-green with a dark spot on either side of its body. Diapausing twospotted mites turn bright orange. Strawberry spider mite



<mark>'wet' undersides. 🖸</mark> Tonia Grundy, Qld DPI



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

Thresholds and yield loss charts in this section 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.

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

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

Using the yield reduction charts

A simple relationship based on the rate of population increase and the time remaining until defoliation allows a quick-reference prediction of yield loss from two-spotted spider mites in various regions (Table 12).

Calculate the rate of increase of the mite population by dividing the change in the percentage of plants infested between consecutive checks by the number of days between the checks. For example, if a field had 10% of plants infested a week ago and 24% infested now, this gives a rate of increase of 2% of plants infested per day. To use the table:

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

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

Selecting a miticide

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

Mite infestations may increase after the application of some broad-spectrum insecticides used for helicoverpa or mirid control, such as synthetic pyrethroids, fipronil, and organophosphates because key beneficial species are removed allowing resistant mite populations to flourish (see Table 5 on pages 18-19 for the impact of pesticides on key beneficials). If mite control is required, use a selective option to help conserve beneficial populations, in accordance with the IRMS (pages 64-65).

Resistance in mites

Two-spotted mite has a long history of developing resistance to miticides and 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.

Overwintering habit and alternative hosts

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

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

USEFUL RESOURCES:

NSW DPIRD, Tamworth

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

youtu.be/cottoninfoaust





TABLE 1	TABLE 12: Yield reduction caused by two-spotted spider mites																				
The c	The charts below can be used to estimate the percentage of yield reduction for different cotton growing regions.										S.										
	Current % plants infested with mites																				
Days from				10							30				60						
planting						se (%/ -							se (%/ -	- J,						se (%/	- J,
	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
		E	Biloel	a, Boi	Warn urke,	ner re Emer	gions ald, M	plar acin	iting tyre, l	to 60 Mung	% bo Jindi,	IIs op St. Ge	en in ' eorge	134-15 , Theo	4 day dore	/s. and	Walg	ett			
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 50	0.7	2.5	5.3 4.4	9.2 7.6	20.0	54.3 44.5	100 86.2	1.3	3.5	6.7 5.6	10.9 9.2	22.6 18.8	58.4 48.3	100 91.5	2.4	5.2 4.6	9.0 7.8	13.9	26.7 22.6	65.0 54.3	100 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 0.7	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
110 120	0.1	0.4	0.7	1.2 0.6	2.4	6.3 3.3	11.9 6.1	0.4	0.8	1.3 0.8	1.9	3.4 2.0	7.7 4.3	13.9 7.6	1.1	1.7 1.4	2.4	3.2 2.3	5.1 3.4	10.2 6.3	17.2 10.0
130	0.1	0.2	0.4	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
					Avera	age re	gions								0 day	rs.					
10	1.5	5.3	11.5	20.0	44.1	100	100	, Gw 2.3	6.7	13.5	yer, L 22.6	6 47.9	Namo 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	2.3	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	8.0	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 90	0.5	1.8 1.4	3.7	6.4 5.1	13.9 10.9	37.4 29.4	72.4 56.8	0.9	2.6	4.9 4.0	7.9 6.4	16.0 12.9	40.9 32.5	77.2 61.0	2.0 1.9	4.1 3.6	6.9 5.8	10.4 8.7	19.5 16.0	46.4 37.4	84.7 67.7
100	0.4	1.1	2.3	3.9	8.4	22.3	43.0	0.3	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
150 160	0.1	0.1	0.2	0.3	0.6	1.6 0.3	2.9 0.5	0.3	0.4	0.6	0.7	1.2 0.4	2.3	3.9 1.0	0.9	1.1 0.8	0.9	1.6	2.3	3.8 1.6	5.7 2.0
100																				1.0	2.0
		pper					egion eeza,			ns, Pi					cqua						
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		62.8	100	100
20 30	1.6	5.6 4.9	12.1 10.7	21.0 18.6	46.4 40.9	100	100	2.3	7.0 6.3	14.1 12.6	23.7	50.3 44.5	100	100	3.8	9.4 8.5	17.4 15.7	27.9 25.0	56.3 50.3	100	100
40	1.4	4.9	9.4	16.2	35.7	97.4	100	1.9	5.6	12.6	18.6	39.1	100	100	3.3	7.7	15.7	25.0	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 1.6	4.1 3.3	7.0 5.6	15.1	40.9 32.5	79.1 62.8	1.1 0.9	2.8	5.3 4.3	8.5	17.4 14.1	44.5	84.2 67.3	2.1 1.9	4.3 3.8	7.3 6.3	11.1 9.4	21.0 17.4	50.3 40.9	92.0 74.3
110	0.5	1.6	2.6	4.3	12.1 9.4	32.5 25.0	48.3	0.9	1.9	3.5	7.0 5.6	14.1	35.7 27.9	52.2	1.9	3.8	5.3	9.4 7.7	17.4	32.5	58.4
120	0.3	0.9	1.9	3.3	7.0	18.6	35.7	0.0	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@dpi.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	Occasional – low	Low	Ensure good coverage. Refer to label for no-spray zones and record keeping. Best on low to increasing populations. Maximum 1 application per season.					
Diafenthiuron	12A	Significant increase in Namoi/Gwydir Valleys in 23/24 season	Low	Treatment at higher infestations may lead to unsatisfactory results. Maximum 2 applications per season.					
Abamectin	6	Widespread – med/ high	Moderate	Resistance levels increasing. Best results will be obtained when applied to low mite populations. Maximum 2 applications per season.					
Emamectin benzoate	6	Cross-resistance to abamectin	Moderate	Suppression only. Reduces rate of mite population development when applied for <i>Helicoverpa</i> control. Maximum 2 applications per season.					
Propargite	12C	Occasional – low	Moderate	Apply before mite infestations reach damaging levels (maximum efficacy occurs 2 weeks postspray). Maximum of 2 non-consecutive applications per season.					
Dimethoate	1B	No data	High	Will not control organophosphate-resistant mites. Maximum 2 applications per season.					
Bifenthrin	3A	Widespread – med/ high	Very high	Applications against <i>Helicoverpa</i> 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 at planting in some states (check label for application rates). #For all control options ALWAYS refer to the label for instructions.

*For more details about impact on beneficial insects (including bees), refer to Table 5 in this guide.



Soil and establishment pests

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

Soil pests can reduce plant establishment and vigour. Symptoms of their damage can be confused with other establishment problems, and the impactb may be worse if seedling development is slow due to climate or other factors such as allelopathy, disease or soil constraints. Preplant sampling for these pests is needed, particularly in fields with a history of soil pest activity.

Sampling

Sampling for earwigs and wireworms is best conducted using baiting, whereas pests such as symphylans and scarab larvae are best detected by soil surveying.

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

- Soak insecticide-free crop seed in water for at least two hours to initiate germination or cut medium sized aged potatoes in half (ideally, potatoes should be beginning to develop eyes and rapidly sprout once buried). The type of seed used makes no noticeable difference in attracting soil-dwelling insects.
- 2. Bury a dessert spoon 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.

Sampling for soil insects youtu.be/i_ODxTAeASw

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

Factors influencing soil pest numbers

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

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

True and false wireworms

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

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

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



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

Black field earwigs

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

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

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





Symphyla

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

Symphyla generally feed on decomposing organic matter but can feed on rootlets and root hairs and have been associated with crop establishment issues in some fields, particularly under dry conditions and often as part of a broader complex of soil pests. In the absence of other soil pests and diseases or under more optimal field conditions their impact is likely to be minimal. If plants show damage symptoms, conduct a basic soil survey, keeping a close eye on newly broken-apart clods for movement. Distribution within a field is generally patchy and symphyla are fast moving and will rapidly shift to avoid sunlight.

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

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

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



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

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.



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



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.



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								
*	Green stink bug	0.5						
stin S	Red banded shield bug	0.33						
er s oug	Pale cotton stainer bug	0.33						
Other stink bugs	Brown stink bug	0.25						
U	Harlequin bug	0.25						
Nymphs	1 st or 2 nd instar GVB nymphs (cluster of 10+)	1.0						
ΕŽ	3 rd instar GVB nymphs	0.5						
Z	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.











See page 16 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/insectidentification





Mating red cotton bugs (top). Adult and juvenile pale cotton stainers (bottom). • Paul Grundy 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 Nortthern Territory. Bottom: The seed bug *Graptostethus servus* is often confused with stainers, but is not considered a significant pest. Simon Ong





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.

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 midseason use of dimethoate for GVB control if possible as it also selects for Group 1 resistance in aphids, particularly if using an organophosphate (OP) in early season furrow treatments for thrips control. SLW carry OP/carbamate resistance, so this action could also 'flare' their population.

There are few products registered for pale cotton stainer control apart from synthetic pyrethroids, however their status as an occasional pest is influenced by their susceptibility to insecticides used for the control of Helicoverpa and other pests such as mirids. Any

decision to use broad-spectrum insecticides should take into account their impact on beneficial insects and the subsequent risk of flaring 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

Old DPI, Toowoomba 💄 Paul Grundy 📮 0427 929 172



Green vegetable bugs in



TABLE 16: Control of green vegetable bug

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

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

*For more details about impact on beneficial insects (including bees), refer to Table 8 in this guide.



Thrips

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

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

Damage symptoms

Thrips nymphs and adults damage seedling terminals, leaves and stems. The most obvious symptoms are smaller, crinkled leaves with a visible 'silvering' on the undersides. At very high densities, thrips can also kill the growing terminal, delaying the plant's growth until a new terminal develops.

Occasionally thrips build to high numbers 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.

Sampling

Use a hand lens to count the adult and larval thrips per plant 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 greater than 80%). If thrips are present in high numbers (>30/plant), check the plant terminal. Complete blackening of the embryonic leaves means the terminal has died.

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



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). During mid to late season, monitor for thrips presence in flowers and on the undersides of leaves in the upper canopy. 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 applied with the seed. This protects plants during the establishment phase, with minimal negative effects on beneficial species compared to an insecticide applied to the crop after emergence (see Tables 5 and 6).

THRESHOLD: Seedling to 6 true leaves

80% reduction in leaf area + 10 thrips/plant (adults and larvae)

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, so yield loss is only likely to occur about one year in every ten. In cooler, shorter season areas (Darling Downs, Upper Namoi, Macquarie and Liverpool Plains), the risk of delayed maturity and/or yield loss is higher because there is less time to compensate, hence yield loss may occur one year in every two, 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.

While a seed treatment or at-planting insecticide should provide sufficient control for plants to establish, 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.

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 below. Western flower thrips are not controlled by seed treatments registered for cotton, but this species is not normally abundant early in the season

Thrips found in cotton in the mid to late season are usually Frankliniella spp. Adult thrips feed on pollen, but are unlikely to affect pollination or fruit set. Eggs are laid on leaves and the hatching numphs may cause damage to the undersides, resulting in distorted, smaller leaves, but



the feeding damage rarely affects yield. Thrips nymphs 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, however 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, EVERY western flower thrips tested since resistance screening commenced has been 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 (Group 2B) was detected for the first time in seedling thrips collected from cotton fields in 2024. Avoid using fipronil in fields where seed treatments containing this insecticide have been used or if the presence of resistant thrips is suspected.

Overwintering habit

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

Alternative hosts

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



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

Lewis Wilson

USEFUL RESOURCES:

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





Several CottonInfo videos featuring thrips identification and management are available on YouTube

youtu.be/cottoninfoaust

TABLE 17: Control of thrips (excluding seed treatments)										
Active ingredient	MoA group	Resistance	Overall impact on beneficials*	Comments#						
Seedling thrips and tomato thrips										
Fipronil	2B	Detected in seedling thrips	Moderate	Takes 3-4 days to reach full effectiveness. Use higher rates under high pressure. Avoid repeated use of this insecticide group.						
Dimethoate	1B	Detected in seedling thrips	High	Do not harvest for 14 days after application. Maximum 2 applications per season.						
Western flower thrips										
Spinetoram	5	Not detected	Low	Maximum 2 applications per season. Refer to mandatory no-spray zone on label.						

Phorate (1B) is also registered for application at planting (Qld, NSW and WA only).

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

*For more details about impact on beneficial insects (including bees), refer to Table 5 in this guide.



Whitefly

Silverleaf – Bemisia tabaci (MEAM1) Greenhouse – Trialeurodes vaporiorum

Silverleaf whitefly (SLW) is a serious pest of mid to latestage cotton. Honeydew producedy 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, SLW honeydew can be difficult to visually detect as it dries to a matte sheen that is not sticky to the touch. However, trehalulose melts at 48°C, a temperature reached during ginning, and 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.



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 nymps below). The augmentative release of *Eretmocerus* sp. is a management approach that has recently been adopted 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.





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.

- 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 a insecticide targetting SLW has been used. Nymph viability is an important factor in management decisions, particularly during open bolls.

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



Identifying parasitism in silverleaf whitefly





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.

Current sampling recommendations are available at:

<u>cottoninfo.com.au/silverleaf-whitefly-sampling-and-thresholds</u>

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 late season 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 the risk of honeydew contamination is high, consider defoliating early.

Also monitor for honeydew presence 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 posttreatment.
- 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 control of SLW 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.

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 level resistance to Group 23 detected in the Lockyer Valley was due to a dominantly-inherited target site mutation, meaning it can develop rapidly and once established, reversal is unlikely.



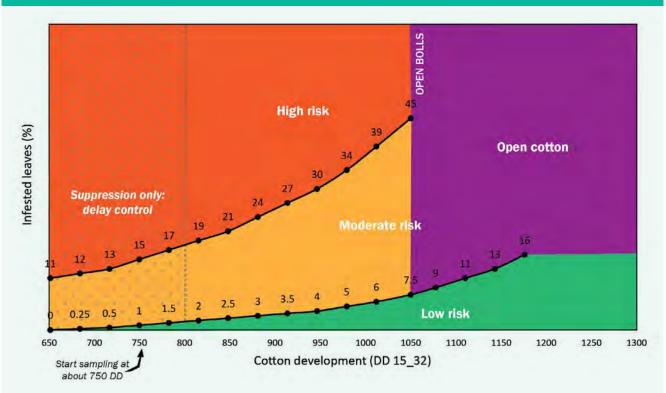


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SLW SAMPLING AND THRESHOLD MATRIX



AN EXPLANATION OF THE MATRIX ZONES

Crop stage

Sampling considerations and management actions

Early to mid flowering (prior to 800 DD)

Mid-flowering to

first open bolls

(800-1050 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.

Low 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

Due to inherent variability associated with sampling, one or two data points slightly above the low zone boundary does not constitute a 'breakout'. Continue to sample population developmen

Moderate risk:

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.

boundary does not constitute a 'breakout'. A follow up treatment may be necessary during later boll opening if natural enemies are disrupted and population development and preserve beneficials. Actively preserve beneficials that will

assist keeping SLW populations low.

High risk:

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.

Selection for resistance in SLW populations can happen very quickly. Compliance with the IRMS (pages 64-65) and avoiding reliance on the same insecticide every year will help ensure the products available for SLW control remain efficacious into the future. ENSURE ONLY SINGLE APPLICATIONS OF PYRIPROXYFEN AND SPIROTETRAMAT OCCUR WITHIN A SEASON.

Overwintering habit

Whitefly does not have an overwintering diapause stage, 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.

USEFUL RESOURCES:

Qld DPI, Toowoomba

- 🛂 Jamie Hopkinson 📋 0475 825 340 (resistance enquiries)
- 💄 Paul Grundy 📋 0427 929 172

The new SLW recommendations are available as a factsheet at

cottoninfo.com.au/silverleaf-whitefly-sampling-and-threshold











Active	МоА	CL) A/	Overall impact	Commonte#
ingredient	group	SLW resistance	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.
Clitoria ternatea extract	UNE	Unknown	Low	Ensure good coverage. Maximum 5 applications per season. Treatment effects may not be seen for 3 or more days. A repeat application may be required at 14-20 days if conditions favour pest development.
Buprofezin	17A	Not detected	Low	An IGR with contact and vapour activity that reduces adult female fertility and disrupts moulting of nymphs. Target the early nymph stages. Use sufficient volumes to achieve good penetration and coverage. Maximum 1 application per season.
Afidopyropen	9D	Not detected	Low	Suppression of both adult and nymph stages, however it is recommended to target the nymph stage.
Diafenthiuron	12A	Not detected	Low	Suppression only. Apply when population densities are low to moderate. Suppression may not be satisfactory once populations are high or migrating in. Maximum 2 applications per season.
Dimpropyridaz	36	Unknown	Moderate	Do not apply by aircraft. Offers residual control for up to 21 days. Maximum 2 consecutive applications and no more than 4 applications per season.
Cyantraniliprole	28	Not detected	Moderate	Target early developing populations. Maximum 2 applications per season.
Spirotetramat	23	Widespread – low (very high – extreme in Lockyer Valley)	Moderate	Controls nymphs and causes sterility in females. Has translaminar and systemic mobility in both phloem and xylem. Use the high rate for periods of high pest pressure, when rapid crop growth are evident, or when crops are well advanced. Ensure good coverage and use an adjuvant as per label. Do not re-apply within 14 days. Maximum 1 application per season.
Acetamiprid	4A	Rare – very low	Moderate	Apply with adjuvant as per label. Use higher rate when conditions favour a rapid increase in the whitefly population, during rapid crop growth or when crops are well advanced.
Emamectin benzoate/ acetamiprid	6/4A	Not detected/ Rare – very low	Moderate	Use before heavy populations become established. Activity is primarily on nymphs and therefore evidence will be slower than for typical contact insecticides. Use adjuvant as per label. Maximum 2 non-consecutive applications per season.
Dinotefuran	4A	Not detected	Moderate	Performance can be reduced in stressed crops, when senescing late season, or when pests are not actively feeding in the upper crop canopy. Maximum 2 nonconsecutive applications per season.
Bifenthrin	3A	Widespread – low Cross-resistance with other SPs.	Very high	Target the adult stage only. Do not spray if a high proportion of juveniles are present. Ensure good coverage. Maximum 1 application per season.

[#]For all control options ALWAYS refer to the label for instructions.
*For more details about impact on beneficial insects (including bees), refer to Table 5 in this guide.



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.



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

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



🖸 P. Room and D. Ironside





lint due to feeding and the entry of boll-rotting fungi.

Cottonseed bug - Oxycarenus luctusous

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.





Leafhoppers (jassids)

Occasional pests of cotton, there are several species that can cause seedling damage or leaf stippling, but they are unlikely to reduce yield unless the stippling is extreme (for example affecting more than 50% of the leaf surface just before cut-out).

Lucerne leafhopper is suspected to have caused leaf chlorosis in some fields in the 2021-22 season. Unnecessary sprays for leafhoppers may adversely affect beneficial species and flare other pests.

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



Cotton leafhopper (left) and suspected lucerne leafhopper damage (right). 🖸 Paul Grundy, Qld DPI



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 - Crocidosema 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.



Redshouldered leaf beetle – Monolepta australis

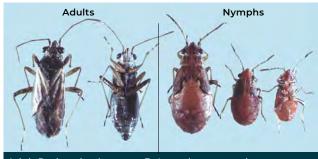
Redshouldered leaf beetle adults chew leaves, terminals, squares and the surface of cotton bolls. They are rarely found in the majority of cotton-growing regions, however, in the tropics (particularly after good rains), swarms of beetles can cause significant damage to patches of plants.



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. Starving nymphs migrating from maturing sunflower or canola crops may damage border areas of adjacent cotton.

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



Adult Rutherglen bugs are 3-4 mm long; nymphs are reddish-brown. 🙆 QId DPI

Weevils

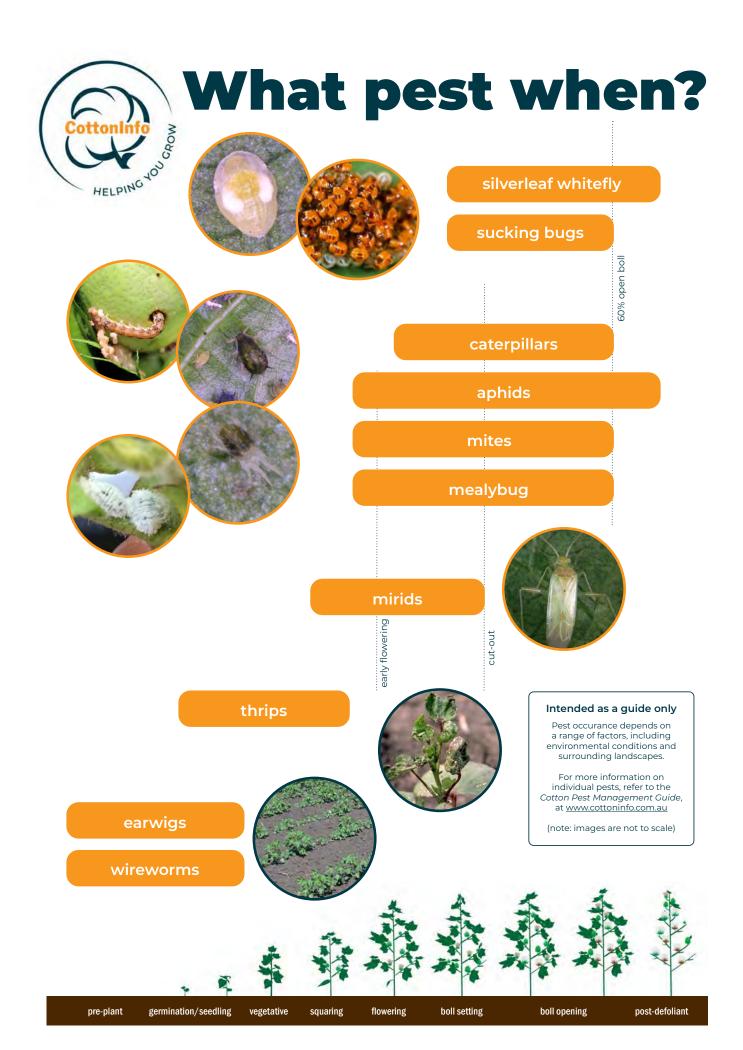
Occasionally leaf or root-eating weevils such as the garden weevil (*Phlyctinus callosus*) are found in cotton crops. They are not the same as cotton boll weevil, a high priority exotic pest that burrows into bolls (see the *Biosecurity* chapter for more information).

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





Bicoloured weevil adults and larva on cotton flowers.





Insecticide Resistance Management Strategy (IRMS) for 2025-26

n 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 67-76).

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 2025-26 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 SLW products. Resistance to pyriproxyfen in SLW is low and stable in most regions. Continue to consider resistance risk when utilising any SLW product. Resistance to spirotetramat is low but widespread in most regions and 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).

Principles underlying the IRMS

- Monitor pest and beneficial populations. Consider species as well as abundance.
- Monitor fruit retention and determine if losses are due to pest damage or environmental factors.
- Use recommended thresholds for all pests (do not use 'insurance' sprays).
- Aim to use the most selective insecticide options first, delaying the use of broad-spectrum insecticides for as long as possible.
- Comply with all directions for use on product labels
- Avoid repeated applications of similar products, even when targeting different pests. Rotate between mode of action (MoA) groups.
- Do not respray an apparent failure with the same product or another product from the same insecticide group.
- Do not exceed the maximum recommended use limits.
- Control weeds and cotton volunteers in fields and around the farm all year to minimise alternate hosts.
- Pupae bust as soon as possible after harvest.
- Aphid resistance to Group 1 actives is likely to lead to field failures with these products in most regions. Cross resistance also occurs between Group 1A (dimethoate and phorate) and pirimcarb (Group 1B). Do not follow an at-planting phorate treatment with pirimicarb or dimethoate as first foliar spray. Do not use pirimicarb and dimethoate in the same field. Avoid dimethoate usage until late season. Targeting aphids with diafenthuiron has contributed to mite resistance always consider the presence of other pests when making control decisions.
- **Fipronil bee risk.** While bees are susceptible to many insecticides used on cotton, fipronil risk to managed hives has been highlighted due to the extended residue risk. The industry recommends fipronil should not be used on flowering crops. Refer to label for 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 43.



Growing together through local strength and global trust—to empower growers, support communities, and promote sustainability.





More about resistance

The role of IPM, refuges and pupae-busting

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

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

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

Cross-resistance versus multiple resistance

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

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

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

What about insecticide mixtures?

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

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

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

For mixtures to be effective, their components should:

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

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

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

What to do if you suspect a spray failure

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

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

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

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

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

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

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



The IRMS includes multiple pests

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

Helicoverpa

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

Mites and aphids

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

Mirids

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

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

Silverleaf whitefly (SLW)

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

In-season troubleshooting

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

IRMS in grains

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

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

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



Insecticide Resistance Management Strategy 2025/26

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

EMERGENCE TO FIRST FLOWER		ERING ← Canopy closure	FIRST OPEN BO TO 60% OPEI		
Helicoverpa viruses (Gemsta	ar®, Helicovex®, Vivus®)	Group 31		N	Note 1
Pirimicarb Group 1A (avoid con	secutive usage)	5			
Paraffinic oil Group UNM		,			
	Pyriprox	yfen Group 7C	Use an alternative from 5% open cotton	N	Note 6,
Sero-X® Group UNE					
From late squaring Etc	xazole Group 10B			N	Note 5
	Buprofe	zin (Applaud®) Gr	oup 16 Use an alternative from 5% open cotton	N	Note 6,
	Chlorantranilip	role Group 28	max 4x Group 28 per season)		
Afidopyropen (Versys®) Grou	p 9D	>			
Spinetoram (Success Neo®) G	roup 5	·			
		Diafenthiuro	1 Group 12A	N	Note 4
Pymetrozine Group 9B					
Indoxacarb Group 22A (use u	ntil 31 January)				
Dimpropyridaz (Efficon®) Gro	oup 36	X			
	Cyantraniliprol	• (Exirel®) Group	28 (max 4x Group 28 per season)		
	Spirotetramat	Group 23		N	Note 5
Flonicamid (MainMan®) Grou	p 29	×			
		Abamectin* (Group 6 (max 3x Group 6 per season)	N	Note 3
		Emamectin b	enzoate Group 6 (max 3x Group	6 per season)	
		Propargite G	oup 12C		
Sulfoxaflor (Transform®) Grou	ip 4C	×		N	Note 2
Fipronil Group 2B				N	Note 12
Neonicotinoids (acetamiprid,	clothianidin, dinotefura	n, imidacloprid, th	amethoxam) Group 4A		Note 2
	If using mixes, consider each group's risk	Acetamiprid	+ Emamectin Group 4A + Gr	oup 6	6, 12
			Carbamates (methomyl*, thiodica		Note 10
Phorate* 1B Note 1			OPs (dimethoate) Group 1B		Note 1
			Synthetic pyrethroids Gro		Note 6

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

CONSIDER IMPACT ON BENEFICIALS & BEES (TABLE 5 CPMG)



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

IRMS notes:

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

Aphids: High 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 while etoxazole {10B} resistance is emerging across NSW. 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 to severe resistance to diafenthiuron {12A} has been identified. DO NOT use more than 1 application/season irrespective of target pest (see label).
 - **5.** Etoxazole {10B} resistance has been detected throughout 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: Pyriproxyfen resistance is stable; spirotetramat resistance continues to increase. SLW has low levels of resistance to pyrethroids in all regions.

- **6.** See www.cottoninfo.com.au/publications/2024-silverleaf-whitefly-sampling-and-thresholds for more quidance.
- 7. Resistance to pyriproxyfen {7C} is low but widespread. To avoid loss of product efficacy DO NOT use more than 1 application of pyriproxyfen per season.
- 8. Low level spirotetramat {23} resistance has been detected consistently in almost all regions. Resistance levels are EXTREME in Lockyer and Bowen regions. A notable increase has also occurred in the St George and Border Rivers regions. For 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 stabilised. Continue to adhere to IRMS.

- **10.** Additional applications can be made if targeting *Helicoverpa* moths using Magnet®.
- **11.** 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.

12. 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 2025-26*). 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	
IB (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	Bacillus thuringiensis	
12A	diafenthiuron	
12C	propargite	
16	buprofezin	
22A (oxadiazines)	indoxacarb	
23	spirotetramat	
28 (diamides)	chlorantranili prole cyantranili prole	
29	flonicamid	
31 (baculoviruses)	Helicoverpa sp. viruses	
36	dimpropyridaz	
	Clitoria ternatea extract	
UNE (botanical extracts)	Clitoria ternatea extract	

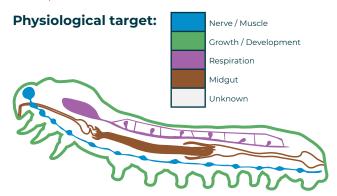
*Actives with HHP status under the Better Cotton™ initiative

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.

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.



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 $^{\text{TM}}$ 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 many of these HHPs are no longer used in the Australian cotton industry, examples of poducts still available include banned products methomyl (Group 1A) and lambdacyhalothrin (3A), and restricted use products phorate (1B), bifenthrin (3A) and abamectin (6).

For more information on the MoA classification system, or to search for groups online (or via an app) visit the Insecticide Resistance Action Committee website:

irac-online.org/mode-of-action



Bollgard 3 Resistance Management Plan (RMP)

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

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

Current status of Bt resistance in Australia

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

The data for current frequencies is sourced from Bayer's 2024-25 monitoring program. Unless otherwise stated, other information around trends in resistance frequencies draws on data collected over time from Bayer. The frequencies of these recessive resistance genes are currently not at a level that impacts performance of the technology (there is currently no resistance to Bollgard 3 that affects its performance against *H. armigera* or *H. punctigera*).

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

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

Cry2Ab: A recessive gene that confers high level resistance to Cry2Ab is present in field populations of *H. armigera*. The mechanism is likely to be an alteration of a binding site in the gut of the insect. The current estimate of resistance frequency is approximately 4% or less.

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

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

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

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

How is resistance monitored?

Bayer invests in an annual program monitoring field populations of *Helicoverpa* spp. for resistance of all three proteins contained in Bollgard 3 cotton (CrylAc, Cry2Ab and Vip3A), providing an early warning of the onset of resistance. The programs have been used by industry to make decisions about the need to modify the RMP each season to ensure its ongoing effectiveness.

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

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

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



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

Paul Grundy, Qld DPI

Elements of the Bollgard 3 RMP

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

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

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

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

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

RMP tactics

1. Using refuges

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

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

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

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

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

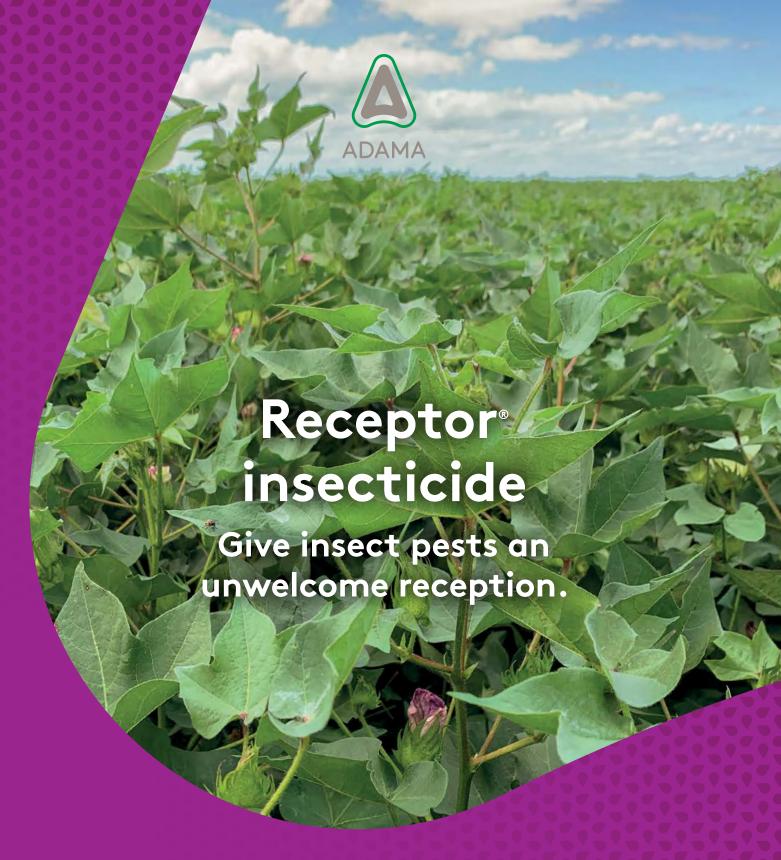
The introduction of Bollgard 3 enabled refuge requirements to be reduced to 5% unsprayed cotton and 2.5% pigeon pea, representing the industry's confidence in the robustness of a 3 gene product in managing resistance risk combined with an industry commitment to improve the quality of refuges. Note that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

The productivity of refuges will vary considerably across regions and seasons. Improving the production potential of each individual refuge is an integral component of the RMP. Growers must ensure that on farm refuge management is a priority. Looking after refuges, including nutrition, weed control, timely irrigation and all factors that make the refuge 'attractive' to female moths laying eggs, is the key to ensuring that they are effective. Guidelines on refuge management are provided in the RMP and the following unsprayed pigeon pea refuge agronomy guide (pages 77-78).

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

2. Controlling volunteers and ratoons

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



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

- Controls Two Spotted Mite and Cotton Aphid, and suppresses Silverleaf Whitefly.
- Translaminar movement and vapour activity
- Target pests are immediately paralysed

ADAMA.COM

- Knockdown and residual activity (7–14 days)
- Minimal impact on beneficials













3. Planting windows

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

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

4. No Bt sprays

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

5. Pupae destruction

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

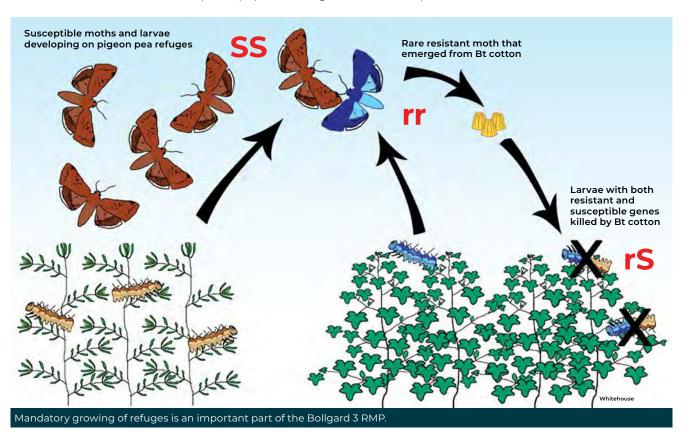
Introducing a defoliation date for Bollgard 3 that determines whether a field requires pupae busting

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

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

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

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





Skope insecticide provides excellent performance against key cotton pests with flexible use timings.

- Controls Green mirid, Silverleaf whitefly, Heliothis spp., Cotton aphid and Green vegetable bug
- Two modes of action
- Suitable for IPM programs
- No mite flaring
- Ideal for managing multi-pest scenarios in Bollgard* cotton

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Guidelines for Helicoverpa management in Bollgard 3 cotton

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

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

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

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

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

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

Insecticide selection for Bollgard 3 crops

When controlling *Helicoverpa* sp. within Bollgard 3 crops, insecticide selection should comply with the cotton industry's Insecticide Resistance Management Strategy (pages 64-65). The beneficial/pest ratio (described on page 29) 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 is a requirement of the Bollgard 3 cotton Resistance Management Plan that foliar Bt not be used on any refuge crops.

Helicoverpa thresholds

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

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

Application of these thresholds requires careful and accurate assessment. Checks should be made over the whole plant including the terminals, squares and especially flowers and small bolls. Be sure to objectively assess larval size. A complete description of the sampling protocols for *Helicoverpa* sp. can be found on page 29.

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

Note that recent changes have been made to both southern and northern RMPs for Bollgard 3 cotton. Updated versions will be available at bollgard3.com.au as soon as APVMA approval is received.





The RMP for Central Queensland to Victoria is included in this manual. However, recent revisions to both RMPs are awaiting APVMA approval, and the updated versions will be available from <code>mbollgard3.com.au</code>.

RESISTANCE MANAGEMENT PLAN

CENTRAL & SOUTHERN QUEENSLAND, NEW SOUTH WALES & VICTORIA

Developed by Monsanto Australia Pty Ltd

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

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

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

1. PLANTING TIMING RESTRICTIONS

Victoria, New South Wales and Southern Queensland

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

Central Queensland

Planting Window 1:

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

All growers who plant Bollgard 3 cotton between August 1 and October 31 (planting window 1) and intend to grow their Bollgard 3 cotton for longer than 230 days (measured from the first day of planting for each field to the date of complete crop destruction, defined as slashed or mulched and controlled to prevent regrowth) must plant 10% irrigated unsprayed cotton refuge (or its equivalent – must be irrigated) of the Bollgard 3 area that will be grown longer than 230 days. Growers intending to grow Bollgard 3 cotton fields for longer than 230 days are required to comply with the timing conditions stipulated in "General conditions for all refuges" section (a).

- e.g., The additional refuge required for irrigated Bollgard 3 cotton grown longer than 230 days must be planted within 3 weeks of the first sowing date of Bollgard 3.
- Any Bollgard 3 fields that are planted between August 1 and October 31 (planting window 1) that only have an associated 5% unsprayed cotton refuge (or its equivalent) must be destroyed 230 days (or prior) after planting (measured from the first day of planting for each field).
 - e.g., A Bollgard 3 field that begins planting on August 1 that only has an associated 5% unsprayed cotton refuge (or its equivalent) must be completely destroyed by March 18.
- Any Bollgard 3 cotton that is planted in planting window 1 and is grown for greater than 230 days with only a 5% unsprayed cotton refuge (or its equivalent) will be recorded as non-compliant and be issued with a Resistance Risk Management Plan (RRMP).

Planting Window 2:

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

2. REFUGES

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

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

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

Table 1. Irrigated Bollgard 3 cotton refuge options

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

Table 2. Dryland Bollgard 3 cotton refuge options

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

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

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

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

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

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

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

If the viability of an unsprayed refuge is at risk due to early or late season pressure by Helicoverpa spp., or any other caterpillar species, contact Monsanto Australia immediately. With prior approval from Monsanto Australia, a non-Bt heliocide can be applied. For the purposes of this Resistance Management Plan, conventional cotton includes any cotton varieties that do not have Bt proteins in the plant that control Helicoverpa spp. larvae.

General conditions for all refuges:

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

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

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

- (b) Pigeon pea refuges should not be planted until the soil temperature reaches 17°C, which is a requirement for germination, and should also be planted into moisture to ensure successful germination. If soil temperatures are not suitable to allow germination of pigeon peas in line with condition (a), an alternative refuge must be planted in its place within the prescribed period (under (a) above).
- (c) All refuges should preferably be planted into a fallow or rotation field that has not been planted to Bt cotton in the previous season to avoid volunteer and ratoon cotton. See Refuge Management Guide for all unsprayed refuges.
- (d) Once Bollgard 3 cotton begins to flower, the corresponding refuge must not be cultivated and ideally should begin to flower.
- (e) All refuges are to be planted within the farm unit growing Bollgard 3 cotton no more than 2 km from the associated Bollgard 3 cotton field. For any cases where it may not be possible to plant the refuge within 2 km from the associated Bollgard 3, approval must be sought from Monsanto Australia.
- (f) To minimise the possibility of refuge attractiveness being affected by herbicide drift, non-herbicide tolerant refuges should be separated from herbicide tolerant Bollgard 3 cotton crops by a sufficient distance to minimise such drift, but no more than 2 km from the Bollgard 3 cotton.
- (g) To account for possible insecticide drift, the options for the width of refuge crops vary according to spray regime. If any sprayed conventional cotton is grown on the same farm unit, Bollgard 3 refuge crops must be at least 48 metres wide and each refuge area must be a minimum of 2 hectares. If sprayed conventional cotton is not grown on the same farm unit, Bollgard 3 refuge crops must be at least 24 metres wide and each refuge area must be a minimum of 0.5 hectares. Different unsprayed refuge options may be planted in the same

field as a single unit; however, a sprayed conventional cotton refuge must not be planted in a field that is also planted to an unsprayed refuge type unless a sufficient buffer is in place to prevent insecticide drift.

- (h) In all regions, destruction of refuges must only be carried out after Bollgard 3 has been harvested (refer to section 4 Pupae Destruction).
- (i) Refuges for dryland Bollgard 3 cotton crops must be planted in the same row configuration as the Bollgard 3 crop unless the refuge is irrigated. If an irrigated option is utilised for a dryland Bollgard 3 crop, then that refuge may be planted in a solid configuration. Dryland cotton is measured as Green Hectares.

3. CONTROL OF VOLUNTEER AND RATOON COTTON

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

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

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

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

4. PUPAE DESTRUCTION/ TRAP CROPS

Victoria, New South Wales and Southern Queensland

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

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

Option for an alternative pupae destruction management

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

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

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

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

Central Queensland

Crop destruction

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

End of season management of refuges/trap crops

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

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

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

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

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

- * A pigeon pea trap crop is to be planted so that it is attractive (flowering) to *Helicoverpa* spp. after the cotton crop has cut out, and as any survivors from the Bollgard 3 crop emerge. Planting pigeon pea too early (e.g. before November) or too late (e.g. mid December) is not adequate for cotton crops planted during September through to October.
- ** The planting rate is a recommendation based on a minimum of 85% seed germination.

Failed crops - all regions

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

5. SPRAY LIMITATIONS

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

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

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

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

For further background information on the various components of this plan see the 'Bollgard 3 Resistance Management Plan' section earlier in this chapter.

The insert included here is the Resistance Management Plan (RMP) for Central Queensland to Victoria. The RMP for Northern Australia can be found at bollgard3.com.au

PLEASE NOTE that revisions to both southern and northern RMPs are currently awaiting APVMA approval, and the updated versions will be made availabe online.

Managing unsprayed pigeon pea refuges

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

Note that pigeon pea refuges serve a different purpose than pigeon pea trap crops. For more information on trap crops, see page 70.

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

Field selection

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

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

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

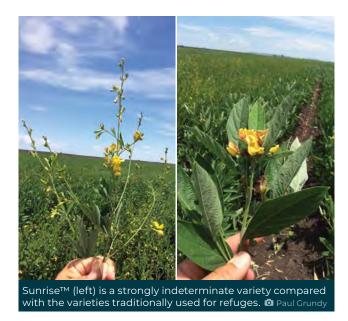
Crop establishment

Timing

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

Sowing and inoculation

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



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

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

Ongoing recycling and saving of seed from undamaged refuges caused an evolutionary shift towards pigeon peas that flower much later (or at times not at all). SunriseTM 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). SunriseTM is strongly indeterminate and has the ability to flower repeatedly, particularly after sustaining insect attack.

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

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

Seed bed preparation and planting

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

Pre-irrigation

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



Crop nutrition

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

Weed management

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

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

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

Irrigation

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

Being a drought-tolerant plant, pigeon pea generally has a lower water requirement than cotton. However, ensure crops do not become moisture stressed as this reduces attractiveness and truncates the flowering period. Sunrise™ is an indeterminate variety, and in some circumstances irrigating too frequently can prolong the vegetative growth stage, delaying the onset of flowering. A good rule of thumb is to plant Sunrise™ on a full profile of moisture and then supply the first in-crop irrigation as the plants begin to develop flower buds. On lighter loamy soil types with lower moisture holding capacity



(<140 mm PAWC) or in hotter climates, two irrigations prior to flowering may be required. Sunrise™ should be exhibiting signs of budding by the time it reaches 50-70 cm in height. After the initiation of buds, Sunrise™ can be irrigated on a similar schedule to the adjacent cotton to prolong flowering and ensure rapid regrowth after insect attack.

Destruction and harvest of pigeon pea refuge crops

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

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

Do not feed crop product or crop residue to livestock. III

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



Integrated Weed Management (IWM)

trategically 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. A key resource that can assist with these decisions, WEEDpak and its associated ID guide, is available from **(#)** cottoninfo.com.au/publications.

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



Another valuable weed ID resource is the Weeds of Australian Cotton app.

🎒 cottoninfo.com.au/ weeds-australian-cotton-app



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.

The Australian herbicide modes of afor herbicides changed from letters to numbers in 2021. Original MoA groups are indicated in this guide as a reference. For more information visit: croplife.org.au/resources/programs/resistance-management/herbicide-moa-alignment



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 emerging weeds, and better conditions for cotton emergence and early vigorous growth. In irrigated crops, weed-free periods of 8-9 weeks from planting provide enough time for cotton to outcompete most later emerging weeds and significantly reduce weed seed production.

Plan weed management to fit with other operations

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

Consider the wider impacts of weeds

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. Some weeds and cotton volunteers/ratoons can 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.

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

TABLE 20: Control of weeds in dry channels									
Active ingredient	MoA group								
Amitrole + ammonium thiocyanate	34(Q)								
Imazapyr	2(B)								
Pendimethalin	3(D)								
Flumioxazin	14(G)								
Diuron	5(C)								
Glyphosate is also registered. Note: This infor as a guide only. Use in dry channels may not for all products with that active. ALWAYS CHE	be a registered use								

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 minimse 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 time use non-chemical weed control, where the impacts of moisture loss are reduced. Alternatively, consider using 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

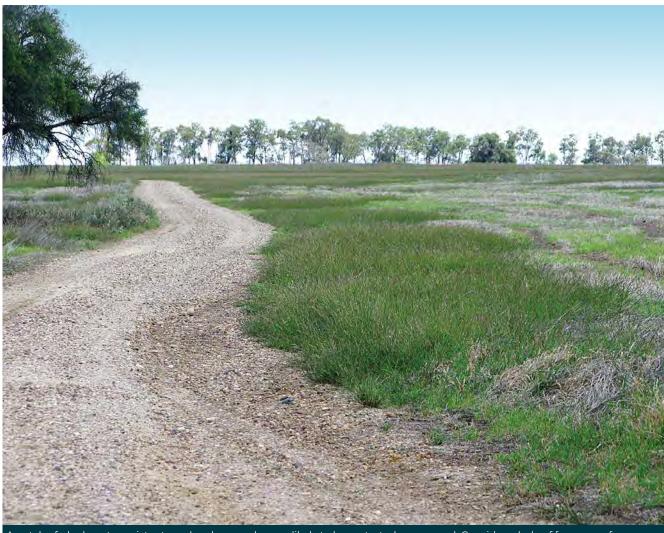
plants. Eradicate any new weeds while they are still in small patches and monitor patches frequently for new emergences. More biosecurity information is available at cottoninfo.com.au/biosecurity

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 should 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.



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

Active ingredient	МоА	Plant-back to cotton	Notes									
Aminopyralid + fluroxypyr	4(I)	9 months*	Plant-back interval on black	cracking clay soils.								
Aminopyralid + picloram + 2,4-D	4(I)	12 months* (northern NSW, Qld)	Under drought conditions co	onduct a bioassay before planting the next crop								
Atrazine	5(C)	6 months	Rates <1.4 kg/ha.									
Attazirie	3(0)	18 months	Rates 1.4 to 3.3 kg/ha.									
Atrazine +	5(C) +	6 months	Rates <3.2 L/ha.									
S-Metolachlor	15(K)	18 months	Rates <3.2 L/ha. On alkaline s	soils, undertake a bioassay or analytical test.								
Chlorsulfuron	2(B)	18 months	Where soil pH is 6.6-7.5 and 7	700 mm of rain has fallen.								
Chiorsaliatori	2(0)	101110111115	If soil pH >7.5, only grow cott	on after growing a test strip.								
		3 months*	Rates <30 g/ha.	Clopyralid plantback times may be extended								
Clopyralid	4(I)	6 months*	Rates 30 to 120 g/ha.	significantly if cotton is to be planted into moderate to heavy stubble loads from crops								
		24 months*	Rates >120 g/ha.	previously treated with clopyralid.								
			Do not replant treated areas otherwise stated on the labe	within 2 years of application of diuron unless ll.								
Diuron	5(C)	Refer to label		to any crop within I year after last spray except grain sorghum) which may be planted in the								
Flumetsulam	2(B)	2 years	For NSW and Qld a minimum of 50 mm and preferably 100 mm rain or momust have fallen over the warm months of the year.									
	7 ((0)	0 months	For zero plant-back for knock	kdown spike rates of 45 g/ha or below.								
Flumioxazin	14(G)	2 months	For residual rates above 210 g/ha.									
lmazamox	2(B)	10 months	Must have 800 mm of rainfall or irrigation.									
lmazamox + imazapyr	2(B)	34 months	Registered for use in Clearfield® (or imidazolinone herbicide tolerant) crops refer to label for varietal constraints.									
l	2(D)	22 months	Dryland cotton.									
Imazethapyr	2(B)	18 months	Irrigated only (providing rain	fall and irrigation exceeds 2000 mm).								
Isoxaflutole	27(H)	7 months	350 mm rainfall (excluding fl planting the subsequent cro	ood/furrow irrigation) between application and p.								
Mefenpyr-diethyl + iodosulfuron- methyl sodium	2(B)	12 months	Rainfall <500 mm may result crops sown in the following s	in extended re-cropping intervals for summer season.								
Metribuzin	5(C)	6 months	Rates <1.5 L/ha. Could be long crops.	ger if there have been long dry periods betwee								
		12 months	Rates >1.5 L/ha.									
Metsulfuron methyl	2(B)	Unknown	Registered for use in wheat,	barley, triticale and as a desiccant in chickpea.								
Metsulfuron-methyl + mefenpyr-diethyl	2(B)	12 months		following application may result in extended nmer crops sown in the following year.								
Picloram + 2,4-D	4(I)	12 months		on land to be cultivated for growing nonths of application. Based on normal rainfall								
Pyroxasulfone	15(K)	5 months		total rainfall between application and planting 0 mm may require extended plant-back period								
Simazine	5(C)	9 months	When up to 2.5 kg/ha are use not be possible for very long	ed. When rates exceed 2.5 kg/ha, plantings ma periods of time afterwards.								
Sulfosulfuron	2(B)	Unknown	Registered for use in wheat a	and triticale.								
Triasulfuron	2(B)	15 months	Soil pH <7.5; 700 mm rainfall back crop.	between application and sowing the plant-								
		18 months	Soil pH 7.6-8.5.									
Tribenuron methyl	2(B)	Unknown	Registered for use in fallows.									
Triclopyr + picloram	4(I)	4 months*	Rates 0.2 L/ha.									
+ aminopyralid	(1)	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.

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 interrow cultivation or spraying. As a tool to prevent survivors setting seed, chipping has been shown to be a very cost effective option.

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.

New weed detection technologies provide an opportunity to use spot spraying (optical sprayers; e.g. See & SprayTM, 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).

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 herbicide registrations and off-label permits:

portal.apvma.gov.au/pubcris and portal.apvma.gov.au/permits

Fallow management

Weed management in the fallow is an important component of a weed management plan. Summer fallows following a Roundup Ready Flex® cotton crop where only glyphosate was used for weed control poses the greatest risk to glyphosate resistance developing. Continued use of glyphosate for controlling summer weeds means that these weeds are only exposed to one mode of herbicide action.

The Herbicide Resistance Management Strategy (HRMS; pages 97-100) recommends at least two non-glyphosate tactics in summer fallows in addition to two non-glyphosate tactics in the cotton crop. Residual herbicides and double knock tactics provide good alternatives in fallows (Table 21). For larger weeds that may be tolerant to herbicides, a strategic cultivation or manual chipping is recommended. Set up field activities such as fertiliser placement and bed cultivators to have adequate soil disturbance to eradicate weeds during these mechanical tasks, and this will lessen the pressure to control weeds with further actions.

In-crop tactics

Pre-plant/at planting

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

Herbicides from Groups 5(C), 14(G), 4(I), 22(L), 9(M), 10(N) and 34(Q) can be used to target weeds that have emerged in the field (see the HRMS diagram on page 95). This can be made more effective when used as a double knock.

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

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

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

Residual herbicide persistence needs to be considered in order to avoid impacts on rotation crops. 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 many herbicides live near the soil surface and require moist soil to flourish. A couple of storms, where the soil surface dries out quickly, won't contribute as much to residue breakdown as a period of rain that moistens the soil surface for days. Refer to product labels for more information. If you suspect that a residual may still be active in the lead up to planting, look for the presence of susceptible weeds in the treated paddock or pot up soil from treated and untreated areas, sow the susceptible crop and compare emergence.

Active ingredient	2,4-D	amine 7	00 g/L	dica	mba 700	g/L	fluro	xypyr 33	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-back¹ (days)	10	14	21	7	7	14	14	14	28	14		

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

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How does it work?

Digestor NP is an advanced soil applied biostimulant formulated with microbial metabolites. Digestor improves soil health by stimulating beneficia microbes within the soil, leading to positive outcomes for the crop.

In the 2024/25 cotton season, Metagen ran over 15 cotton field trials across 750 hectares from QLD's Darling Downs to Hay, NSW. Results showed an average yield increase of 0.56 bales/ha and a return on investment of 3.6 when using Digestor NP.

1800 229 994 metagen.com.au

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

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

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

Where there is a concern, consider planting an alternative crop that is tolerant of the herbicide, or if cotton is to be used, plant the paddock last and pre-irrigate (if it is to be irrigated). Always ensure that best practice is followed in terms of capture and management of runoff water.

Post-emergence

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

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

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

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

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

		Plant-backs from cotton to rotation crops (months)																					
	Cereal grain-crops								Legume crops										Other crops				
Active ingredient		Maize	Millet	Oats	Sorghum	Triticale	Wheat	Adzuki bean	Chickpea	Cowpea	Faba bean	Field pea	Lablab	Lupin	Lucerne	Mungbean	Pigeon pea	Soybean	Canola	Safflower	Linseed	Sunflower	
Diuron	24	24	24	24	24	24	24	24	24	24	24	24	24	24	12	24	24	24	24	24	24	24	
Fluometuron + prometryn	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	
Halosulfuron- methyl	24	2	24	24	2	24	3	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	
Metolachlor	6	0	6	6	Oı	6	6	6	6	6	6	6	6	6	6	6	6	0	6	6	6	0	
Pendimethalin	6	O ²	12	12	12	_	_	_	_	_	_	_	_	_	6	_	_	_	6	_	_	_	
Prometryn	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	
S-Metolachlor	6	0	6	6	O¹	6	6	6	6	6	6	6	6	6	6	6	6	0	6	6	6	0	
Trifloxysulfuron sodium	6	22	22	6	22	22	6	22	18	22	7	22	22	22	22	9	15	15	22	22	22	22	
Trifluralin	12	12	12	12	12	12	12	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FΗ	FH	

²Maize can be resown immediately post-use in a failed crop provided it is sown below treated band of soil. — = no information

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



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 (or products) used is the best choice for the crop and weed. Carefully study the container label before using any herbicide, noting any specific instructions relating to mixing, rates, timing, application and safety.

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

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

See the Spray application chapter for more details.

USEFUL RESOURCES:

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

cottoninfo.com.au/publications/ australian-cotton-production-





A range of weed-related videos can be found on the CottonInfo YouTube channel, including:

- IWM in cotton
- Late season weeds
- Sources of weed seed
- Minimising glyphosate resistance

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



The ultimate super-weed?







Key weeds

hese 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 to 27 list weed species with confirmed resistance to glyphosate, paraquat and 2,4-D respectively).

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 consitute an endorsement of the product.

Broadleaf weeds

The Asteraceae or 'daisy' family includes several key weed species, including the fleabanes, sowthistle, and tridax daisy. Other broadleaf species with confirmed resistance to these products can be found in Tables 25-27.

Fleabanes (Conyza spp.)

Often seen as roadside weeds, fleabanes (Asteraceae family) are prolific wind-dispersed seeders. Seeds have relatively low dormancy, so while they can gerrminate 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.



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 postemergent 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 \Rightarrow Fallow
- Terbuthylazine (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
- 2,4-D (Colex-D®) fb paraquat at 1 (autumn/winter) to 1.69 (spring/summer) L/ha fb 1.6-2 L/ha ⇒ Fallow; 6.16 L/ha OSST ⇒ Fallow (less than 30% weed cover)
- Clopyralid (Lontrel® Advanced) at 150 mL/ha ⇒ Winter cereals
- Paraquat (Gramoxone® 360 Pro) at 4.17 to 6.25 L/100L OSST ⇒ Fallow (less than 30% weed cover).



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 postemergent 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:

- 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
- Terbuthylazine (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®) 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/Millets
- Xtendimax® 2 at 335 m/L to 1.17 L/ha + 1% v/v VapourGrip® Xtra ⇒ Xtendflex® cotton varieties (see label for application restrictions)
- Paraguat + diguat (Spray.seed®) at 2.4 L/ha ⇒ Fallow
- Glufosinate (Biffo®) at 3.75 L/ha ⇒ Fallow and Xtendflex® cotton varieties.



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 Chickpeas
- Terbuthylazine (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 ⇒ Chickpeas
- Flumioxazin (Valor®) at 210 to 280 g/ha ⇒ Fallow; 120 g/ha IBS ⇒ Wheat (not Durum)
- 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)
- Paraquat (Gramoxone® 360 Pro) at 4.17–6.25 L/100L OSST ⇒ Fallow (less than 30% weed cover).





Tridax daisy (Tridax procumbens)

Also known as 'coat buttons', tridax daisy is a perrenial, semi-prostrate herb with 'toothed' leaves and small daisylike flowers on hairy stems about 30 cm long. It is a common environmental weed in the tropics and subtropics 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). Seed typically germinates in autumn, winter and 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
- Fluometuron + prometryn (Cotogard® WG) at 1.4–2.9 kg PRE or 1.7-2.9 kg/ha PSPE or 855 g to 1.4 kg/ha EPOST or 1.1–1.9 kg/ha directed ⇒ Cotton
- 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 ⇒ Chickpeas, 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 ⇒ Chickpeas, Faba beans
- Saflufenacil (Sharpen®) at 17–34 g/ha plus label rate of glyphosate or paraquat ⇒ Fallow
- Saflufenacil + Trifludimoxazin (Voraxor®) at 100 mL/ha plus label rate of glyphosate or paraquat ⇒ Fallow
- Roundup Ready® PL at 660 mL to 1.9 L/ha

 Cotton
- Paraquat (Gramoxone® 360 Pro) at 1.1-1.67 L/ha ⇒ Fallow.



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
- Flumioxazin (Valor®) 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:

- Haloxyfop at 150 mL/ha fb paraquat 1.6–2.4 L/ha
 ⇒ Fallow; 100–150 mL/ha ⇒ Cotton
- Clethodim (Platinum® Xtra 360) at 165–330 mL/ha

 ⇒ Cotton
- Paraquat (Gramoxone® 360 Pro) at 2.08–6.25 L/100L OSST ⇒ Fallow (less than 30% weed cover)
- 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.







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. Ofen 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 preemergent 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®) at 210–280 g/ha ⇒ Fallow.
- Key post-emergent herbicides:
- Haloxyfop at 150 mL/ha fb paraquat 1.6–2.4 L/ha
 ⇒ Fallow
- 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









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 occuring 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
- Flumioxazin (Valor®) at 210–280 g/ha ⇒ Fallow
- Diuron at 1–2 kg/ha PSPE or lay-by ⇒ Cotton.

Key post-emergent herbicides:

- Haloxyfop at 150 mL/ha fb paraquat 1.6-2.4 L/ha ⇒ Fallow
- 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.





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:

- Using tillage to bury seed
- Montoring emergences and control weeds when they are small
- Using 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 postemergent herbicides include:

- Haloxyfop at 150 mL/ha fb paraquat 1.6-2.4 L/ha ⇒
- 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. 111





Herbicide resistance management

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

croplife.org.au/resources/programs/resistancemanagement/herbicide-moa-alignment

eed 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 currently 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, regular mowing of annual bluegrass, Poa annua, in golf courses selected strains for lower grass seed heads, which is essentially a resistance to mechanical control.

By Mid-2025, there were 534 unique cases (species x mode of action) of herbicide resistant weeds recorded globally across 273 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 101 crops in 72 countries.

While historically the Australian cotton industry has had a strong integrated weed management system, the extensive use of herbicide tolerant cotton varieties since 2006 has led to an over-reliance on glyphosate. More than half of the confirmed glyphosate-resistant weed species in Australia listed in Table 25 occur widely in cotton farming systems.

TABLE 25: Glyphosate-resistant weeds i	n Australia
Grasses	First documented
Annual ryegrass (Lolium rigidum)	1996*
Awnless barnyard grass (Echinochloa colona)	2007*
Liverseed grass (Urochloa panicoides)	2008
Windmill grass (Chloris truncata)	2010
Great brome (Bromus diandrus)	2011
Red brome (Bromus rubens)	2014
Sweet summer grass (Brachiaria eruciformis)	2014
Feathertop Rhodes grass (Chloris virgata)	2015*
Winter grass (Poa annua)	2017
Northern barley grass (Hordeum glaucum)	2018
Wild oats (Avena spp.)	2018
Johnson grass (Sorghum halapense)	2019
Broadleaf weeds	
Flaxleaf fleabane (Conyza bonariensis)	2010*
Wild radish (Raphanus raphanistrum)	2010
Sowthistle (Sonchus oleraceus)	2014*
Prickly lettuce (Lactuca serriola)	2014
Tridax daisy (<i>Tridax procumbens</i>)	2016
Tall fleabane (Conyza sumatrensis)	2017
Willow-leaved lettuce (Lactuca saligna)	2017
Capeweed (Arctotheca calendula)	2021

*Resistance documented at more than 100 sites within Australia.

An industry-wide strategy

Experience with conventional 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 enables you to determine which other weed control tactics can be incorporated into your management system by providing guidance on how much extra time they will give you until resistance develops, and demonstrating the effect they will have on the weed seed bank, which is critical to effectively managing resistance.

Non-cropping areas and the HRMS

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

TABLE 26: Species that have developed resistance to paraquat (Group 22/L) in Australia					
Species	Common name	Year	State	Crop	Resistance to other MoAs/herbicides
Hordeum glaucum	Northern barley grass	1983	Vic	Lucerne	Diquat (22/L)
Arctotheca calendula	Capeweed	1984	Vic	Lucerne	Diquat (22/L)
Hordeum leporinum	Barley grass	1988	Vic	Lucerne	Diquat (22/L)
Vulpia bromoides	Silver grass	1990	Vic	Lucerne	Diquat (22/L)
Mitracarpus hirtus	Small square weed	2007	Qld	Mangoes	Diquat (22/L)
Lolium rigidum	Annual ryegrass	2010	SA	Pasture seed	1(A)/9(M) - 2 populations
Gamochaeta pensylvanica	Cudweed	2015	Qld	Tomatoes, sugarcane	
Solanum nigrum	Blackberry nightshade	2015	Qld	Tomatoes, sugarcane	
Eleusine indica	Crowsfoot grass	2015	Qld	Tomatoes, sugarcane	
Conyza bonariensis	Flaxleaf fleabane	2016	NSW	Grape vines	
Conzya sumatrensis	Tall fleabane	2018	Qld	Wheat/fallow	



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Rotate crops and pastures

Crop and pasture rotation is the recipe for diversity

- Use break crops and double break crops, fallow and pasture phases to drive the weed seed bank down.
- In summer cropping systems, use diverse rotations of crops including cereals, pulses, cotton, oilseed crops, millets and fallows.
- Add greater diversity to weed management strategies by adopting herbicide tolerance traits.

Increase crop competition Optimise crop growth

- Adopt at least one competitive strategy, but two is better.
- Target higher plant populations using increased seeding rates, weed-free seed tested for germination, vigour and 1,000 seed weight.
- Aim for even seed distribution and establishment.
- Sow competitive crop types and varieties.
- Improve soil health (fertility) and structure) and crop nutrition, e.g., soil amelioration (if necessary), no-till, stubble retention, nutrient budgeting.
- Utilise early sowing and adopt East/West sowing if practical.
- Reduce row spacing where possible.

Mix and rotate herbicides

Rotating buys you time, mixing buys you shots

- Rotate between herbicide modes of action.
- Mix different modes of action within the same herbicide mix or in consecutive applications.
- Always use full label rates.
- Incorporate multiple modes of action in a double knock e.g., glyphosate/ Group 1/Group 2 knockdown followed by paraguat and Group 14 and pre-emergent herbicide.
- Test weeds for resistance to know what herbicides will and won't work for you.
- In cotton systems, aim to target both grasses and broadleaf weeds using two non-glyphosate tactics in crop and two non-glyphosate tactics during the summer fallow, and always remove any survivors (2 + 2 & no survivors).

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. Avoid antagonistic tank mixes.
- Always use the largest spray droplet feasible that gives the highest efficacy and consider water quality.
- Avoid spraying during inversions (particularly from evening through to early morning), in high temperatures, frost and dew conditions, and when the wind speed is below 5km/h or above 20km/h.

Stop weed seed set

Take no prisoners

- · Aim for 100% control of weeds and diligently monitor for survivors in all post weed control inspections.
- Crop top or pre-harvest spray in crops to manage weedy paddocks.
- Consider hay or silage production, brown manure or long fallow in high-pressure situations.
- Use all appropriate strategies in the pasture phase to reduce the weed seed bank prior to cropping phase.
- Consider shielded spraying, optical spot spraying technology, targeted tillage, inter-row cultivation or chipping.
- Windrow (swath) to collect early shedding weed seed.
- Use two or more different weed control tactics (herbicide or nonherbicide) to control survivors.
- In cotton farming systems, consider late season strategic tillage operations for better overall weed and Helicoverpa pupae control.

Implement harvest weed seed control

Capture weed seed survivors

- Capture weed seed survivors at harvest using weed seed impact mills, chaff lining, chaff tramlining/ decking, chaff carts, narrow windrow burning, or bale direct.
- Ensure optimal harvester set-up.













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

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.

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



Assessing your own risk

For a more detailed assessment of the glyphosate resistance risks for individual paddocks, use Qld DPI's Online Glyphosate Resistance Toolkit



cottoninfo.com.au/glyphosate-resistance-toolkit

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

The Barnyard Grass Understanding and Management (BYGUM) tool enables the resistance risk from summer weed control to be considered in the context of economics and seed bank management.



This weed management scenario testing tool combines biological, agronomic and economic factors to examine the economics of current summer grass management strategies and compare with new tactics.

cottoninfo.com.au/barnyard-grass-understanding-and-management-bygum

higher application rate is required to kill these individuals in subsequent years this indicates non-target site resistance is present.

Many of the symptoms of herbicide resistance can also be explained by other causes of spray failure. Regularly maintain and calibrate spray equipment, spray under appropriate conditions and keep good records to ensure maximum spray efficacy.

Resistant weed seeds can also be transported into 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.



A demonstration of weed resistance

youtu.be/y7Jj1laiSLk



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. 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.
- 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 store or 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:

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

L Dr John Broster

Charles Sturt University (Seed test only)

Herbicide Resistance Testing Service, PO Box 588, Wagga Wagga NSW 2678

62 (02) 6933 4001

ibroster@csu.edu.au



All dilliddi Tyegrass sai vivor. Maelie Roetz, cottoliillio/NSW Brike

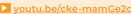
How do I manage resistant weeds?

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.



Minimising glyphosate resistance







Information on resistant weeds has been partially sourced from I.Heap, The International Survey of Herbicide Resistant Weeds, June 2025. Visit the international herbicide-resistant weed database at: www.weedscience.org

access to the paddock and hence there was no effective

treatment at an early growth stage. 🖸 T.Cook, NSW DPIRD

USEFUL RESOURCE:



Weedsmart

weedsmart.org.au







TABLE 28: Resistance risk for herbicides used in cotton						
Herbicide active ingredient	Pre plant	At plant	Post plant	Mode of action	Years to resistance	Resistance status
Amitrole + paraquat	Υ	N	N	34(Q) + 22(L)	>15	Rare
Amitrole + ammonium thiocyanate	Υ	N	N	34(Q)	>15	Rare
S-Metolachlor or Metolachlor	Υ	Υ	Υ1	15(K)	>15	Rare
Saflufenacil	Υ	N	N	14(G)	>15	Rare
Glufosinate-ammonium	Υ	N	N ²	10(N)	10-15	Rare
Dicamba ³	Υ	N	N ²	4(1)	10-15	Rare
Fluroxypyr	Υ	N	N	4(1)	10-15	Rare
Fluroxypyr+ aminopyralid	Υ	N	N	4(1)	10-15	Rare
Diuron	Υ	Υ	Υ	5(C)	10-15	Rare
Fluometuron + prometryn	Υ	Υ	Υ	5(C)	10-15	Rare
Prometryn	Υ	Υ	Υ	5(C)	10-15	Rare
Triclopyr	Υ	N	N	4(1)	10+	Rare
Triclopyr + picloram	Υ	N	N	4(1)	10+	Rare
Triclopyr + picloram + aminopyralid	Υ	N	N	4(1)	10+	Rare
Carfentrazone-ethyl	Υ	N	N	14(G)	10	Rare
Flumioxazin ⁴	Υ	N	Υ	14(G)	10	Rare
Oxyfluorfen	Υ	N	N	14(G)	10	Rare
Isoxaflutole ³	Υ	N	N	27(H)	10	Rare
Paraquat	Υ	Υ	Υ	22(L)	>15	Occasional
Paraquat + diquat	Υ	Υ	N	22(L)	>15	Occasional
2,4-D ³	Υ	N	N	4(1)	10-15	Occasional
Pendimethalin	Υ	Υ	Y ⁵	3(D)	10-15	Occasional
Trifluralin	Υ	Υ	N	3(D)	10-15	Occasional
Bromoxynil	Υ	N	N	5(C)	10-15	Occasional
Glyphosate ⁶	Υ	Υ	Υ	9(M)	>12	Widespread
Butroxydim	N	N	Υ	1(A)	6-8	Widespread
Clethodim	N	N	Υ	1(A)	6-8	Widespread
Fluazifop-p	N	N	Υ	1(A)	6-8	Widespread
Haloxyfop	N	N	Υ	1(A)	6-8	Widespread
Propaquizafop	N	N	Υ	1(A)	6-8	Widespread
Halosulfuron-methyl	N	N	Υ	2(B)	4	Widespread
Trifloxysulfuron sodium	N	N	Υ	2(B)	4	Widespread

Lowest resistance risk

Moderate resistance risk

Highest resistance risk

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

Always read the label for detailed use patterns and application rates.

- Dual Gold® formulation.
 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 24 for plant-back periods.

Herbicide Reistance Management Strategy 2025/26

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 broadleafs every 2 years, and allow NO SURVIVORS to set seed

Fallow

Strategic cultivation Double knock Optical sprayers Patch management Cover crops

Fallow herbicides

Group 9/M

Group 5/C bromoxynil, terbuthylazine

Group 14/G flumioxazin, pyraflufen, saflufenacil

Group 27/H

Group 22/L paraquat, diqu

Group 22/L+34/Q paraquat+amitrole

Group 10/N

Group 4/l 2,4-D, dicamba, fluroxypy

Rotation Crops³

Crop competition
Rotate modes of action
Plant back restrictions
Cover crops

Pre/at plant

Cultivation
Double knoc

Knockdowns

Group 5/C bromoxyni

pyraflufen, flumioxazin, saflufenacil, oxyflurofen

Group 4/I

dicamba, fluroxp

Group 22/L

Group 22-L/34-Q

Group 10/N

Group 9/M glyphosate

Residuals³

Group 5/C

orometryn, terbuthylazine, diuron

Group 3/D

pendimethalin, trifluralin

Group 15/K

S-metolachlor, metolachlor

Post-emergent

In-crop cultivation Manual chipping Rogueing Spot spraying

Post-emergent OTT

Group 1/A²

sethoxydim, clethodim, butroxydim, haloxyfop, propaquizafop

Group 15/K⁴ S-metolachlor

Lay-by, directed or shielded spray

Group 5/C prometryn, terbuthylazine, diuron

pendimethalii Group 14/G⁴

Group 15/K⁴

Maturing crops

Cultivation Chipping Rogueing Spot spraying

Aim for 100% control of survivors

Target survivors — aim for 100% control

In fallow survivor control

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

Optical sprayer

Pre-plant survivor control

Cultivation, chipping or

flumioxazin pyraflufen-ethyl (added to complementary product carfentrazone-ethyl bromovynil

Post-emergent

Inter-row cultivation, chipping or spot sprayin

Post-harvest

Root cutting for crop destruction Cultivation, chipping or spot spraying carfentrazone-ethyl, pyraflufen-ethyl bromoxynil fluroxypyr

COMMENTS

$\cdot\,$ 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.
- Reep 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:

- 1. APVMA permits: 88120, 90223 for fallow use.
- 2. Group 1/A herbicides already exhibit widespread resistance. Controlling survivors is esssential.
- 3. Refer to label for plant-back restrictions to following crop.
- 4. 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. Take 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 ensure that no survivors set seed. Effective postspray 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 plantback 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 92-95 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 mamangement in cotton is available from:

cottoninfo.com.au or 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- Iow	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, These registered products are: Roundup Ready® herbicide with PLANTSHIELD®, Roundup Ready PL herbicide with Plantshield Technology, XtendiMax® 2 herbicide with VapourGrip® Technology (XtendiMax 2), Roundup Xtend® 2 herbicide with VapourGrip Technology and Nufarm BIFFO® herbicide.

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

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

 Completion of the XtendFlex® cotton spray applicator training when applying XtendiMax® 2 herbicide in XtendFlex® cotton.



XtendFlex® guides are downloadable from

crop.bayer.com.au/ products/biotechnologytraits/xtendflex-cotton



Reporting suspected resistance

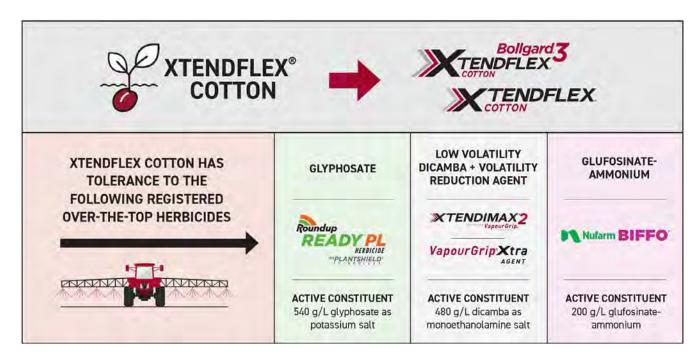
Naturally occurring populations of some weeds may possess biotypes with resistance to glyphosate, dicamba or glufosinate. Growers should be aware of this prior to using any of the registered over the top (OTT) herbicides in XtendFlex® cotton and should aim to decrease the development and spread of resistant 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 quarantee that resistance will not occur.

Understanding your herbicide resistance risk

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

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



On-farm factors that change resistance risks Factors that decrease resistance risk:

- Monitoring and preventing herbicide weed control escapes from setting seed.
- Planning and implementing an IWM strategy to reduce the weed seed-bank.
- Strategic use of alternative knockdown herbicides and tillage in fallows prior to sowing.
- Use of alternate herbicide modes of action including residual herbicides in crops and fallows.
- Use of a double-knock glyphosate followed by tillage or an appropriate double-knock product such as paraquat (Group 10) based products at effective rates.
- Applying stewardship plans when growing herbicide tolerant crops.
- Farm hygiene to prevent importing and moving herbicide resistant weed seeds.

Factors that increase resistance risk:

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

Resistance management principles for XtendFlex® cotton

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

Key IWM principles for XtendFlex® cotton are:

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

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

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

Bayer strongly recommends that growers consult an agronomist when designing an IWM strategy for their property. For further resources and information see weedsmart.org.au.



Resources on weed management and minimising the risk of resistance can be found at

weedsmart.org.au



Monitoring herbicide efficacy

All growers or agronomists should inspect fields between 14 and 28 days after spraying with glyphosate, dicamba or glufosinate to monitor the effectiveness of the herbicide application. During an inspection, any surviving weeds that are normally susceptible to the herbicide/s used should be identified. The outcomes of any inspection and any remedial application used should be recorded. Any case of suspected resistance should be reported immediately to Bayer (Nufarm for glufosinate) for further investigation.

Growing Roundup Ready Flex® cotton?

If you are planning to grow Roundup Ready Flex® cotton in the 2025/26 cotton season, please refer to the Roundup Ready Flex® Weed Resistance Management Plan (see link below) or refer to the 2025/26 Bayer Technology User Agreement document.

Roundup Ready Flex® Weed RMP:

crop.bayer.com.au/-/media/bcs-inter/ws_australia/use-our-products/product-resources/cotton-traits/rrflex-cotton-weed-rmp-m0181.pdf



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

USEFUL RESOURCE:

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







TABLE 29: Key principles for	weed control in XtendFlex® cotton crops
PRE-PLANT KNOCKDOWN	Always start clean by planting into a weed-free field using either tillage or an effective herbicide application.
	Know your field history in order to identify whether any volunteer cotton present is XtendFlex® cotton.
	Consider using approved tank mixes when applying any of the OTT registered products in XtendFlex® cotton (do not mix any ammonium containing products e.g. ammonium sulfate, glufosinate-ammonium or glyhosate 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 pattens 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 1.9 L/ha for Roundup Ready® PL Herbicide with PLANTSHIELD® Technology.
	This application can be used to control late season weeds and improve harvest efficiency.
	Compatible with commonly used defoliants (see Roundup Ready® Herbicide with PLANTSHIELD® and Roundup Ready® PL with PLANTSHIELD® Technology labels).
	Do not use on crops intended for planting seed production.

Management of volunteer and ratoon cotton

Controlling unwanted cotton is an essential part of good integrated pest and disease management and general farm hygiene. Volunteer (established unintentionally) and ratoon (regrown from surviving root stock) 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 ration 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 accidently 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. Volunters 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 minimse 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.

O Lewis Wilson

Inadequate end of season crop destruction can lead to ratoon cotton.

Murray Sharman, Old DPI

Cultivation and herbicides are the most common methods of volunteer cotton control. Both require the plants to have germinated and emerged (following preirrigation 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 raingrown farming systems).

Seedling volunteers can also be controlled reasonably well with less invasive physical removal such as Kelly chains, which break the young stems and can be used relatively close to planting. In-crop cultivation with sweeps is also effective on small volunteer cotton plants.

Most herbicides work best on young cotton seedlings (up to 4 nodes). Larger plants are usually much harder to kill, even when using double knocks.

Tables 30 and 31 provide a list of herbicide actives registered for volunteer control, including established plants. Note that glufosinate will not be effective in controlling XtendFlex® cotton volunteers.

Refer to product labels for specific use information as not all products containing these actives have volunteer cotton on the label. Use different modes of action than utilised in-crop where possible, to help prevent resistance in other weed species that may be present, ensure any plant-back intervals fit with your proposed planting schedule, and take precautions to minimise drift.

Excellent spray coverage 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). Fluroxypyr (Comet®) can be used on larger (15-30 nodes) plants (see Table 31). Where isolated plants establish in fallows or non-field areas such as along roadsides and fences, physical removal by chipping can be very effective.



Rogue cotton plants in the farming community

youtu.be/CJP14_swggE



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.

In minimum-till situations, thorough crop destruction can be particularly challenging and care must be taken to ensure regrowth is prevented.





Effective end of season crop destruction

youtu.be/rO-JAX7s7jg

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.

Ratoon cotton plants that have survived crop destruction can be difficult to control, having developed a large root system and small leaf surface area. Three herbicide options, registered for both optical booms and broadacre application, are available for the control of large volunteer cotton or ratoon cotton amongst stubble or in fallow (see Table 31). ALWAYS FOLLOW LABEL DIRECTIONS.

USEFUL RESOURCES:









Australian Cotton Production Manual: Chapter 23, Postharvest pest and stubble management

💮 <u>cottoninfo.com.au/</u> publications/australian-cotton production-manual



TABLE 30: Herbicides for control of volunteer cotton			
Active ingredient	MoA group	Comments (always refer to product labels)	
Amitrole + paraquat*	34(Q) + 22(L)	Can be applied after glyphosate (as a double knock). See label for spot spray rates.	
Bromoxynil	5(C)	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(G)	Apply minimum spray volume of 80 L/ha to ensure effective coverage. To broaden weed spectrum may be tank mixed with the recommended rate of a knockdown herbicide. See label for adjuvant recommendation.	
Paraquat + diquat*	22(L)	Apply in 50-100 L water/ha. Avoid spraying under hot dry conditions. For best results, spray in the evenings or in humid conditions.	
Flumetsulam	2(B)	May be banded (>40%) over the row or broadcast. Minimum spray volume 150 L/ha for optimum results.	
Flumioxazin	14(G)	Do not apply post-sowing pre-emergent. Do not sow crops for at least one hour after application. Can be tank mixed with glyphosate to control other weeds that may be present See label for adjuvant details.	
Glufosinate- ammonium**	10(N)	Good coverage is essential. Do not apply more than three applications per season. Best results are achieved when applied under warm humid conditions.	
Metribuzin	5(C)	Registered for control of volunteer cotton in pigeon pea. See label for critical comments.	
Fluroxypyr	4(I)	Summer fallow.	
Saflufenacil	14(G)	Do not apply post-sowing pre-emergent. Always apply with adjuvant or high quality methylated seed oil. See label for mandatory no-spray zone and spraying rates.	
Pyraflufen-ethyl	14(G)	Prior to sowing summer crop or starting a summer fallow. Apply by ground rig only. Good spray coverage is essential. Do not sow crops for at least 1 hour after application.	

paraquat and diquat are currently under APVMA review, with a final decision expected late in 2025. If reduced rates are recommended, this control option may be less effective.

For the latest registration details, refer to 🌐 portal.apvma.gov.au/pubcris

TABLE 31: Herbicides for control of large (15 to 30 node) volunteer cotton and ratoon cotton in fallow

Active ingredient	Rates	Comments
	1 L/ha followed by 1 L/ha OR	For control of large cotton plants or ratoon cotton a sequential application of Comet followed by Comet is required for maximum control. Ensure sufficient leaf regrowth has occurred on the ratoon cotton to maximise chemical uptake.
Fluroxypyr 4(I)	1 L/ha followed by Shirquat® (22/L) 2 L/ha OR	For control of large cotton plants or ratoon cotton a sequential application of Comet followed by Shirquat is required for maximum control. The sequential application interval should be 7-14 days. Ensure sufficient leaf regrowth has occurred on the ratoon cotton to maximise chemical uptake.
	1 L/ha + 1 L/ha Amicide Advance® (4/I) 700/ha	For a single pass operation apply Comet + Amicide Advance 700. Ensure sufficient leaf regrowth has occurred on the ratoon cotton to maximise chemical uptake.

Refer to the Comet * 400 registration label for further details on control rates for optical spot spray technologies. Note that paraquat is currently under review by the APVMA, and if reduced rates are recommended, a double knock with this product may not be as effective. Note that control rates are based on L/ha for broadacre application and L/100L (spot spraying rate) for optical sprayers. For the latest registration details, refer to #portal.apvma.gov.au/pubcris

^{**}Note that volunteers with XtendFlex® traits will be tolerant to glufosinate-ammonium; adjust your IWM plan accordingly.



Integrated Disease Management (IDM)

plant disease occurs when there is an interaction between a plant host, a pathogen, and the environment. Effective IDM involves a range of control strategies that should be implemented regardless of whether a disease problem is evident, as the absence of visible symptoms does not necessarily indicate an absence of disease. Effective management can also delay the establishment of diseases in a cropping system.

Disease management in cotton focuses on improving the resilience of the farming system and preventing pathogen spread as complete eradication is usually not possible. Many strategies may help to reduce the disease burden for subsequent crops and minimise the risk of diseases spreading within and between farms and regions.

IDM at planting

Optimal seed bed conditions

- Check field history for disease problems. Avoid back-toback cotton and rotations that promote cotton diseases.
- Prepare firm, high beds to optimise establishment and seedling vigour.
- To avoid root damage, don't place 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 if seedling disease is likely to be an issue, aim to plant when soil temperatures are at least 16°C (if possible) 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

A number of varieties have some resistance to verticillium or fusarium wilts (indicated by higher V rank and F rank respectively). Consider the disease status of each field when selecting varieties. Also consider a 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.

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 rain-fed cotton compared to irrigated cotton because consistent moisture from irrigation can create a more favourable environment, while the variable moisture in rain-fed 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 foliar diseases that are associated with potassium deficiency (such as alternaria, cercospora and stemphyllium leaf spots) can be exacerbated by dry conditions that restrict the plant's ability to access sufficient nutrients.

Macrophomina phaseolina, the fungus that causes charcoal rot in cotton, thrives in dry, hot conditions and can cause significant damage. Symptoms include wilting, defoliation, and root rot. The fungus survives in the soil as microsclerotia that can persist for years, and thrives under dry conditions with temperatures between 35 and 39°C. 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 casued 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 33 (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.





Monitoring for disease

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

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 formal disease surveys (in addition to general monitoring) that record the incidence and severity of disease allows you to make a comparison over time and adjust your management strategies accordingly.

If a disease is suspected, sample plants both with and without symptoms for submission to cotton pathologists. If unsure, contact your nearest CottonInfo REO (see inside back cover) for more information or to determine the appropriate pathologist and process for submitting a sample. Be aware that plants infected with verticillium or fusarium wilt may display minimal or no external symptoms, particularly in varieties with high disease rankings - you will need to cut plants in several places along the stem and look for discolouration.

This chapter includes examples of the key diseases in cotton and their common symptoms. Note that symptoms of nutrient deficienct/toxicity, herbicide residues or environmental impacts may be misinterpreted for disease (see Table 1 on page 7 for examples of potential biotic and abiotic causes of plant symptoms).

Implement your own in-season surveys

Conduct formal disease surveys early in the season (within 3 to 4 weeks of planting), and again late in the season (after the final irrigation but before defoliation) to help assess pathogen and disease pressure during critical crop stages. In early season surveys, also measure plant establishment by counting the number of plants in one metre of row and comparing with number of seeds planted per metre. Each survey should consist of two transects located at opposite sides of the field 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).

To avoid edge effects, maintain a minimum distance of 50 meters from field edges, head ditches, and tail drains, and use GPS to mark the start of each transect for consistency across seasons. Use a step-point sampling method, moving 10 meters along the row and then 10 rows across between each sampling point. Assess plants directly in front of you, regardless of condition, to ensure the sample remains unbiased and representative. At each sampling point, record disease incidence by counting the number of affected versus healthy plants, and estimate disease severity. Ensure that information on the environmental conditions (such as temperatures, humidity, rainfall, and stubble loads) are included in your record keeping, and that your recording systems allows for easy comparison within and between seasons.

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

The CottonInfo video on *Collecting samples for disease testing* features the Queensland Department of Primary Industries pathology team demonstrating how to collect plant samples. > youtu.be/4mCk2883IOO





Please note: When collecting leaves for foliar disease identification, it is best to place individual leaves between paper towel to absorb moisture, before placing into a paper bag. If possible, before posting, open up the paper towels and dry the leaves in an air conditioned room. When dry, place between a fresh paper towel for postage. This will help reduce the risk of leaves becoming mouldy during transit. When leaves arrive mouldy it is too difficult to isolate and determine the cause of leaf spots. 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.

Contact one of your state pathologists BEFORE sending the sample to ensure there is someone available to receive it while it is still fresh.





			Cotton disease					
Family	Scientific Name	Common Name	Alternaria leaf spot	Black root rot	Cotton bunchy top	Fusarium wilt	Tobacco streak virus	Verticillium
Malvaceae	Abutilon theophrasti	Velvetleaf	~-	<i>V</i>	<i>V</i>		- v	- V
Maivaceae	Anoda cristata	Anoda weed	V		V			,
		Cotton volunteers/ratoons	V	V	<i>'</i>		V	
	Gossypium hirsutum Hibiscus trionum	Bladder ketmia	V	V	V	V	V	•
			•		V	•		7
	Malva parviflora	Small flowered mallow						
	Malvastrum americanum	Spiked malvastrum			V			
	Sida rhombifolia	Paddy's lucerne			V			
Aizoaceae	Trianthema portulacastrum	Black pigweed			'			
Amaranthaceae	Alternanthera nodiflora	Common joyweed						4
	Amaranthus macrocarpus	Dwarf amaranth				V		V
	Amaranthus retroflexus	Redroot amaranth		/				V
	Gomphrena celosioides	Gomphrena weed						ı
Asteraceae	Bidens pilosa	Cobler's pegs					V	4
	Carthamus lanatus	Saffron thistle						ı
	Centaurea solstitialis	St Barnaby's thistle						
	Helianthis annuus	Sunflower volunteers					V	
	Parthenium hysterophorus	Parthenium weed					V	
	Silybum marianum	Variegated thistle						
	Sonchus oleraceus	Common sowthistle		V			V	
	Verbesina encelioides	Golden crownbeard		<i>V</i>			V	
		Bathurst burr		•			•	
	Xanthium spinosum						V	'
	Xanthium occidentale	Noogoora burr					, v	
Brassicaceae	Brassica spp.	Wild turnip						•
	Capsella bursa-pastoris	Shepherd's purse		V				•
	Rapistrum rugosum	Turnip weed						١
Chenopodiaceae	Rhagodia nutans	Climbing saltbush						١
Convolvulaceae	Convolvulus erubescens	Australian bindweed						•
	Ipomoea lonchophylla	Cowvine, peach vine						•
	Ipomoea plebeia	Bellvine		V		V		(
Cucurbitaceae	Citrullus lanatus	Wild melon				✓		
Euphorbiaceae	Chamaesyce hirta	Asthma plant			V			
	Euphorbia drummondii	Caper spurge						
- -abaceae	Medicago polymorpha	Burr medic		V	V			
	Medicago sativa	Lucerne volunteers		V				
	Medicago spp.	Medic		V				
	Neptunia gracilis	Native sensitive weed						
	Sesbania cannabina	Sesbania pea				V		
amiaceae	Lamium amplexicaule	Dead nettle		~	V			
Larriaceae	Salvia reflexa	Mintweed			_			
Martyniacoao	Proboscidea louisianica	Devil's claw						
Martyniaceae		Black bindweed						
Polygonaceae	Fallopia convolvulus							
D	Rumex crispus	Curled dock						
Portualacaceae	Portulaca oleracea	Red pigweed						•
Solanaceae	Datura ferox	Fierce thornapple		V			V	•
	Datura stramonium	Common thornapple		V			V	•
	Nicotiana glauca	Wild tobacco		V				•
	Physalis ixocarpa	Groundcherry						•
	Physalis minima	Chinese lantern					/	•
	Physalis virginiana	Perennial groundcherry						•
	Solanum nigrum	Blackberry nightshade					V	١
Verbenaceae	Verbena bonariensis	Purpletop						ı
	Verbena officinalis	Common verbena						

blank = unknown



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Irrigation and scheduling

Early season, the temperature of irrigation water is considerably lower than soil temperatures, so preirrigating fields before planting can avoid cold shock and provide better conditions for seedling emergence, provided the hills or beds sub-up adequately. Irrigations late in the season to extend plant maturity can result in a higher incidence of verticillium wilt.

Irrigation cools the soil, enhancing pathogen survival and increasing infection rates. Moisture can also be an important component for 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 also follow the same order.

Agronomic management

High planting rates can compensate for seedling mortality, but a dense canopy favours development of a range of leaf spots and boll rots. Optimise nutrition and 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 cotton nutrition.



IDM post harvest

Control alternative hosts and volunteers

Having a host free period prevents build-up of pathogen inoculum and carryover of disease from one season to the next. Pathogens that cause verticillium wilt, fusarium wilt, tobacco streak virus, alternaria leaf spot, some rots, and cotton bunchy top can also infect common weeds found in cotton growing areas (see examples in Table 32). 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 and 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 all survive in cotton and some rotation crop residues. Carefully manage crop residues to minimise carryover of pathogens into subsequent crops.

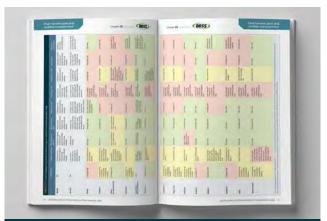
If fusarium wilt is known to be present, slash residues and retain them on the surface for 60-120 days if possible (or at least one month) prior to incorporating, in order to disinfect the stalks through exposure to the UV component of sunlight. Bleaching of stems from pale brown to grey is a good indication of adequate UV exposure.

In all other circumstances (including the presence of verticillium wilt and other diseases), incorporate crop residues as soon as possible after harvest to promote faster decomposition.

Use crop rotations to help manage disease

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

The pathogen that causes verticillium wilt has a very large host range (see Table 32), and most legume crops host the black root rot and fusarium wilt pathogens. Some alternative crops such as vetch, canola and mustards can provide a biofumigation effect against black root rot under specific management regimes. Consider all pathogens present when planning crop rotations.



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.



Australian trial work with cotton has shown crop rotations influence the abundance and diversity of soil microbial populations. After two years of rotation, verticillium wilt disease levels were lowest in cotton following bare fallow compared to maize, sorghum or continuous cotton. However, soil analysis indicated the fallow also had the lowest diversity of soil microbial communities which is not good for long term soil health. Disease incidence was significantly lower following maize and sorghum compared to continuous cotton, and these crops are a good rotation option.

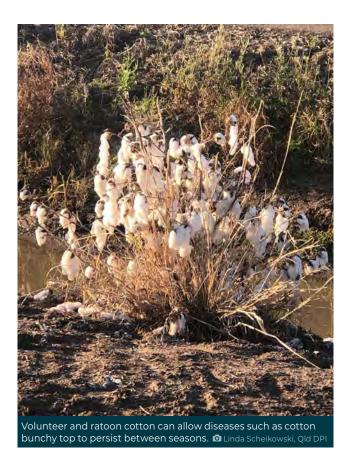
Cotton is highly dependent on arbuscular mycorrhizal fungi (AMF) which form beneficial associations with plant roots and can act as agents in nutrient exchange. Bare fallow for more than 3 to 4 seasons or removal of topsoil (especially more than 40 cm), such as in the development of a bankless channel system or laser level cuts, may result in a severe lack of AMF. A cereal or green-manure crop may restore sufficient mycorrhizal fungi.

IDM all year round

Manage insect vectors

The risk and severity of diseases caused by viruses can be minimised by managing the vector that carries the pathogen. Cotton bunchy top can be transmitted by aphids feeding on infected plants before migrating to healthy plants. Transmission of tobaccvo streak virus to plants relies on the virus from infected pollen entering plant cells through the feeding injury caused by thrips. Several exotic diseases also have insect vectors (see the Biosecurity chapter for more details). Consider integrated pest management principles and resistance risks when managing vectors.

Viruses can only survive in living plants. Control of cotton ratoons and volunteers throughout winter will reduce pathogen levels and also lower vector insect populations, drastically reducing disease risk.



Come Clean. Go Clean. A GUIDE TO EFFECTIVE WASH DOWN OF VEHICLES AND MACHINERY

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

- ✓ On a clean wash down pad with a hard surface
- ✓ Located away from production areas
 ✓ Where wash off contaminants can be



 Use a sponge or spray to cover all surfaces with an agricultural detergent Leave the detergent to work for 10 minutes* before rinsing, making before rinsing, making sure to remove any remaining soil or plant material



REMEMBER

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



RINSE

- Rinse off vehicle, machine and/or other
- Use high pressure water to remove mud and debris from the wash down area so it is clean for the next person



This 'Come Clean. Go Clean.' poster can be downloaded from the Biosecurity page of the CottonInfo website.

On-farm biosecurity and hygiene

Minimise the risk of moving pathogens on or off your farm, from field to field or farm to farm by considering vehicle and machinery movements within the farm. Have a strategy for ensuring clean movement of vehicles and machinery onto and around the farm. Ensure contractor equipment has been thoroughly cleaned before entering your fields. Minimise spillage and loss when transporting modules, hulls, cotton seed or gin trash.

Ensure all staff, contractors and visitors are aware of the requirements and your commitment to 'Come Clean. Go Clean.' before entering the farm.

A documented biosecurity plan for each cotton producing farm is highly recommended to identify biosecurity risks and management options for disease outbreaks.

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. youtu.be/gR8hf8-hYOA





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 107).

KEY DISEASES	Page
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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. rouxige. 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 'Postharvest 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.



Bolls affected by *Diplodia* spp. are covered in 'sooty' black spores. ② Linda Smith, Qld DPI

Anthracnose boll rot

Only occasionally seen in Queensland crops, anthracnose boll rot (caused by *Colletotrichum* spp.) 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.





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 scletotinia 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, Old 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*.



Sclerotia and hyphae 🖸 Tegan Brownie, Nutrien Ag Solutions

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.



Girdling of cotton stem 🖸 Dinesh Kafle, Qld DPI



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 ration cotton. Rations 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 ration 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.

Other natural field hosts of CBT include: velvetleaf, spurred anoda, asthma plant, Sturt's desert rose, rosella, bladder ketmia, deadnettle, marshmallow weed, prickly malvastrum, burr medic, Paddy's lucerne, and black pigweed (see Table 32). Rose cotton bush (*Gossypium australe*) and chickpea were also hosts in field or pot experiments, and the virus may have an even wider host range, including other non-Malvaceae species.

IDM tactics

Step 1. Avoid the problem – 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

🖸 Linda Smith, Qld DPI



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.



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. Send any suspect samples to Dr Linda Smith (Qld DPI). See page 107 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 110) 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
- Managing fusarium wilt youtu.be/Cygy6XiRDcw
- Post-harvest management of fusarium wilt



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



Leaf spots

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

Cercospora leaf spot: Cercospora spp.

Target spot: Corynespora spp.

Stemphylium leaf spot: *Stemphylium spp.* **Ramularia leaf spot:** *Ramulariopsis spp.*

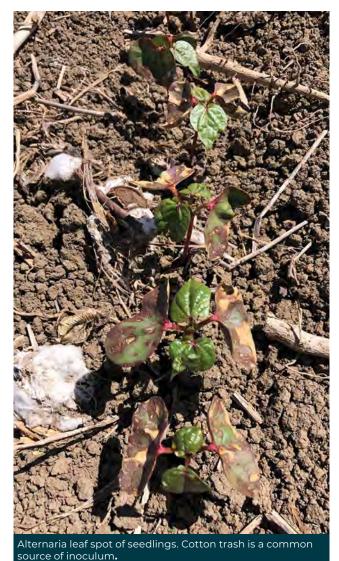
ALS is the most common cause of leaf spots in cotton in cooler regions. As you move further north other leaf spot fungi and disease complexes occur due to the warmer and/or more humid climate.

Ramularia leaf spot of cotton is a foliar disorder caused by *Ramulariopsis* spp. (including *R. gossypii* and *R. pseudoglycines*) that may be referred to in overseas literature as grey mildew, frosty blight, false mildew or areolate mildew. Preferring tropical conditions, it was recently found in the Northern Territory and Western Australia, although according to historical records, it had previously been present in Queensland also. In May 2025, it was also confirmed as present in several fields in central Queensland.

Symptoms

Cotton plants are prone to leaf spot infections at all growing stages, but are most susceptible as seedlings and late in the season as the crop begins cut-out. Symptoms start as pinhead spots that develop into necrotic lesions surrounded by a purple halo. They can be seen on cotyledons, young to mature leaves, squares and bolls. Under favourable conditions, lesions continue to enlarge and join to form irregular shapes. Severe infection may result in leaf desiccation.





While ramularia leaf spot also begins as spots, it produces distinctive fungal 'mildew' growth and can be easily identified by the presence of white to greyish spores on the underside of the leaf (powdery growth may also occur on the upper surface), a symptom not associated with any other commonly found cotton disease. Ramularia infections generally start in the more humid lower canopy before spreading to upper leaves and potentially affecting the entire plant. Infected leaves dry up from margin and cup inward before turning yellowish brown and falling off prematurely. This disease can have ongoing cycles

Favoured by

throughout a season.

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

Ramularia sp. requires temperatures of 20–30°C with prolonged high humidity (>80%) and frequent rain for infection and disease development. However, cool weather and prolonged dewy periods are also a trigger. Close planting or excessive nitrogen applications can increase disease severity.



Host range

Leaf spots are widely distributed and while they generally have a wide host range, some strains show host specificity.

Perennial and self-sown cotton plants can harbour these pathogens. The primary method of infection is through spores from infected debris or volunteer and ratoon cotton. Spread may occur from infected leaves, but the fungi can also be moved by wind, rain splash, irrigation water and farm equipment.

Unlike other mildews such as powdery mildew of cucurbits, *Ramulariopsis* sp. can grow without the presence of a living host. Because of this ability to live on non-living organic residues, the pathogen can persist on decomposing plant material between seasons.

IDM tactics

- Avoid back-to-back cotton (plant a break crop).
- Avoid planting into fields containing unincorporated infected residues from a previous crop.
- Provide balanced crop nutrition (especially potassium) and avoid excessive application of nitrogen.
- Consider planting densities and spacings that encourage air flow and manage crop to avoid extremely rank growth.
- Apply registered or permitted foliar fungicides according to label.
- Ensure complete crop destruction at season's end incorporate crop residues as soon as possible after harvest.
- Control alternative weed hosts, volunteer and ration cotton plants before, during and post season.







USEFUL RESOURCE:

A CottonInfo factsheet on ramularia can be found at www.cottoninfo.com.au/publications/managing-ramularia-leaf-spot-rls-cotton-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 dihystera*), and stubby-root nematode (*Paratrichodorus minor*) have been detected in very low populations in cotton fields across Queensland and New South Wales, however they do not currently pose any significant threat as high numbers are required to cause substantial harm.

Symptoms

Reniform nematodes produce minimal symptoms on the roots, while root-knot nematodes typically cause galling. Above ground symptoms of nematodes (including stunted growth, wilting, and leaf yellowing) may resemble water and nutrient stress. Nematodes typically reduce crop productivity rather than causing complete plant death. Populations can be quite uniform in their distribution across a field, making detection of early plant symptoms difficult.

Favoured by

These nematodes prefer warm climates (tropical and subtropical regions), although they can be found in warm temperate regions as well.

Damage potential differs widely according to soil type. Sandy soils tend to promote the greatest level of damage, while nematode survival and reproductive success is favoured by soils with higher (20-40%) silt or clay.

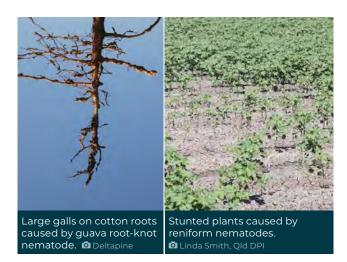
Root-knot nematodes thrive in sandy and sandy loam soils and causes little damage in soils with clay content greater than about 15%. However, the reniform nematode has been associated with soil types having higher silt and (or) clay contents compared with most plant-parasitic nematodes

Host range

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 Dr Linda Smith or Dr Dinesh Kafle (Qld DPI): 13 25 23.
- Manage cotton stubble. Cut cotton stalks and till soil through the stubble zone as soon as possible after harvest to destroy breeding sites. Ensure root cutting is successful and there is no re-growth.

Assessment

Monitor for patches of unexplained unthrifty or stunted plants and send a sample of soil if concerned. Nematodes cannot be seen with the naked eye, but affected roots may have small nodules (which are the egg masses).

- Mark patches with a GPS or on a map so you can re-monitor next season.
- Scrape off the dry top soil and sample 10-15 cm deep using a small trowel or soil corer.
- If there is more than one patch in a field, collect multiple samples from these areas in a bucket, and mix through.
- Place approximately 400 g of the soil in a clearly labelled plastic bag.
- The extraction process relies on live nematodes so please keep cool in an esky without an ice brick, DO NOT STORE SAMPLES IN THE FRIDGE.
- Include information about the sample sheet (see page 107 for more information on sending plant samples for diagnosis).

Reniform nematode in cotton youtu.be/QgBn4vfkOzl





Reoccurring wilt

Pathogen: Novel Eutypella species

Reoccurring wilt, caused by novel species of *Eutypella* was first observed in the 2017/18 season and is the first known detection of this fungus causing disease on cotton.

Symptoms

The disease typically presents as wilting and sudden death of plants, either as single plants or in a patch similar to a lightning strike, but some plants within the patch may not be affected. Leaves turn bronze-brown, die and remain attached to the plant. A section of bark on affected plants will become blackened.

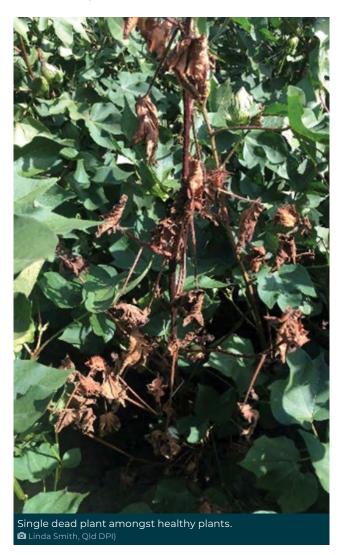
Internal symptoms can be observed by cutting the stem. A reddish-grey vascular discolouration can be seen and may not appear evenly through the cross-section, often appearing in a 'V' shaped sector of the stem.

Favoured by

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.

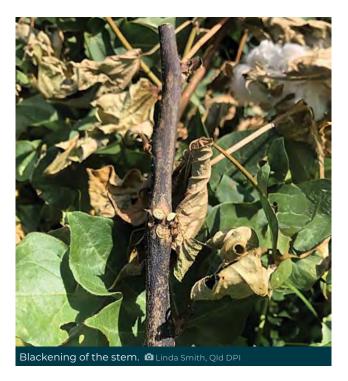
USEFUL RESOURCES:



Identifying reoccurring wilt ink.springer.com/article/10.1007/s13313-021-00843-8



Contact your nearest REO (see inside back cover) or a cotton pathologist if you suspect the disease on your farm. For information on collecting and submitting disease samples, see page 107.





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.



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



In vitro production of apothecia on sterile sand and ascospore discharge of *Sclerotinia sclerotiorum*.

H.R. Dillard, Cornell University

Favoured by

The disease is favoured by cool temperatures (between 15 and 24 $^{\circ}$ 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).

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.

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.



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.





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

Vverticillium 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 latematuring 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, barley, oats, triticale, canary grass, lablab, black gram, vetch and maize may be hosts. Weed hosts include Noogoora and Bathurst burr, saffron thistle, thornapple, caustic weed, bladder ketmia, burr medic, black bindweed, red pigweed, devils claw, turnip weed, mintweed and blackberry nightshade. See Table 32 for a more detailed list. There is some host specificity between strains.



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

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
- 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 107 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.

Verticillium wilt in cotton youtu.be/hgiatA52nNw



of cotton stems infected with V. dahliae. 🙆 Duy Le, NSW DPIRD

Under the protection of Sero-X and with BMP you <u>CAN</u> manage vert







The Fast Facts: Be wilt aware

	FUSARIUM WILT	VERTICILLIUM WILT	SUDDEN WILT	LIGHTNING STRIKE	REOCCURRING WILT	
CAUSAL AGENT	Fusarium oxysporum f.sp. vasinfectum	Verticillium dahliae	Potentially caused by Fusarium spp./ physiological effect of environmental conditions	Lightning (thunderstorm)	Novel Eutypella species	
PLANT STAGE AFFECTED	Plants may be affected throughout the season	Most common late season or after wet and/or cool weather	Plants may be affected throughout the season	Lightning can cause damage at all crop stages	Plants may be affected throughout the season	
FAVOURED BY	Cool and wet conditions with temperatures below 23°C	Temperatures below 25°C and excessive nitrogen. Disease incidence is most severe during extended wet weather	Hot weather following an irrigation or rainfall. Root damage from cultivation can contribute to incidence		Unknown	
SYMPTOMS	Plant stunting; yellowing or browning of leaves; plant wilting and death. Plants die from the top and may regrow from the base later in the season	Yellow mottling of leaves between veins and around leaf margins; dead tissue replaces mottling. Defoliation can occur depending on severity and strain	Sudden wilting followed by defoliation; plants die and occasionally regrow	Leaves can be completely desiccated or partially blackened; blackening or burnt bark (stems) in mature crops	Sudden wilting and plant death; bronzing of leaves and petioles; dead plants have blackened stems with leaves remaining on the plant	
VASCULAR TISSUE & ROOTS	Solid brown/chocolate discolouration of vascular tissue	Speckled dark brown, tan to black discolouration of vascular tissue	Brown discolouration is confined to woody parts of root and lower stem	No vascular discolouration. Roots and lower stems of surviving plants relatively unaffected	When the stem or tap root is cut horizontally, infected tissue may have a wedge-shaped discolouration which is reddish-grey in colour. Discolouration of the roots and vascular tissue. Root decay i.e. if plants are pulled out of the soil, the taproot snaps due to a dry rot.	
APPEARS AS	Single plants or small patches, often near the tail drain or low- lying areas in the field	Single plants or small patches	Single plants or small patches. Does not reoccur in the same place	Circular or irregular patches of dead or damaged plants	Single plants or in patches. Reoccurs in the same place	
SPREAD BY	Soil inhabiting, spread with soil and plant debris – especially in irrigation water	Soil inhabiting, spread with soil and plant debris – especially in irrigation water	Soil inhabiting, spread with soil and plant debris – especially in irrigation water or floodwater		Pathogen confirmed to be spread with infected cotton residue. Plants can become infected via buried cotton stems.	



Figure 1.
Fusarium wilt can cause some leaves to develop a yellow mottle.



Figure 2.
A key feature of
Fusarium wilt is the
brown discolouration
in the woody part of
the stem.



Figure 3.
Fusarium wilt can cause plants to die back from the top and may regrow back from the base later in the season.



Figure 4.
An early symptom of Verticillium wilt is leaf wilting and mottling.



Figure 5.
Verticillium wilt
causes a speckled
vascular discolouration
throughout the stems.



Figure 6.
Severe Verticillium wilt infection may cause defoliation.



Figure 7. Reoccurring wilt causes plants to wilt and suddenly die with dead leaves remaining on the plant.



Figure 8.
Reoccurring wilt causes root decay i.e. if plants are pulled out of the soil, the taproot snaps due to a dry rot, and reddening of the vascular tissue.



Figure 9.
When the stem or tap root is cut horizontally, infected tissue may have a wedge-shaped discolouration (Reoccurring wilt).



Figure 10.
Reoccurring wilt
causes blackening
of the stem.



Figure 11. Sudden wilt (right plant) can cause plants to suddenly wilt and die. Does not reoccur 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 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.



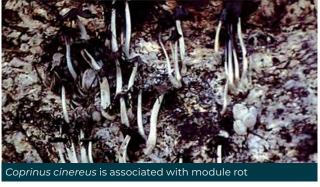
Bacterial stunt results in slow growth (left) compared with healthy plants (right)

Charcoal rot

Charcoal rot (*Macrophomina phaseolina*) causes wilting and death, and can be distinguised 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.









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.



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.



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 prevalant during the dry season.



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 liase 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). The Disease Management page contains 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.



	Active ingredient	Trade name		MoA	Targets	Comments	
	Active ingredient	Trade Harr		group	rargets	Comments	
Seed treatments	Azoxystrobin 75 g/L + Metalaxyl-M 75 g/L + Sedaxane 35 g/L + Fludioxonil 12.5 g/L	Vibrance® CST	Vibrance®	4, 7, 11, 12	Damping- off caused by <i>Pythium</i> spp. and <i>Rhizoctonia solani</i>	Seed treatment available through CS when ordering seed.	
	Acibenzolar-S-methyl 500 g/L	Bion®	Complete	No group	Fusarium wilt, black root rot	Seed treatment available through CS when ordering seed. Suppression on Activates the plant's natural resistant mechanisms.	
	Metalaxyl-M 350 g/L	Various		4	Damping-off caused by Pythium and Phytophthora. Fusarium wilt disinfection on seed	Seed dressing. Qld & NSW only. Does not protect against damping off by Rhizoctonia, Fusarium or other fungi 97% R-enantiomer. Much more effective in controlling diseases. Low rates can be used.	
planting	Quintozene 750 g/kg	Terraclor®		14	Damping- off caused by <i>Rhizoctonia</i> spp.	Qld, NSW & WA only. Soil fungicide. Spray over seed and surrounding soi at planting.	
At plan	Tolclofos-methyl 500 g/L	Tolex® Rhizolex® In Furrow		14	Rhizoctonia solani	Qld & NSW only. Mix with seed immediately before planting. Applied as an in-furrow spray or wate injection at planting.	
Foliar fungicides	Clitoria ternatea extract 400 g/L	Sero-X®		UNE	Verticillium wilt microsclerotia	Will reduce the amount of microsclerotia (inoculum) returning to the soil. Qld, NSW & WA only. Thre applications are required: 1. When majority of plants are betwe 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 reduct the severity of the disease in the season it is applied.	
	Metentrifluconazole	Belanty®		3	Ramularia leaf spot (PER94282. Expires 28 February 2026.)	NT, QLD and WA only. Do not apply by a vertical sprayer. Check permits for restrictions regarding release	
	75 g/L				Target spot (PER95141. Expires 31 December 2029.)	height, droplet size and buffer zones Maximum 3 applications per crop, 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 7 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 treatmer only – not registered for seed used in Australia.	

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



Biosecurity – we all have a responsibility

iosecurity 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 everyone plays a part in preparing for and minimising their 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 is something that 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 of an exotic plant pest threat, 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 pests, weeds and diseases could enter the farm and what practices are in place to manage or reduce these risks. Ensure all staff are aware of and understand your plan.
- Declare visits to farms overseas on re-entry to Australia. All clothes and footwear worn on-farm overseas should be left behind or thoroughly washed before you return.
- Ensure all farm inputs are pest free, including seed for cotton, refuges and other commercial crops. Keep records of all farm inputs.
- Maintain zero tolerance of volunteer cotton plants and other weeds at all times throughout the year to prevent pests harbouring there.

Come Clean. Go Clean.

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 $^{\text{TM}}$ or most industrial and domestic brands of soaps and detergents) provide optimal soil removal.

Agricultural disinfectants

Disinfectants specifically marketed for agricultural situations (such as Path- X^{TM} , 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. geminating weeds).

Step-by-step procedures in the Come Clean. Go Clean. process are detailed in the poster on page 131.

Biosecurity Plan for the Cotton Industry

Plant Health Australia (PHA) is the national coordinator of the government-industry partnership for plant biosecurity in Australia. Cotton Australia is a member and CRDC is an associate member of PHA.

The PHA-facilitated *Biosecurity Plan for the Cotton Industry* is a framework to coordinate biosecurity activities and investment for Australia's cotton industry. It provides a mechanism for industry, governments and stakeholders to better prepare for and respond to incursions of pests that could have significant impacts on the cotton industry.

More infomation on biosecurity stewardship, including the cotton biosecurity plan, is available from Cotton Australia. (#) cottonaustralia.com.au/biosecurity

The Biosecurity unit within the cotton industry's *my*BMP 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





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

SEED TREATMENTS

- Genero 600 SC
- Methoxam 600

HERBICIDES

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

INSECTICIDES

- Abamectin
- AceTam 225
- Alpha-Cyp 100 Duo.
- Amitraz 200 EC/ULV
- Bifenthrin 100 EC
- Chlorpyrifos 500
- Difen 500
- Fipronil 200 SC
- Indox 150
- Pyrip 100



Farm biosecurity management plans

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

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

Developing a farm biosecurity management plan can help you to:

- Identify and assess the biosecurity risks to your farm and business
- Outline the biosecurity practices currently being implemented
- Identify biosecurity practices that can be implemented in the short and long-term to reduce biosecurity risks.

The suggested practices in a farm biosecurity management plan cover a range of farming scenarios and can be adapted to suit your particular circumstances. In some cases alternative practices may be better suited to your farm and business; the important thing is that you are aware of your biosecurity risks and are taking reasonable steps to minimise 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. III

Biosecurity Top Tips:

risk; the practices you implement should reflect what suits you and your farming business. Check out our Biosecurity 'Top Tip' videos of growers, consultants and researchers sharing how they are implementing biosecurity in their day-to-day routines.

Visit www.youtube.com/CottonInfoAust





Come Clean. Go Clean.

Dirty vehicles, machinery and equipment carry pests, weeds and diseases

A GUIDE TO EFFECTIVE WASH DOWN OF VEHICLES AND MACHINERY

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



- 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



B 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



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



Exotic insects and diseases

umerous pests of cotton not found in Australia pose a threat to production if they were to arrive and establish. Among these, certain pests are identified as 'high priority', based on risk assessments of the likelihood of entry and potential impact to cotton production. To improve the chance of an effective eradication or containment response, it is important that anyone working on-farm are aware of these pests, as well as what to do if they see anything unusual.

Some of the high priority exotic pests look similar to or are variants of endemic pests and diseases, and are included under 'Are your usual control measures not working?'. For more information on the current high priority list, contact Cotton Australia or Plant Health Australia.

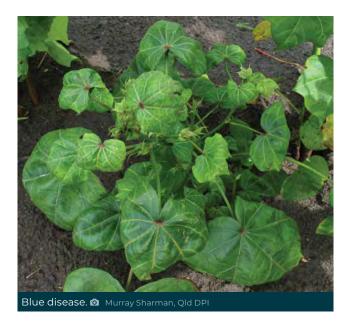
High priority exotic pests

Blue disease

Cotton leafroll dwarf virus

Blue disease is caused by cotton leafroll dwarf virus (CLRDV) that is spread by cotton aphids and infects cotton and some other hosts. In Brazil, blue disease is reportedly capable of reducing productivity of susceptible varieties by up to 80%. Cotton blue disease has similarities to cotton bunchy top and anthocyanosis (a disorder reported from Brazil). CLRDV has not been detected in Australia.

Blue disease-affected leaves tend to be smaller, thicker, more leathery and brittle and are intense green with yellow veins (CBT-affected leaves have an angular pattern of pale green margins and darker green centres). Reddening of stem petioles and leaf veins can occur in some infections. Leaf edges tend to roll downwards and under and plants become stunted (due to shortened branch internodes) and produce many branches, giving a bunchy zig-zag stem habit. Symptoms and stunting are more obvious in plants infected at an early age. Infected plants also produce smaller bolls and boll shedding may occur. Single infected plants can be difficult to spot if overgrown by nearby healthy plants.



Cotton boll weevil

Anthomonus grandis

A pest specific to cotton that damages developing bolls leading to large yield losses. In the USA, the cotton boll weevil eradication program has been largely successful, but has cost hundreds of millions of dollars.



Cotton leaf curl disease (CLCuD)

CLCuD is spread by whiteflies and can cause yield losses of up to 35% in cotton. There are at least seven different begomoviruses and several different DNA satellite molecules associated with CLCuD. 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 are common and vary in size from a few millimetres in diameter to almost the size of a normal leaf. These larger structures are often cup-shaped.



Indian green jassid

Amrasca devestans

A sap-sucking leafhopper that can cause yield losses of up to 25%. Indian green jassids inject a toxin as they feed that causes leaves and bolls to drop and can stunt plant growth. While several leafhopper species are found in Australian cotton (see page 56) the damage they cause is usually relatively minor, rarely if ever affecting yield.





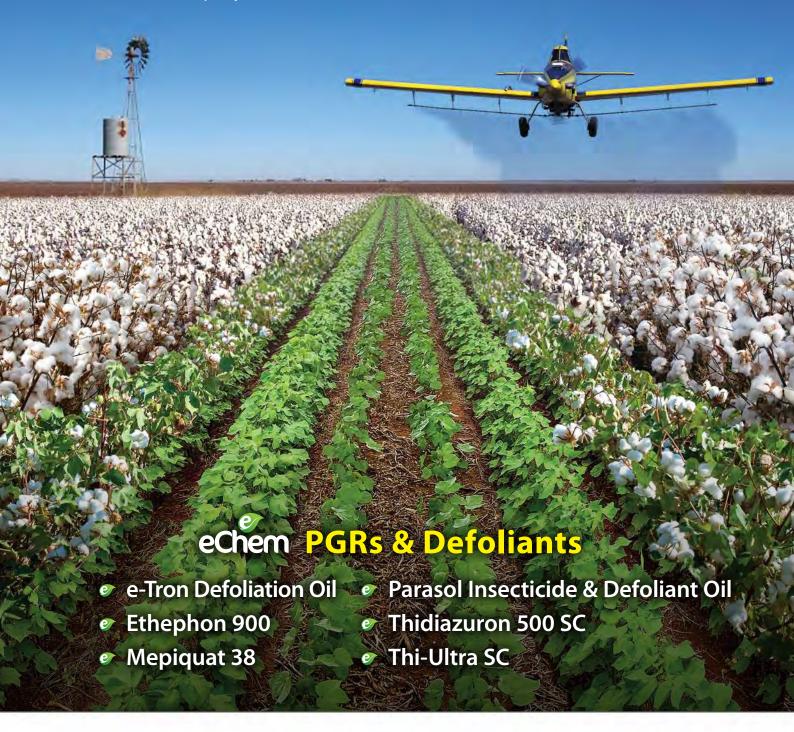


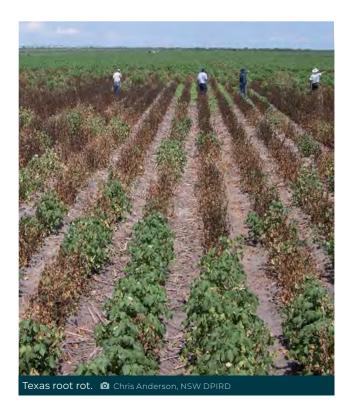


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Texas root rot

Phymatotrichopsis omnivora

Texas root rot is an extremely damaging fungal disease with a wide host range. It causes sudden death, usually during the warmer months and can result in 100% crop loss. Symptoms include yellowing or bronzing of leaves, which then wilt and die but usually remain attached to the plant. At this stage, the roots are dead and their surface is covered with a network of tan fungal strands. External symptoms of Texas root rot are similar to reoccurring wilt caused by *Eutypella* spp. It is important to investigate any unusual symptoms to determine the cause.

Are your usual control measures not working or is pest damage worse than expected?

Some exotics are variants of endemic pests and diseases. These exotic strains could become a problem if they reached Australia, either through different insecticide resistance profiles or the potential to overcome host plant resistance bred into Australian cotton varieties.

It is important to report if you've experienced an insecticide spray failure without a reasonable explanation, or are seeing new or unusual disease symptoms, so that appropriate sampling and testing can be organised.

American cotton bollworm

Helicoverpa zea

American cotton bollworm, also known overseas as corn earworm, is a pest of many crops including cotton, pigeon pea, soybean, maize, sorghum, chickpea and millet. Larvae are not distinguishable visually from *H. armigera* and cause similar damage. Dissected adult male moth genitalia are required for identification.

Bt-resistant cotton bollworm

Helicoverpa armigera (carrying Bt resistance alleles)

Bt cotton has dramatically reduced the need to control *Helicoverpa* spp. Exotic strains of *H. armigera* that carry resistance alleles (e.g. dominant resistance to CrylAc) would have a significant impact on Australia's cotton industry if they were to establish here. With the movement of *H. armigera* into South America, there is also some concern that *Helicoverpa zea* (American cotton bollworm) may hybridise with *H. armigera*.

Fall armyworm

Spodoptera frugiperda (exotic strains)

Fall armyworm was detected in Australia in early 2020 and has been declared endemic. Although FAW has the capacity to feed on cotton, it appears to prefer grass species with whorls (such as maize and sorghum), and to date no impact on cotton crops has been reported in Australia. Overseas there are strains that can impact cotton.

Cotton aphid

Aphis gossypii (exotic strains)

Cotton aphids are potential vectors for exotic pathogens such as blue disease. As well as the risk of disease, there is a risk that new aphid strains entering the country will have different insecticide resistance profiles, making control more difficult.

Bacterial blight

Xanthomonas axonopodis or X. campestris pv. mavacearum (exotic strains)

Although strains of bacterial blight are already present in Australia, they are no longer a problem due to varietal resistance. Exotic strains (races) occur, however, that are 'hypervirulent' and, if established in Australia, could cause large yield losses.

Initial symptoms include angular water-soaked lesions on the undersides of leaves that dry and darken with age, followed by leaf shedding. Black lesions spread along the stem and bolls are often infected at the base or tip (where the dried lesions prevent the boll from opening). This seedborne pathogen is capable of symptomless transfer and could therefore remain undetected through quarantine.

Verticillium and fusarium wilts

Verticillium dahliae (exotic strains) Fusarium oxysporum f. sp. vasinfectum (exotic strains)

While fusarium and verticillium wilts already affect Australian cotton, it is important to get new or unusual wilt symptoms tested as this could indicate incursion of exotic strains.

Whitefly

Exotic Bemisia species

There is a risk of further incursions of exotic *Bemisia* species, with different genetic profiles to current pest populations (e.g. additional forms of insecticide resistance) entering the country. Invasive whitefly could potentially introduce viruses (such as CLCuD) that they vector.

Lygus bugs

Lygus lineolaris and L. hesperus

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

Some high priority exotics are variants of endemic pests and diseases. These exotic strains could become a problem if they reached Australia, either through different insecticide resistance profiles or the potential to overcome host plant resistance bred into Australian cotton varieties.

It is important to report if you've experienced an insecticide spray failure without a reasonable explanation, or are seeing new or unusual disease symptoms so that appropriate sampling and testing can be organised.



Other exotic threats

Brown marmorated stink bug (BMSB)

Halyomorpha halys

Stink bugs have a shield-shaped body and emit a pungent odour when disturbed. A number of native stink bugs look similar to BMSB, but lack the distinctive white bands on the antennae (and legs of nymphs). BMSB can damage more advanced bolls than other stink bug species.



Cotton stainer

Dysdercus spp.

Related to the already endemic pale cotton stainers (see page 46), these colourful red bugs are often found in groups. While feeding on cotton bolls they can transfer microorganisms that increase lint staining.



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) dictiools.org (right)

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

L 1800 084 881



CottonInfo insect ID guide on brown marmorated stink bug (updated February 2025)

cottoninfo.com.au/ publications/insect-id-guide -endemics-exotics-brown -marmorated-stink-bug





Applying pesticides

esticides are chemical products or mixtures 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 efficacy in both the short and long term largely relies on not only appropriate product choice, but effective handing and application. Many of these products can be highly toxic, not just to their intended target, but to humans, beneficial insects, wildlife, and other crops and vegetation. Some registered products or adjuvants may cause crop phytotoxicity in certain situations. Always read the entire label before applying any product.

Planning ahead

The development of a comprehensive spray plan, such as a Pesticide Application Management Plan (PAMP) prior to the season is an important part of the Best Management Practice (myBMP) program for cotton. The spray planning process should include discussing cropping intentions and communication processes with spray applicators. The spray plan should include consideration of farm layout, weather monitoring and record keeping, identification of sensitive areas and potential hazards, and procedures for communication with staff, contractors and neighbours. More information on spray plans can be found at cottoninfo.com.au/pesticide-input-efficiency

Having a spray plan in place helps to ensure that everyone involved in pesticide application has a clear understanding of their responsibilities.

Legal responsibilities

Be aware of 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.

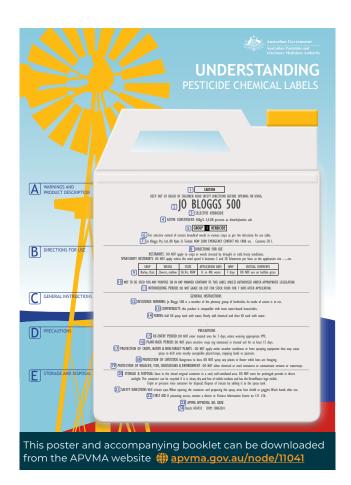
There may also be workplace health and safety requirements related to storage and use of hazardous chemicals, such as completing a hazard analysis, maintaining a chemical inventory and easily accessible current copies of relevant Safety Data Sheets.

Always read and follow the label when handling and applying chemicals. Specific label conditions may include minimum spray quality, appropriate spray conditions (including wind speed range), specifications for no-spray zones/buffers, and record-keeping requirements.

 Spray quality (the droplet sizes produced) is influenced by nozzle design, operating pressure, the spray pattern angle, the properties of the tank mix, and (for some nozzles) the inclusion of air into the droplet. Nozzles are

Best practice...

Product and application technique needs to 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.



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 your nozzles and ensure that equipment is set up and used appropriately to achieve the required spray quality.

- Wind speeds are measured at the application site the label-specified range is usually above 3 km/h and less than 15-20 km/h.
- No-spray zones are a specified distance downwind that must not include a sensitive area (such as a residence, school, public area, water body, pasture, terrestrial vegetation or crop). Always check the product label(s) as the distance required may differ depending on the type of sensitive area and application method. No-spray zones for aerial applications can be larger than those required for ground application.
- **Keep records** of the application details. Specific requirements are included on the label or permit conditions for many products. These records are in addition to any state-based record-keeping requirements.

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. See also the 'Pesticides and regulation' section in this chapter.

Monitoring and recording conditions

Labels contain a legal requirement to measure weather parameters (including temperature, humidity, and wind speed and direction) at the site and time of application. This can be done with handheld equipment (e.g. Kestrel or equivalent) or portable weather stations. On-board weather stations that provide live weather information while the sprayer is operating (such as the Watchdog systems) are also available. See page 145 for an example of a pesticide application record sheet.



Access to a network of spray hazard identification towers that can quickly detect hazardous conditions is available.

@ goannaag.com.au/wand-network

There are also subscription websites that provide forecasts of conditions for spraying up to 10 days in advance. These sites evaluate a range of factors to produce tables indicating suitable times for spraying.

Good communication

Prior to product selection and spray application, determine the proximity of susceptible crops and sensitive areas (cotton is extremely sensitive to phenoxy herbicide drift). It is good practice to notify neighbours and staff of your spray intentions, regardless of label requirements.

BeeConnected can help identify nearby location of hives and facilitate communication between spray applicators and beekeepers **(#)** beeconnected.org.au.

SataCrop is a free online tool for mapping crops, including cotton, allowing growers and applicators of all products to be better informed of the location of potentially sensitive crops before spraying satacrop.com.au.

Optimising spray application

Application technique needs to be matched to the target and weather conditions. Always consider the potential for off-target drift. Achieving the best outcome requires careful attention to many factors, including:

- Appropriate nozzles for product/adjuvants and target
- Appropriate operating parameters, including nozzle spacing, operating pressure, travel speed and spray release height
- Meeting label requirements for optimising spray quality and minimising drift risk
- Considering suitable timing for mobile targets (insects)
- Careful calculation of 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).

Be aware that mixing order and water quality can have a significant impact on spray efficacy.

Effective decontamination

Thoroughly decontaminate application equipment after use, particularly when herbicides have been used. Follow decontamination instructions on pesticide and cleaning product labels. View the CottonInfo video on decontaminating a spray rig youtu.be/-zDQwolEcB0

Much of the information contained in GRDC's GrowNotes TM Spray Application Manual for Grain Growers is also applicable for cotton.

grdc.com.au/resources-and-publications/grownotes/ technical-manuals/spray-application-manual





Top tips for agronomists...

- 1. Run through a pre-season spray plan with your growers (see module 5 of the GRDC spray application manual) and consider if spray practices can be improved.
- 2. Ensure your growers have realistic expectations of timeframes for pest control.
- 3. Check that each grower's spray rig set-up is fit-for purpose to deliver your spray recommendations.
- 4. Highlight the importance of identifying spray drift factors and avoiding hazardous inversion conditions (including halting the spray operation if conditions become unfavourable).
- 5. Ensure growers are aware of factors that may impact on spray coverage and performance (nozzle selection, pressures, speed, adjuvants, water quality, tank mix compatibilities etc).
- 6. Recommend a nozzle that complies with the 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/prrdlapp/plpr.aspx and in Queensland at business.qld.gov.au/industries/farms-fishing-forestry/agriculture/land-management/chemical-controls/licence-search

Banded sprays present an opportunity for strategic and economical use of products by applying the equivalent rate of active per hectare to the target, but using less pesticide overall. Label rates are always given as litres of active/sprayed ha. Advisors also give recommendations as L/sprayed ha, however confusion over banded spraying can lead to significant differences between the consultant's recommendation, the applicator's instincts and what the application equipment can physically achieve. A detailed example of how to calculate banded sprays is available in the *Australian Cotton Production Manual*.

Optical spray technology applies significantly less product by detecting and only spraying individual weeds and weedy patches. This technology can provide savings in time and fuel and helps reduce drift. Not all products can be used in optical sprayers – check product labels for compatibility.



Aerial application

Aircraft are extensively used to apply pesticides in cotton. Fixed wing aircraft and helicopters are able to cover large areas quickly and in conditions that may not suit ground application (e.g. dense canopies or wet ground).

Large specialist RPA (remote piloted aircraft, often referred to as drones) are also capable of aerial application of pesticides, although the tank size is limited by the capacity of the unit. Aircraft, including RPA, used for commercial operations must be registered with CASA. The business and the pilot must be appropriately licenced to apply pesticides from the aircraft.

Aerial operators are professional spray applicators that understand the parameters required for getting the best out of a spray job. Discuss your requirements in advance with the operator, including the target, timeliness, coverage required, and sensitive crops nearby to assist them in ensuring optimal set up for the aircraft. The best results are achieved when growers/agronomists work closely with their aerial operator in planning, executing and following up on their spray applications.

Some key points that should be discussed are:

- Target 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 cm on the target. Aerial operators are well positioned to select the correct droplet size to achieve this. Small droplets may increase the risk of off-target movement.
- Swath width A spray plane's swath width is wider than the wingspan, due to the vortex effect created by the wings as they move through the air. Each aircraft has recommended swath widths that they can use in various conditions. Many aerial operators do regular pattern testing as well to optimise the swath width that they use for each aircraft. Review this data with your aerial operator to ensure that all parties are satisfied with the spray parameters being used.

It is highly recommended that growers select an aerial applicator with Aerial Application Association of Australia (AAAA) membership, Spraysafe or AIMS accreditations to ensure that they are getting the most professional service. The AAAA has also produced some comprehensive documents about aerial spraying to assist with working more effectively with your aerial operator. ## aaaa.org.au



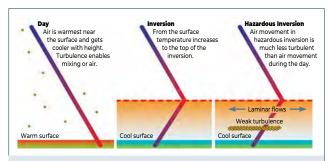
Reducing drift

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. An operator must decide whether to stop spraying or to continue using a larger droplet size and higher water rate when Delta T exceeds 8. GRDC have a factsheet on weather monitoring equipment available from their Spray Drift Hub at grdc.com.au/GRDC-FS-SprayEquipment



Typical vertical temperature profiles for normal, inversion and hazardous inversion conditions. Blue represents cooler air, red represents warmer air and yellow dots represent

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.



 $\begin{tabular}{ll} \bf Strongly\ unstable\ conditions\ promote\ vertical\ dispersion\ and\ widespread\ dispersion\ of \end{tabular}$

Strongly stable conditions (hazardous inversions) cause high concentration of drifting plumes near the surface in contained layers.

Three common states of atmospheric stability and their relationship to spray application and drifting sprays.





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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 have developed a spray drift hazardous weather warning system that provides real-time weather data and alerts to growers and spray operators about the presence of hazardous temperature inversions. Sign up at

goannaag.com.au/wand-network

More information is available in chapter 17 of the Australian Cotton Production Manual or GRDC's Weather essentials for pesticide application (see GRDC's Spray Drift hub).

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





Optimise spray rig setup and operation

Nozzle types, operating pressures, boom height, delivery speed and the characteristics of the product or products used (particularly adjuvants) will all influence the risk of droplets moving away from the target area. Always check the product label(s) for operation requirements/restrictions, regularly calibrate your equipment and avoid excessive travel speed during application. GRDC's GrowNotes™ Manual on Spray Application includes a section on sprayer set-up.



Multi-outlet nozzle bodies can be used to easily change nozzle types across a boom, or operate multiple nozzles in differing directions to increase coverage. Ensure that spray equipment has been recently calibrated and poorly performing nozzles have been replaced.
© Ruth Redfern, CRDC

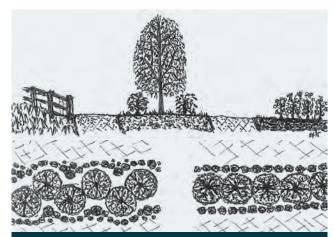
Use vegetative plantings as spray drift barriers

Plant dedicated field borders of vegetation to 'catch' spray drift. Do not utilise remnant native vegetation or environmental corridors as a vegetative barrier. Identify habitat vegetation as 'sensitive' and protect it from spray drift, along with riparian areas and waterways.

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

The planting arrangement and density should allow air to partly flow through – dense barriers will act like a wall, directing wind containing the spray drift up and over the top and increasing how far drift may travel. Aim for a porosity of around 50% (you can see 50% light and 50% dark when you look through the vegetation) and a height of at least 1.5 times the release height of the spray. As vegetation density increases, the height of the barrier needs to be increased.

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



Side and overhead view showing suggested structure and planting configurations of trees and shrubs for a permanent vegetative barrier.

Bill Gordon



Understorey foliage needs to be thinned a little to increase the porosity of this vegetative barrier to 50%. • Stacey Vogel



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- ▶ 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.







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SPRAY APPLICATION APPLYING PESTICIDES



USEFUL RESOURCES (COTTONINFO):



Chapter 17 in the Australian **Cotton Production Manual**

publications/ production-manual





CottonInfo's Pesticides and application video playlist

🏟 youtube.com/cottoninfoaus





CottonInfo's Pesticide input efficiency page

com.au/pesticide-<u>input-efficiency</u>





CottonInfo's Vegetative barriers factsheet

cottoninfo.com.au/publications/ nrmpesticide-input-efficiency-usingvegetative-barriers-minimise-spray-

USEFUL RESOURCES (OTHERS):



GRDC's practical tips to reduce spray drift

🎒 grdc.com.au/GRD0 FS-SprayPracticalTips





myBMP's Pesticide application module

mybmp.com.au





Mary O'Brien **Rural Spray Drift** resources

maryobrienrural com.au/resources

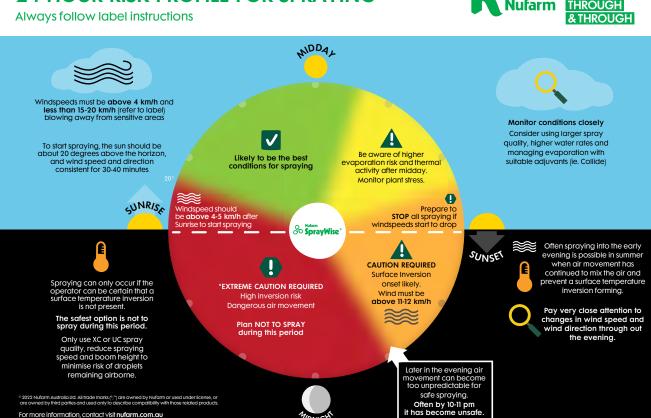


A number of spray-related mobile apps are also available for weather forecasting, nozzle selection, calibration and/or tank mixing. Research them carefully (including the reviews) before installing to enure they will meet your needs.

24 HOUR RISK PROFILE FOR SPRAYING



AUSTRALIAN THROUGH & THROUGH



Guidelines for temperature inversion risk (if access to a wand tower is unavailable). Source: Nufarm Australia

For more information, contact visit nufarm.com.au

Pesticides and regulation

APVMA product registration

The federal, state and territory governments work together to regulate agricultural and veterinary (agvet) chemicals in Australia. The Australian Pesticides and Veterinary Medicines Authority (APVMA) evaluates the safety and performance of agvet chemicals intended for sale in Australia to protect the health and safety of people, animals, crops, trade and the environment.

Before agvet chemical products can be legally sold, supplied, marketed or bought in Australia, they must be registered by the APVMA. The assessment uses broad risk analysis, including how human and environmental exposure can be minimised through instructions for use and safety directions on the label of registered products. Risks to market access are also evaluated, as one of the criteria for registration is that use of agvet chemicals will not unduly prejudice Australia's international trade. The APVMA approves product labels that explain how the product is to be used, stored, disposed of and managed in the event of poisoning.

Agvet chemical product labels are legally binding. State and territory governments are responsible for monitoring post-sale compliance with label instructions and limitations

The APVMA website

Visit APVMA's website **apvma.gov.au** for up to date information on product registrations and permits, active ingredients, residue issues, regulatory operations and to access a wide range of resources about using chemicals.

Check the site regularly as registrations can be amended or revoked at any time. Formal reviews are undertaken to scientifically reassess the risks and determine whether changes are needed to ensure a chemical can continue to be used safely and effectively. This may include modifying the way chemicals are used or if risks cannot be managed, cancelling registrations or label approvals. A list of products currently under review is available at approximately emicals-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

The PubCRIS database can be searched by:

- Product name or registration number;
- · Active constituent or other ingredients;
- Permit holder;
- Host; or,
- Pest.

There are also advanced search and filter options, such as product type, the territory/state(s) in which the product is registered and the formulation type.

Simply select the type of search term(s) and enter into the search box. A drop-down list will provide suggestions as you type.

PubCRIS search results display by product number (with the most recent at the top) and provide links to a summary



of registration details or a PDF copy of the label. Search results can also be exported as a CSV file.

Bear in mind that labels usually cover multiple uses and the search engine 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.

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 chlorthal dimthethyl 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.

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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 controlof-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, constraints and all other label instructions are read and understood before each use. Keep in mind that labels can be revised and amended, so review EVERY time.

Note that the term 'label' refers to all of the product information attached to the pesticide container, which may include a fold-out leaflet or booklet if space is insufficient.

For more information, visit:

apvma.gov.au/node/935#Label_layoutremains

There are some limited exceptions to the requisite adherence to all label instructions, most notably when an APVMA permit approves a minor, emergency or research use of an agricultural chemical (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 should be licenced. The commercial application of pesticides through ground application equipment will also often require licensing of both the spray applicator and the business. Check with the agricultural chemical licensing agency in your state or territory for more information about licensing requirements for pesticide application.

Licensing exemptions typically exist for growers applying agricultural chemicals with ground equipment on their own land. In most instances, this means that cotton growers do not need to hold a licence for agricultural chemical application, unless operating under fee-forservice arrangements as a contractor. However, some states require specific training and accreditation for operators. All operators are strongly encouraged to complete chemical application training to improve their skills and knowledge in application technology and the handling, storage and transportation of chemicals.

Most people who use pesticides while working in an agricultural business are required to be trained. The most appropriate vocational education and training competency units for cotton growers to meet this training obligation will generally be AHCCHM304 (Transport and store chemicals) and AHCCHM307 (Prepare and apply chemicals to control pest, weeds and diseases). There may be additional qualification requirements for using Schedule 7 poisons or restricted chemical products.

Best practice is to know the training requirements in your state or territory and ensure that all people handling and applying pesticides are trained and maintain their competency.

Record-keeping obligations may include when a record should be made and a period of time for which records should be kept. The particulars required in each jurisdiction will vary slightly but are largely aligned with best practice spray record-keeping, i.e. that which is relevant in meeting cotton production objectives, as well as managing risk and providing evidence that label conditions have been met. Some of the parameters that need to be recorded include the time, date, location and crop as well as those 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 recordkeeping particulars under their spray drift restraints.

An example record keeping sheet (developed by NSW DPIRD) is provided in this chapter, and is available from

@ dpi.nsw.gov.au/agriculture/chemicals/ farm-chemical-management/records.

Some commercial farm management software and apps include the ability to record spray details.

Further information on relevant State regulations and training requirements:

epa.nsw.gov.au/your-environment/pesticides

Qld: <u>business.qld.gov.au/industries/farms-fishing-forestry/agriculture/land-management/chemical-controls</u>

WA: www.health.wa.gov.au/Articles/N_R/Pest-industry-licensing-and-registration

NT: # nt.gov.au/industry/agriculture/farm-management/using-chemicals-responsibly

VIC: ### agriculture.vic.gov.au/farm-management/chemicals



Pesticide Application Record Sheet



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, by N W Treated Area E			s, buffers):	*		Comments (including risk control measures for sensitiv areas):			
_	S		_						
lost/Pest									
Paddock Number/Name: Paddock Are			Area:		Order of Pa	Order of Paddocks Sprayed:			
Crop/Situation:					Type of Animals:				
Crop/Pasture Variet	ty:				Age/Growth	Stage:			
Growth Stage:					Mob/Paddock/Shed:				
Pest/Disease/Weed:	1				Animals — Number Treated:				
Application Data									
Full Label Product	Name:				Rate/Dose:		Water R	ate L/ha:	
	Name:	Expi	ry Date:		Rate/Dose: Additives/We	tters:	Water R	ate L/ha:	
Permit No.:	Name:	Expi	-	ESI*:	Additives/We	tters:		ate L/ha:	
Permit No.: Total L or kg:	Name:	+	-	ESI*: Nozzle	Additives/We		r Sale:	ate L/ha:	
Permit No.: Total L or kg: Equipment Type: Date Last Calibrated		WHI	-	Nozzle '	Additives/We Date	ate Suitable fo	r Sale:	1	
Permit No.: Total L or kg: Equipment Type: Date Last Calibrated Weather	d:	WHI	Water Quality	Nozzle 'v (pH or de	Additives/We Date	ate Suitable fo	r Sale:	1	
Total L or kg: Equipment Type: Date Last Calibrated	d: st □ Lig	WHI	Water Quality	Nozzle v (pH or de	Additives/We Date	ate Suitable fo	r Sale:	1	
Permit No.: Total L or kg: Equipment Type: Date Last Calibrated Weather Showers Overca Rainfall (24 hours b	d: st ☐ Lig before and mm	WHI	Water Quality d	Nozzle v (pH or de	Additives/We D: Type: escription):	Nozzle Ar	r Sale: ngle:	Pressure: Variability	
Permit No.: Total L or kg: Equipment Type: Date Last Calibrated Weather Showers Overca Rainfall (24 hours before: Time (show time	d: st ☐ Lig before and mm	ht Cloud after)	Water Quality d	Nozzle v (pH or de	Additives/We Distribution Distr	Nozzle Ar	r Sale: ngle: mm	Pressure:	
Permit No.: Total L or kg: Equipment Type: Date Last Calibrated Weather Showers Overca Rainfall (24 hours before: Time (show time in this column)	d: st ☐ Lig before and mm	ht Cloud after)	Water Quality d	Nozzle v (pH or de	Additives/We Distribution Distr	Nozzle Ar	r Sale: ngle: mm	Pressure: Variability	



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.

Re-entry period

Re-entry periods and any specific personal protective equipment (PPE) to be worn as advised on the label help manage the risk associated with dermal (skin) contact with spray deposits. Include re-entry periods (see Table 34) 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 the field needs to be entered before the spray is dry, limit the duration of entry and wear the PPE specified on the label.

Even after the re-entry period has been observed, some protective clothing may be advisable. If not specified, appropriate PPE should be determined using a risk assessment.

Withholding period

A withholding period (WHP) is the minimum period from when a pesticide is applied to when the treated area is allowed to be grazed, cut for fodder or harvested (see Table 34). 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 are unlikely to be exceeded as long as pesticides are used in accordance with approved label instructions. Residue limits for exported products are set by the importing country.

Label WHPs assume label compliance and effective application techniques, including even coverage with well-maintained equipment. Excessive residues may still occur due to a range of factors, including mixing issues, inappropriate application volumes, worn nozzles, or an overlap in sprayed areas.

Crop residues MUST NOT be fed to stock if any product that specifically prohibits grazing or cutting for stock feed has been applied to that crop. Crops treated with a product that has a no grazing WHP specified should also not be grazed either before or after harvest. Contact the relevant chemical manufacturer for advice on managing chemical residues in stock.

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS.

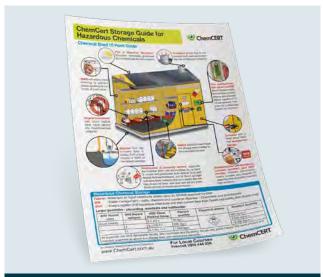
Handling and storage

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 any potential negative impacts to you, your staff, your business, your neighbours and the environment

Many registered pesticides are classified as hazardous chemicals, or pose some degree of health risk to those who use them or are exposed to them. Workplace health and safety regulations exist to protect workers from both short and long term health effects of exposure to hazardous chemicals.

Avoid transporting 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, maintain an up-to-date collection of easily accessible copies of Safety Data Sheets (SDS) for all products used. *my*BMP provides guidance and resources to meet legal requirements for handling, storage and application of agrochemicals. It also includes templates to help document farm-specific procedures to minimise harm and respond in the event of an injury, fire, or spill. These procedures must be communicated to all staff.



This storage guide can be downloaded from ChemCert www.chemcert.com.au/resources

Safe disposal

Disposing of empty containers

Empty chemical containers present a risk to people and the environment. Clean 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**

receival 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.

Intermediate Bulk Containers (IBCs) are not recycled by the drumMUSTER program, however a quick and easy Agsafe guide is available on how to send IBCs back for recycling or reuse.

drummuster.org.au/container-recycling/ the-abcs-for-your-ibcs

Disposing of unwanted chemicals

Unwanted agrichemicals may result from discontinued use due to changes in cropping or animal practices, development of newer/more effective/safer chemicals, or changes in a chemical's registration and/or banning from use. They may also be due to unknown product, property sale; inherited product or deceased estate. Any unwanted or unknown chemicals held on farm are potentially hazardous and must be disposed of responsibly and lawfully.



ChemClear program
1800 008 182
chemclear.org.au



ChemClear is an industry stewardship program that collects currently registered agricultural and veterinary chemicals at the end of their life cycle, or when they become surplus. The program aims to meet disposal requirements of agvet chemical users and prevent potential hazardous chemicals from being dumped in landfills, creeks or otherwise inappropriately disposed of.

- Take an inventory of any unwanted rural chemicals, including all identifiable container features (e.g. label, manufacturer, expiry date, container size and the remaining quantity left in the container). An inventory form can be obtained from the ChemClear website.
- 2. Register the inventory for the next collection in your area. Book on freecall 1800 008 182; fax 03 9371 8501 or at the chemclear.org.au
- 3. Continue to store your registered chemicals safely and securely. ChemClear will contact you direct to advise the location for retrieval.
- Deliver chemicals ensuring that transportation is safe (never place chemicals in the boot of a car or back of a station wagon). Refer to the ChemClear website for more information.

Group 1 chemicals (currently registered, within 2 years of expiry/deregistration, or containers displaying the drumMUSTER logo) are collected free of charge under the program. Group 2 chemicals (no longer registered, do not display the drumMUSTER logo, unknown, unlabelled, out of date, or mixed product) attract a fee for disposal, although the ChemClear program covers the transport costs. This fee is payable directly to the contractor after a quote has been accepted by the holder of the chemicals. Individual state EPA funding may be available from time to time to subsidise disposal of Group 2 chemicals.





A not-for-profit subsidiary of CropLife Australia, Agsafe helps promote the safe and responsible management of agricultural chemicals. They assist 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.

<mark>🏠 (02) 6206 6888 🏻 🌐 agsafe.org.au</mark>



TABLE 34: 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	Re- entry	Withholding (days)*		
		group	entry	Harvest	Stock	
	Abamectin	6	dry	20	20	
	Acetamiprid	4A	dry	10	NG	
	Afidopyropen	9D	dry	7		
	Alpha- cypermethrin	3A	24 hrs	14	_	
	Amorphous silica	_	dry	0	0	
	Bacillus thuringiensis	11A	N/A	0	0	
	Bifenthrin	3A	dry	14	NG	
	Beta- cypermethrin	3A	_	14	_	
	Buprofezin	16	dry	14	NG	
	Chlorantraniliprole	28	N/A	28	NG	
	Clitoria ternatea extract	UNE	dry	0	_	
	Clothianidin	4A		5	NG	
	Cyantraniliprole	28	dry	14	NG	
	Cypermethrin	3A	12 hrs	14		
	Deltamethrin	3A	dry	7	NG	
	Diafenthiuron	12A	24 hrs	14	NG	
S	Dimethoate	1B	dry	14	NG	
ide	Dimpropyridaz	36		28	NG	
itic	Dinotefuran	4A	dry	14	NG	
Insecticides and miticides	Emamectin benzoate	6	12 hrs	28	NG	
Sa	Esfenvalerate	3A	dry	7	_	
ide	Etoxazole	10B	dry	21	NG	
tic	Fipronil	2B	dry	28	NG	
se	Flonicamid	29	dry	7	NG	
=	Gamma-cyhalothrin	3A	dry	21	_	
	Helicoverpa NPV		dry	0	0	
	Imidacloprid	4A	12 hrs	91	NG	
	Indoxacarb	22A	dry	28	NG	
	Lambda- cyhalothrin	3A	dry	21	_	
	Magnet®	_	24 hrs	See inseemi		
	Methomyl	1A	24 hrs	0	NG	
	Paraffinic oil	UNM	_	1	_	
	Pirimicarb	1A	dry	21	21	
	Phorate	1B	48 hrs	70	70	
	Propargite	12C	dry	28	NG	
	Pymetrozine	9B	dry	28	NG	
	Pyriproxyfen	7C	24 hrs	28	NG	
	Spinetoram	5	dry	28	NG	
	Spirotetramat	23	dry	21	NG	
	Sulfoxaflor	4C	dry	14	NG	
	Thiamethoxam	4A	dry	28	NG	
	Thiodicarb	1A	24 hrs	21	21	

		• • •					
	Active		MoA group	Re- entry	Withholding (days)*		
			group	entry	Harvest	Stock	
		Clitoria ternatea extract	_	dry	0	_	
7	des	Metentrifluconazole (PERMIT)	3	_	30	NG	
Fungicides	rungic	Pyraclostrobin/ Fluxapytoxad (PERMIT)	7/11	dry	30	NG	
		Quintozene	14	dry	N/A	NG	
		Tolclofos-methyl	14	dry	N/A	N/A	
		Carfentrazone-ethyl	desiccant (14)	dry	1	NG	
		Diquat	desiccant (22)	dry	N/A	1 day	
-	~	Ethephon	conditioner	4 hrs	14	NG	
2	: = =	Mepiquat	PGR	dry	28	NG	
, and a	Other (including aids & adjuvants	Paraffinic oil & other non-ionic surfactants	adjuvant	_	1	_	
7:0	alds	Paraquat + diquat	desiccant (22)	dry	7	1-7	
2	20	Petroleum oil	adjuvant	_	1	_	
10.10	מחוטו	Pyraflufen-ethyl	defoliant (14)	dry	7	7	
	٥	Sodium chlorate	desiccant	dry	0	NG	
4	בב	Thidiazuron	defoliant	dry	N/A	NG	
Ċ	כ	Thidiazuron/ Diuron	defoliant (-/5)		N/A	NG	
	Thidiazuron/ Pyraflufen-ethyl	defoliant + boll opener (-/14)	dry	7	NG		

dry = do not re-enter field until spray has dried.
NG = no grazing and/or feeding trash to livestock.
— = not specified or unknown.
N/A = not required when used as directed.
*Refer to label for export market requirements and slaughter

intervals.

Cotton growth regulators and harvest aids

he 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 withincanopy light interception, reducing fruit retention, increasing the risk of boll rots, and delaying crop maturity. Large dense canopies also pose a challenge for pest sampling and insecticide penetration efficacy. Mepiquat chloride (also known as pix) is used to moderate canopy expansion by reducing gibberellin (a natural growth regulator within the plant). While it will not alter already

expanded/matured growth, it remains active in the plant for up to 2 weeks after application, impacting the actively growing cells of the plant (i.e. the elongating stems, leaves and roots).





What is pix?

youtu.be/cIFpyymWW6Q

When making the decision to regulate crop growth, it is critical to consider the presence (or imminent likelihood) of other factors or stresses that may influence canopy expansion (e.g. temperature, humidity, soil moisture or nitrogen status) and adjust the timing and rate of applications accordingly. Cotton is sensitive to environmental changes and stressed plants will respond differently to mepiquat chloride than crops growing under optimum conditions.

Note: Some defoliant products containing ethephon are labelled as a 'growth regulator'. Ethephon is used for preparing the crop for harvest and will cause significant fruit loss if applied to immature crops.

For more information refer to the Managing crop growth chapter of the Australian Cotton Production Manual cottoninfo.com.au/publications/australian-cotton-production-manual

For cotton production in the tropics, see NORpak Burdekin cottoninfo.com.au/publications/norpak for detailed mepiquat chloride usage guidelines for wet season production.

Harvest aids

Harvest aids can be categorised by mode of action within the plant:

- Defoliants (e.g. thidiazuron) impact plant hormonal balances to enhance natural plant senescence and cause the leaves to fall off. Defoliant activity is HIGHLY temperature dependent.
- **Desiccants** (e.g. sodium chlorate, paraquat) dehydrate and kill the leaves within one to several days. They are often used to remove stubborn leaves after defoliation or kill juvenile re-growth.
- Boll openers/conditioners (e.g. ethephon) are often applied in tandem with defoliants to enhance boll opening through increased ethylene release and withinplant synthesis that promotes abscission and leads to a quicker separation of boll walls (carpels).

Both the crop senescence process and the plant's response to applied harvest aids are heavily influenced by plant and environmental factors. Cotton leaves naturally senesce (detach and fall off) when they get old, but a cotton plant would not normally lose all its leaves at once. The application of defoliants to induce senescence is therefore a key component of harvest management. Artificially-induced defoliation ideally enables leaf separation while the leaf remains green, with the fresh 'weight' of the leaf helping it reach the ground and reducing the potential

for leaf trash in harvested modules. Rapid leaf trauma from desiccation by herbicide or frost usually kills the leaf blade before the leaf drops, and can result in dead leaves remaining in the canopy.



Desiccants dry all plant parts (including stems), potentially increasing the trash content of harvested lint. Avoid them unless conditions (e.g. very cold weather) do not enable the effective use of defoliants. Desiccants are also a reliable method to reduce leaf regrowth. High rates of some defoliants can act as desiccants.

Boll opening is a largely mechanical process of boll wall dehydration, causing the boll to split open and unfurl. Leaf removal exposes bolls to more direct sunlight; the increased temperatures promote maturation, and drying and cracking of the boll walls. Only consider using boll conditioning/opener products if the bolls that will be forced open are mature; if applied prior to boll maturation they may cause bolls to shed and reduce yield. The safe timing for defoliation is when the youngest boll expected to reach harvest is physiologically mature. This usually occurs when 60-65% of bolls are open.

Wetting agents and spray adjuvants (e.g. paraffinic oil, non-ionic surfactants or petroleum oil) are used to assist with defoliation as cool temperatures, low humidity and water stress prior to defoliant application can result in increased wax and thickness of the leaf cuticle, reducing the efficiency of chemical uptake.

Improving defoliation product performance

In addition to timing, it is important to consider product, rate and application. If rates are too high, plant cells may die before releasing enough ethylene to cause defoliation, resulting instead in leaf desiccation. Temperature is critical (warmer conditions improve crop response), so defoliate before the onset of frost. Apply defoliants during the day when conditions are warmer to assist uptake. Avoid application if there is a risk of rainfall shortly afterwards.

Plants that are naturally beginning to senesce as the bolls mature will be much more responsive to applied defoliants than plants that are either not in decline or showing signs of continued growth. Encourage senescence by having soil moisture at refill just prior to defoliation and avoid excessive nitrogen application. Crops that are 'navy' green at maturity (as opposed to those showing signs of leaf aging and senescence) are more difficult to defoliate. For more information, refer the 'Preparing for harvest' chapter of the Australian Cotton Production Manual.

Satisfy yourself that the chemical you choose is the best one for the crop and situation. Before use, note any specific label instructions relating to rates, timing, application and safety. Take every precaution to minimise the risk of causing or suffering spray drift damage.





Cottoninfo booklet on defoliation cottoninfo.com.au/publications/

cottoninfo.com.au/publications/ defoliation-optimising-your-endseason-management





Pesticides and the environment

he cotton industry's guidelines for minimising risk to the environment are a component of the *my*BMP program.

Pesticides, carriers, surfactants, and pesticide metabolites can be inherently hazardous for aquatic organisms, insects (including bees), birds, and other fauna. The risk that a particular product poses to the environment (native terrestrial and aquatic plants and animals) is reflected in statements on the label under headings like 'Protecting wildlife, fish, crustaceans and the environment'.

Pesticide residues may accumulate in animals treated with pesticides or fed any crop product, including crop residues, that have been sprayed with pesticides. Animals that test positive for chemical residues (i.e. with readings which exceed maximum residue limits) at slaughter will be rejected.

Pesticide residues may also contaminate other plant products for human use and consumption. Observe harvest withholding periods on the pesticide label and do not assume that in the absence of a withholding period or after the expiry of a withholding period that plant products will be free of residues.

Significant off-target environmental damage can be reported to APVMA's adverse experience reporting program at <u>apvma.gov.au/node/86336</u> and 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 indicator currently used to assess the average amount of toxic pressure on the environment from pesticides applied on one hectare. To reduce your ETL, aim to reduce total volume of pesticides used, as well as selecting pesticides with lower toxicity.

A factsheet on how pesticide use in cotton has changed over time for the better is available from the the Australian cotton industry's sustainability website:

australiancottonsustainability.org.au

Protecting the environment

The best way to manage any long term adverse environmental risk is to work with spray applicators to develop a spray plan that identifies environmentally sensitive areas, choose products and equipment that have the lowest risk profile without compromising effectiveness, follow the protection statements on labels, ensure that sprays hit the target and that drift is minimised, and to dispose of chemical containers and waste in accordance with label directions and codes of practice.



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 many 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 well away, and use bunding/sumps to prevent movement of concentrate or rinsate into surface waters.
- Install valves that prevent back-flow in equipment used to fill spray tanks from surface waters and in suction lines for chemigation systems that draw directly from surface waters.
- Avoid aerial sprays while fields are being irrigated.
- Build sufficient on-farm storage capacity (including provision for storm runoff) to contain pesticidecontaminated tail water from irrigation.
- Spray in an upstream direction (when spraying near water is necessary), to reduce the maximum concentration at any one point in the watercourse.
- Use only registered products to control aquatic weeds, e.g. Roundup Bioactive® rather than Roundup®.
- Avoid disposal of used containers in surface waters and on flood plains and river catchments.

Birds

Broad-spectrum insecticides can be particularly toxic to birds, especially in granular formulations, and insecticidal seed dressings can pose similar risks. Spillages can be very hazardous as birds can easily ingest a toxic dose from a small area.

- Ensure complete incorporation beneath the soil, particularly at row ends where spillage may occur.
- Immediately clean up spillage, however small.

Bait materials for the control of rodents or soil insect pests can also be hazardous to birds and other fauna, either through direct consumption of the bait or from feeding on bait-affected animals or pests.

- Ensure even bait distribution, with no locally high concentrations.
- Don't bait over bare ground or in more open situations, such as near crop perimeters, where birds may see the baits.
- Don't bait near bird habitat such as remnant native vegetation.
- Use bait stations to prevent bird access, particularly near bird habitat.
- Only bait where pest pressure is high.
- Bait late in the evening when birds have finished feeding.
- Promptly collect and bury rodent carcasses in open situations



Foliar-applied insecticide sprays can also be hazardous to birds, either because of direct contact with the sprayed chemical, or by feeding on sprayed insect pests or crops.

Even where birds are not killed, they may be more vulnerable to predation. Contaminated seed and insects collected from sprayed fields by parent birds can also be lethal to chicks still in the nest.

- Communicate with spray operators where known sensitive areas exist (such as nesting sites during waterbird breeding events).
- Minimise drift into remnant vegetation, wildlife corridors, nesting sites, or other bird habitats.
- Actively discourage birds from feeding in crops that are to be sprayed.

Pesticides can also indirectly impact bird populations through the loss of plants and animals on which they feed and through loss of habitat.

- Protect sensitive areas such as remnant vegetation, riparian areas and waterways from spray drift.
- Where possible use target-specific as opposed to broadspectrum pesticides (that are more likely to impact on non-target organisms and plants in the environment) and adopt an integrated approach to controlling pests.
- 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 on your farm:

- Do not lay baits at times or locations where native wildlife are likely to be harmed.
- Place baits and/or design bait stations so that wildlife access is minimised and tie or bury baits (where applicable) to limit removal by non-target species.
- Regularly check and replace baits to reduce excess baiting and to be more effective.
- Check if your state or territory has additional requirements for using vertebrate poisons.

Soil health

Pesticides can have undesirable side effects on soil biota. The impacts are highly variable, influenced by the ingredients and application rate of the product(s), the application method, soil conditions (including temperature, moisture, and organic matter), the speed of chemical degradation, and the extent of leaching from the site. Generally, herbicides are less toxic than insecticides, with fungicides most likely to cause harm to soil biota.

A Soil Sustainability Framework to promote soil health in Australian cotton farms is under development. For more information on the key principals involved in maintaing soil health, download australian-cotton-soil-health-framework.pdf

A relatively easy way to check your soil's biological health is the 'Soil your Undies' challenge. Find out how in a series of three videos at youtube.com/CottonInfoAust

Remnant native vegetation

Remnant native vegetation (i.e. any native patches of trees, shrubs or grasses that still remain in the landscape) can be damaged by herbicide and defoliant poisoning either via leaching through the soil or absorption through the leaves.

- Prevent drift by implementing best practices for spray application.
- Install natural or artificial barriers to intercept spray drift.
- Adhere to product label no-spray zone instructions.
- Select target-specific herbicides.
- Select non-soil active herbicides when remnant vegetation is nearby.
- Use an Integrated Weed Management (IWM) approach when managing environmental weeds.

Native revegetation options

The Native Revegation Guide for Australian Cotton Growers is a resource to help cotton farmers plan, prepare, plant, grow, and monitor revegetation projects, providing practical and cost-effective solutions for restoring habitat connectivity and managing revegetation projects.

cottoninfo.com.au/publications/nativerevegetation-guide

Meet 3 different cotton growing family operations that have used the guide's 6 steps for success.

cottoninfo.com.au/publications/revegetationgrower-case-studies

GOLDACRES Sponsored by

Protecting pollinators

Ithough cotton is commonly regarded as being largely self-fertile and self-pollinating, pollinators, including bees, provide an important service to catchments and communities in which cotton is grown. Many solitary wild insect pollinators are also present on and around farms but are less easily seen because they do not have the obvious hives of managed honeybees and social native bees. Remnant vegetation and other bushland on the farm should be thought of as pollinator habitat and protected accordingly.

As with many other crops, cotton can be a high-risk environment for bees as they are particularly susceptible to many insecticides. Contamination can occur through:

- · Direct contact with spray or spray drift;
- Subsequent contact while foraging; and,
- · Carrying of contaminated material back to the hive.

Insecticide contamination can result in individual bee death, diminished productivity or even destruction of the whole hive. Insecticides that are particularly toxic to bees are identified with a special statement on the label such as: Dangerous to bees. DO NOT spray any plants in flower while bees are foraging.

The Insecticide Resistance Management Strategy (IRMS; pages 64-65) highlights insecticides with a label warning about bee safety. The relative toxicity of cotton insecticides to honeybees is listed in Table 5 on pages 18-19.

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. The label provides information about what action must be taken to avoid impacting bees (label recommendations may vary between different formulations containing the same active ingredient). Refer to the APVMA Pubcris database to search for information about individual insecticides

mportal.apvma.gov.au/pubcris.

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS.

Protect bees when using fipronil

regarding bees, for example:
"Dangerous to bees. DO NOT apply where bees from managed hives are known to be foraging, and crops, weeds or cover crops are in flower at the time of spraying, or are expected to flower within 28 days (7 days for pastures and sorghum). Before spraying, notify beekeepers in order to keep managed bees out of the area. If an area has been sprayed inadvertently, in which the crop, weeds or cover crop were in flower or subsequently came into flower, notify beekeepers in order to keep managed bees out of the area for at least 28 days (7 days for pastures and sorghum) from the time of spraying. Where the owner of managed hives in the vicinity of a crop to be sprayed is not known, contact your State Department of Primary Industries/Agriculture, citing the hive registration number, for assistance in contacting the owner."



Bee ecology

Honeybee field activity is temperature and food-related; bees become more active above 12-13°C with most foraging activity occurring between 19-30°C. With water gatherers, the main flight activity occurs when temperatures are above the mid-thirties. Honeybees usually forage within 2-4 km of their hive, although they will fly long distances (7-10 km) in search of high quality food. Native bees often have much shorter flight ranges; as little as 500 m for some of the smaller species.

Bees collect nectar from 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.

Coolibah trees (Eucalyptus microtheca), black box (E. largiflorens) and river red gums (E. camaldulensis) are a primary source of nectar and pollen for honeybees and grow on the black soil plains along many of the river courses in cotton growing areas, flowering in response to good spring rains. In northern NSW, they flower mid to late December to about the end of January. This may vary by a few weeks in the southern/central areas of Queensland. When heavy flowering is expected, beekeepers may move large numbers of hives into these regions.

Reducing the risk

- Follow the registered label directions.
- Create a spray plan including risk mitigations for pollinators.
- Register with BeeConnected (see next page) and map crops on Satacrop. @ satacrop.com.au
- If beehives are in the vicinity of crops, notify apiarists at least 48 hours before spraying.
- Inform contract pesticide applicators of apiary locations.
- Pay particular attention to wind speed and direction, air temperature and time of day before applying pesticides.
- Use buffer zones to reduce the impact of spray drift or overspray on non-target crops and native vegetation.
- Avoid contamination of surface waters where bees may
- Use an IPM framework to minimise the need for pesticides.
- 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 in preference to wettable powders or microencapsulated formulations as bees can transport the particles back to the hive.
- Monitor crop development closely to identify when flowers will be present.
- Manage weeds to prevent them flowering in or near the crop.

With good communication and goodwill, it is possible for apiarists and cotton growers to work together to minimise risks to bees, as both honey (including pollination services) and cotton are important agricultural industries.



Other information sources





Communication between growers and beekeepers is critical in reducing the risk of unintended exposure of bees to products that may have the potential to negatively impact bee health. BeeConnected is a nation-wide, user-driven smart-phone app and website that enables collaboration between beekeepers, farmers and spray contractors to facilitate best-practice pollinator protection. Growers log the location of their properties and beekeepers can log the present or future locations of their beehives through a Google Maps-based platform with GPS capability. When a beehive is logged near a farmer's property, both users are sent automated notifications and can chat further about their activities via a secure internal messaging service. CropLife Australia provide BeeConnected to the community free of charge as part of their Pollinator Protection Initiative. The effectiveness of the BeeConnected system is greatest when as many growers and beekeepers as possible use the service. It is important to keep an eye out for bees or apiaries near your property that might not be logged in the system.

For more information and to participate in this great service

beeconnected.org.au





Insecticide-treated seed

CropLife Australia's Seed Treatment Stewardship Strategy outlines measures to reduce risks from dust generated during handling and planting of treated seed, and provides guidance on minimising off-target movement of crop protection products to protect important pollinators.

croplife.org.au/resources/programs/ seed-treatment-stewardship-strategy





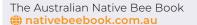
BeeAware is a hub of information for beekeepers and growers about honeybee biosecurity and pollination of agricultural and horticultural crops. The site contains information about the pollination of crops and how beekeepers and growers can work together to provide and receive best practice pollination services.

BeeAware 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





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 64-65) includes a best practice recommendation to avoid applying fipronil to flowering crops. The Australian Cotton Sustainability Update 2023 reported that the hazard to bees (from insecticides) has reduced by 91% since 2004.

Bees in cotton youtu.be/LBRUaqZaVoQ

Australian Cotton Sustainability Update 2023

crdc.com.au/publications/australian-cotton-sustainabilityupdate-2023

not logged in BeeConnected, note the registration



NSW DPIRD Biosecurity Helpline 1800 680 244

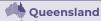
NSW Apiarists' Association

info@nswaa.com.au

mswaa.com.au

Apiaries on public land in NSW are displayed on the BPASS map

bpass.dpi.nsw.gov.au/s/view-sites-public



Biosecurity Queensland 🏗 13 25 23

Queensland Beekeepers' Association

qbabees.org.au

Western Australia

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Bee Industry Council of Western Australia

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nt.gov.au/bees

Plant Biosecurity Branch - Department of Agriculture and Fisheries

1 (08) 8999 2118



Victoria

Agriculture Victoria 2 13 61 86

⋈ honeybee.biosecurity@agriculture.vic.gov.au

Victorian Apiarists' Association

vicbeekeepers.com.au

Licensed apiary sites in Victoria can be identified in the Department of Land Water and Planning -Mapshare system

mapshare.vic.gov.au/MapShareVic

Glossary & acronyms

- **Abiotic.** Physical rather than biological (not derived from living organisms).
- **ACPM.** Australian Cotton Production Manual (available from CottonInfo).
- **ACRI.** Australian Cotton Research Institute, based in Narrabri, NSW.
- Action threshold. See threshold.
- **Adjuvant.** A substance (e.g. wetting agent, sticker, thickener, buffering agent) added to a spray mixture to enhance performance or overcome an inhibiting factor.
- **Allelopathy.** Chemical inhibition of one organism by another.
- **AMF** (formerly VAM). Arbuscular mycorrhizal fungi symbiotically colonise plant roots, transferring extra nutrients, especially phosphorus, from the soil in exchange for photosynthates from the plant.
- **Aphid colony.** Four or more aphids within 2 cm² on a leaf or terminal.
- **APVMA.** Agricultural Pesticides and Veterinary Medicines Authority.
- **Area wide management (AWM).** Growers working together in a region to manage pest populations.
- **Arthropod.** A member of the taxonomic group Arthropoda, that includes insects and mites.
- **At-planting insecticide.** Insecticides applied as a granule or spray in the seed furrow with the seed during planting.
- **Beat sheet.** Large sheet of yellow or white canvas, placed in the furrow and extended over the adjacent row. Plants are beaten against the sheet with a stick, dislodging insects which are quickly counted.
- **Beneficials.** Biological agents that are beneficial to the crop, including natural enemies and pollinators.
- **Beneficial to pest ratio.** Ratio used to incorporate predatory insect activity into pest management decisions.
- Better Cotton™. An international program supported by Cotton Australia (and administered through *my*BMP) supporting the production of sustainable cotton. Better Cotton growers must abide by the program's highly hazardous pesticide restrictions.
- **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 the application site and downwind sensitive areas. For some products the distance is mandated on the label. For boom and aerial spraying, it is measured from the edge of the sprayer swath closest to the downwind sensitive area.
- **Calendar sprays.** Application on a timed schedule, regardless of pest density or the actual need for pest control.
- **Carbamates.** Broad-spectrum insecticides classified into MoA Group 1A.
- **Chipping.** Manually digging out weeds with a mattock or chip hoe. Chipping usually cuts through the root. See also 'roqueing'.
- **Cold shock.** A delay in cotton growth/development caused by temperatures below 11° C.
- **Come Clean. Go Clean.** Industry slogan promoting thorough cleaning to prevent transfer of pests between fields and farms.
- Conditioner. Product used to hasten boll opening.
- **Consecutive checks.** Successive insect checks taken from the same field or management unit.
- **Conventional cotton.** Cotton varieties that are not genetically modified (in this guide the term is usually used to indicate absence of genes that produce Bt-derived insecticidal proteins).
- **Cotton bunchy top (CBT).** Cotton virus vectored by aphids.
- **Cotyledon.** Seed leaf (part of the embryo within a seed). Functionally similar but different in appearance to true leaves, which form after germination.
- **Crop compensation.** Plant's capacity to 'catch-up' after insect damage without affecting yield or maturity.
- **Cut-out.** Assimilate (photosynthesis products) demand exceeds supply and no more harvestable fruit is set.
- 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 methods of weed control from different control tactics in a short timeframe.

- **Dryland.** Non-irrigated cropping. Also often referred to as 'rain-grown' or 'rain-fed'.
- **D-vac.** Small portable suction sampler or blower/vacuum machine used to suck insects from the cotton plants into a fine mesh bag.
- Economic threshold. See 'threshold'.
- **Efficacy.** Effectiveness of a product or natural enemy against pests.
- **Egg parasitoids.** Parasitoid species that specifically target insect eggs, killing the developing host.
- **ETL (environmental toxic load).** An indicator used to assess the average amount of toxic pressure on the environment from applied pesticides.
- **Eretmocerus sp.** Parasitoid wasp of SLW that occurs naturally in most cotton regions or can be purchased for commercial release.
- **Exotic pests.** Pests that have not yet been detected in Australia
- **Flaring.** Increase in an arthropod pest population (usually in species with very fast life cycles) following a pesticide application targeted at another species.
- **Flush (irrigation).** High volume irrigation carried out in minimal time.
- **Food sprays.** Natural food products applied to attract beneficials, particularly predators, into crops to help control pests. Yeast-based sprays attract; sugar-based sprays retain beneficials already present.
- **F rank.** Ranking of each cotton variety in accordance with its resistance to fusarium wilt.
- **Frass.** Insect faeces is an indicator of insect activity, and sometimes helpful for identification.
- **Fruit retention.** Percentage of fruit (squares or bolls) retained compared with the overall number produced.
- **Fungicide.** A substance used to kill or inhibit the growth of fungi.
- GVB. Green vegetable bug.
- **Herbicide.** A substance used to kill or inhibit the growth of weeds.
- **Herbicide Resistance Management Strategy (HRMS).**Voluntary industry strategy designed to delay resistance to herbicides (predominantly glyphosate).
- **Highly hazardous pesticide (HHP).** Pesticide associated with siginificant environmental or health risks relating to acute or chronic toxicity, persistance, bioaccumulation or other hazardous properties (e.g. chemically reactive, flamamble or explosive). Specific restrictions on HHP use apply to growers in the Better Cotton™ program.
- **Honeydew.** Sticky sugar-rich waste excreted by sapsucking insects that can interfere with photosynthesis, promote sooty mould, affect lint quality and cause problems with fibre processing.
- **In-furrow insecticide.** See 'at-planting insecticide'.
- **Infested.** A large number of pests are present. Also used as a sampling term to indicate a pest presence of more than a given number of pests (see sampling information within aphid, mite and whitefly sections).

- **Insect growth regulator (IGR).** Compound that influences insect growth and development.
- **Insecticide.** A substance used to kill or inhibit the growth of insects
- **Insecticide Resistance Management Strategy (IRMS).**Voluntary industry strategy that imposes restrictions on pesticide use to help prevent the development of insecticide resistance.
- **Instar.** Juvenile insect development stages between moults.
- **Integrated disease management (IDM).** The integration of appropriate disease control strategies with management of the whole farming system.
- **Integrated pest management (IPM).** Using knowledge of pest biology, behaviour and ecology to implement a range of tactics in an integrated way to suppress or reduce pest populations.
- **Integrated weed management (IWM).** Strategy to plan and implement a range of different tactics to achieve sustainable weed management.
- **Knockdown (weed control).** Herbicide applied to rapidly control weeds.
- **Lay-by herbicide.** Residual herbicide used to control weeds during crop growth.
- **Larva.** Immature 'grub' stage of insects that undergo complete metamorphosis (e.g. moths, beetles, flies, lacewings). See also 'pupa'.
- Lesion. A localised, defined area of diseased tissue.
- Lock. Segment of cotton boll.
- **Management unit.** Farm area managed in the same way for the purposes of sampling and insect management.
- Maximum residue limit (MRL). Maximum amount of pesticide residue legally permitted on food products, based on levels considered toxicologically acceptable.
- **Mepiquat chloride.** Plant growth regulator used to prevent excessive growth or node elongation.
- **Miticide.** A substance used to kill or inhibit the growth of mites. Miticides may also have activity against other arthropds.
- Mode of action (MoA). Pesticide classification scheme based on target site that aims to prevent the development of cross-resistance to related pesticide compounds. Australia adopted the international numbering system for classifying herbicides in 2021.
- **Monitoring.** Checking crops (for insects, damage, weeds, growth stages etc). Also commonly called sampling or monitoring. Often refers to the gathering of data only; interpretation and management recommendations are then generated based on the data collected.
- Mycorrhizae. See 'AMF'.
- **Natural enemies.** Predators, parasitoids and pathogens of pests.
- **Natural mortality.** Expected death rate of insects in the field due to environmental factors (including natural enemies).
- **NAWF.** Nodes above white flower, a measurement of crop development.

- No-spray zone. See 'buffer zone'.
- **NPV** (nucleopolyhedrovirus). An entomopathogenic virus. Commercial formulations targeting *Helicoverpa* are available in Australia.
- **Nymph.** 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.
- **OTT.** 'Over the top' of the crop application of herbicides.
- PAMP. Pesticide application management plan.
- **Parasitoid.** Insect that lays its eggs on or in another arthropod; the larva develops within the host, killing it on emergence.
- **Parthenogenesis.** Reproduction occurs without fertilisation, resulting in a genetic clone.
- **Pathogen.** Microorganism that causes disease (e.g. Fusarium wilt is the disease caused by a soil-inhabiting fungus *Fusarium oxysporum* f.sp. *vasinfectum* (Fov)).
- PAWC. Plant available water capacity.
- **Peak flowering.** Period where the plant has the highest numbers of flowers opening per day.
- **Permits.** Issued by the Australian Pesticides and Vetinary Medicines Authority (APVMA), permits legalise the offlabel use of pesticide product or active for a specific minor use or in an emergency.
- **Pesticide.** A substance used for destroying or inhibiting organisms that are harmful to agricultural production.
- Pix. See 'mepiquat chloride'.
- **Plant-back period.** The minimum time recommended between a residual herbicide application and the planting of sensitive crops.
- **Plant growth regulator (PGR).** Chemical that can be applied to reduce growth rate and prevent rank growth.
- **Plant mapping.** Recording the fruiting dynamics of a cotton plant to help interpret the effects of pest damage or environmental factors.
- **Planting window.** Restriction on planting time used to restrict the number of pest generations exposed to particular control measures.
- **Post-emergent herbicide.** Herbicide applied after crop emergence.
- **PPE.** Personal protective equipment used when handling/applying pesticides.
- **Pre-emergent herbicide.** Residual herbicide applied prior to or at planting.
- **Presence/absence (sampling).** Noting presence or absence of a numerous pest rather than counting absolute numbers.
- **Prophylactic sprays.** Insecticides applied in anticipation of a potential 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 agrochemcials registered for use in Australia (portal. apvma.gov.au/pubcris). Use the 'Permits' tab within PubCRIS to search separately for products with temporary permission for off-label use.
- **Pupa.** Stage where larva undergoes transformation into an adult (e.g. from caterpillar to moth).
- **Pupae busting.** Tillage to reduce the survival of overwintering pupae.
- **Rank growth.** Excessive vegetative growth; usually managed using mepiquat chloride.
- **Ratoon cotton.** Regrowth from previous season's rootstock.
- **Re-entry period.** Mandatory period between chemical application and re-entry to the treated area.
- **Refuge.** Area left untreated with an insecticide or technology that generates unexposed susceptible individuals to act as a dilution factor when mating with resistant adults. Refuges are a requirement of the Bollgard RMP.
- **Remnant vegetation.** Patches of native trees, shrubs and grasses that remain in the landscape post-clearing.
- **Resistance (to pesticides).** Individual pests (arthropods, weeds or pathogens) develop a mechanism for dealing with a particular pesticide or mode of action group, potentially resulting in poor control (less than expected) or control failures (much less than expected).
- **Resistance management plan (RMP).** Proactive plan to mitigate the risks of resistance (to Bt toxins) developing. Complicance to the Bollgard 3 RMP is required under the Bt cotton Technology User Agreement.
- **Resurgence.** Increase in a targeted arthropod pest population following a pesticide application. Usually due to a reduction in beneficial populations.
- Retention. See 'fruit retention.'
- **Rogueing.** The systematic removal, usually by hand, of plant off-types (inferior, unhealthy, nontypical or not displaying sufficient characteristic varietal traits). Can also refer to hand weeding by pulling, which reduces the likelihood of regrowth (compared to chipping).
- **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/fungicide coating on cotton seeds that offers protection during germination and establishment.
- **Selection pressure.** Pesticide sprays remove susceptible individuals. More selection events from a particular chemical group leads to greater 'pressure' or chance of selecting a resistant population.

- **Senescence.** Biological deterioration associated with aging where plant cells stop growing and dividing, but without dying.
- **Shedding.** Abortion/loss of reproductive structures (squares, flowers or bolls) caused by environmental factors or pest damage.
- **Siphunculi.** Pair of wax-secreting tubular organs on the abdomen of aphids (also called cornicles).
- **SLW.** Silverleaf whitefly.
- **'Soft' approach.** Managing insect and mite pests using options that have minimal impact on beneficial populations.
- Square. Cotton flower bud.
- **Stacked genes.** Two or more genes that express similar activity (e.g. in Bollgard 3 there are three genes CrylAc, Cry2Ab and Vip3a), or different activities in the same variety (e.g. Bollgard + Roundup Ready®).
- **Stewardship.** Activities (such as resistance management strategies) that protect the long-term effectiveness of the chemicals and technology used to control pests and weeds in the Australian cotton industry.
- **Sucking pests.** Bugs with piercing mouthparts (e.g. mirids, aphids, whitefly).
- **Sweep net.** Large cloth net with long handle used to sample insects in the upper canopy.
- **Synthetic insecticides.** Non-biological insecticides (artificial versions of natural insecticides or synthetic molecules with insecticidal/miticidal activity).
- **Systemic pesticide.** Pesticide that is taken up through plant tissue (as opposed to remaining on the surface) and transported through the plant's vascular system.
- **Synthetic pyrethroids (SPs).** Broad-spectrum insecticides classified into MoA Group 3A.
- **Terminal.** Uppermost growing point, particularly on the main stem.
- **Threshold.** The point at which an action is taken. Action thresholds are based on a level/number of pests/damage. Economic thresholds consider the commodity value and treatment cost to identify a 'break even' point.
- **TIMS.** Transgenic & Insect Management Strategy (Committee).
- **Tipping.** Loss of the terminal, causing the plant to develop multiple stems.
- **Trap crop.** Small area of more attractive host plants that concentrates a pest population to allow easier management. 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.** Deliberately planted vegetation strips designed to protect adjacent sensitive areas (remnant vegetation, waterways, other crops) by capturing airborne spray droplets.
- **Visual sampling.** Counting insects in the field without the use of additional equipment such as a beat sheet.

- **Volunteer cotton.** Plants that have germinated and established unintentionally in-field or elsewhere (roadsides, fencelines etc).
- **V rank.** Ranking of each cotton variety in accordance with its resistance to verticillium wilt.
- **Waterlogging.** Excess water in a plant's root zone decreases the oxygen available to roots.
- **Wildlife corridors.** Narrow areas of habitat that provide either direct or discontinuous connection allowing fauna to move between larger areas of natural habitat.
- **Withholding period.** Minimum period allowed between application of an agrochemical and crop harvest (or use for stockfeed).

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