Cotton Pest Management Guide 2022–23

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Contents…

Cover photos courtesy Paul Grundy and Michelle Keenan.

Foreword

Tonia Grundy (DAF), **Susan Maas** (CRDC) and **Warwick Waters** (CottonInfo)

Welcome to the 2022-23 *Cotton Pest Management Guide*. 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 projects for the Australian cotton industry. A partnership between the Australian cotton industry and the Australian Government, CRDC exists to enhance the industry's performance. In 2022-23, CRDC will invest $18.6 million into RD&E projects on behalf of growers and the Government, across approximately 300 projects and in collaboration with over 100 research partners.

CottonInfo is an initiative of the joint venture partners: CRDC, Cotton Australia and Cotton Seed Distributors. It is designed to connect you – our cotton growers and consultants – with research and provide you with information, when and where you need it. The CottonInfo team takes the research and development invested in by CRDC and turns it into practical information and knowledge, applicable to you and your farm.

CottonInfo integrates closely with the industry's best management practices program, *my*BMP, supported by Cotton Australia and CRDC, which sets the industry's best practice performance criteria and provides a framework by which growers can participate in, and be accredited in, best practice.

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

The herbicide mode of action classification system (an important consideration for herbicide resistance management) has changed from letters to numbers. This year's edition includes both systems to help readers with the transition. The beneficial insects, key weed and key disease sections also contain additional images.

Remember, the CottonInfo team of regional extension officers, technical leads and *my*BMP experts are standing by 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 (www.cottoninfo.com.au), while best practice information for your farm is available at the *my*BMP website (www.mybmp.com.au). And you can find information about all of CRDC's investments online at www.crdc.com.au.

On behalf of CRDC and CottonInfo, thank you to 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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Integrated Pest Management (IPM)

Integrated Pest Management could really be called Intelligent Pest Management as it aims to use our knowledge and understanding of the pest, the crop, and the environment to minimise the likelihood of pest outbreak and reduce our reliance on insecticides. Some pest populations (such as mites, mealybug and whitefly) have limited chemical options for control and populations can quickly increase if IPM is not implemented.

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

The outcome of an effective IPM system is long term stable management of pests and beneficials, reducing the risk of resistance, so that economic losses of crop yield and quality and threats to human health and the environment can be minimised.

IPM – the basics

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

- **Farm hygiene.** Minimise cotton volunteers, ratoons and other weeds in fallow fields, field edges, roadways and drainage lines to limit the survival and spread of overwintering pests such as mealybugs or resistant aphids that might also carry bunchy top disease. **PUT SIMPLY, CLEAN FARMS TEND TO HAVE LESS PEST PROBLEMS THAN DIRTY ONES.**
- **Preventing problems.** Sowing date, crop sequences and field selection are just some of the tactics available to disadvantage pests. Avoiding back-to-back cotton in fields that had mealybugs to limit season carryover, or not planting as late so that your crop is not exposed to displaced populations of silverleaf whitefly (SLW) are just two examples of how to strategically avoid giving pests the upper hand.
- **Grow a healthy crop.** Cotton plants have a significant ability to recover from damage (especially early season damage) with no reduction in yield or delay in maturity. Plant monitoring in conjunction with regular insect monitoring allows an assessment of pest effects that might be difficult to detect in regular sampling. Plant monitoring can assist in decision making where pest levels are just below threshold or where there are combinations of pests present. Acceptable damage levels will vary depending on crop physiology stage, yield expectations and climatic conditions.
- **Sample your crop effectively.** Detecting and being able to quantify both pests and beneficials is a fundamental requirement for good decision making. Depending on the crop stage and pest or beneficial type, sampling techniques may vary. While some thresholds only require monitoring of one lifecycle stage, awareness of all life stages can help identify if a population has built up within the crop or has migrated in recently.
- **Take note of where your crop is at.** The development stage of your crop has a big bearing on (i) whether it is susceptible to yield loss and (ii) if it can recover from pest damage without intervention.
  - Minimal squares on a normal crop at 10-12 nodes might indicate poor retention due to pest or weather damage, but if the plant has been developmentally delayed, the retention levels may be appropriate.
  - Cotton can compensate for early season damage, particularly vegetative plant parts, if growing conditions remain favourable.
  - Ensure you can distinguish between vegetative and fruiting branches when measuring retention during early crop development. View a CottonInfo video that explains the difference between branch types in young crops: https://youtu.be/7PXIAuinmeY
  - Pests that can contaminate open cotton with honeydew (such as SLW or aphids) become more important as bolls open.
- **Know your enemy.** This guide outlines the key pests that you would expect to deal with on a regular basis when growing cotton. Key to managing these pests is to understand what they are, what damage they cause, preventative steps you can take to minimise their numbers or impact, how best to sample for them, when control is likely to be required (action thresholds), and what types of control techniques (chemical, biological or physical etc) are likely to be suitable and effective. Knowledge of the pest's interaction with the environment can help determine whether a spray is warranted. For example, two-spotted mite populations can be suppressed by cool conditions, but will increase rapidly when it is hot and dry.
- **Know your friends.** Cotton crops host a diverse array of beneficials that can suppress pests, particularly mites, SLW, aphids and mealybugs. Noting which beneficials are present when sampling can help inform your control decisions. Conserving beneficials can have a significant impact on whether you develop a mite or mealybug problem later in the season. Table 4 (see pages 14-15) allows you to compare the potential impact of different products so that you can make a balanced control decision.

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.**

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 alone at the end of the season is not sufficient to prevent pest carryover unless it is followed with tactics that prevent regrowth.**

- **Do you even need to spray?** Many pest insects have scientifically-based action thresholds that can help you decide whether your pest populations or crop damage might require control action. Resist the urge to use insecticides prophylactically with herbicide application operations. Economic thresholds are defined as the pest density or damage level at which control must be implemented to prevent economic loss, and should be considered in the context of other factors that may influence the need to spray. For pest abundance just over threshold but with low damage and high beneficial populations, consider delaying control for several days. This is a low risk strategy to allow time for beneficials to reduce pest levels to below threshold, thereby avoiding a potentially disruptive spray and reducing insecticide costs and selection for resistance. Conversely, for high pest damage with low beneficial populations, immediate control with an insecticide may be the best option. Thresholds for cotton aphid, two-spotted mite and SLW are based on cumulative population changes and require comparison of multiple samplings to determine if action thresholds have been reached.
- **Choose insecticides wisely.** When insecticide control is warranted make sure the product you have selected appropriately balances effectiveness against the target pest with any potential harm to natural enemies. Being aware of the product's mode of action (MoA) group, and 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. Also be aware of restrictions on the use of certain products as part of the Industry's Insecticide Resistance Management Strategy (IRMS). If several pesticide options are available, examine their selectivity profiles (see Table 4). For example, clothianidin will reduce populations of ladybird beetles (aphid predators) and *Eretmocerus* wasps (whitefly parasitoids) but conserve predatory bugs and thrips (mite predators). In contrast, the low rate of fipronil will reduce predatory bug populations, and conserve ladybird beetles, but its impact on the key wasp parasitoids of whitefly is unknown. Increases in populations of non-target pests such as aphid, mite and whitefly may follow insecticide applications if the beneficial populations keeping them in check are disrupted. Lower registered rates of a product may provide sufficient efficacy against the target pest, while minimising impact on beneficials.
- **Preserve the usefulness of insecticides and Bollgard.** The ability of insecticides or *Bacillis thuringiensis* (Bt) protein-expressing Bollgard crops to provide control depends on pest populations being susceptible to the active compounds. Follow label directions and consider both your application technique and environmental conditions to optimise chemical efficacy. Adhere to resistance management programs to ensure that the industry continues to have access to pest control tactics that give good control.
- **Look after bees.** Bees are particularly susceptible to many of the insecticides used on cotton farms (see Table 4). The productivity of hives can be damaged by direct or indirect contact with the applied product by foraging bees, or when insecticide drifts over hives or neighbouring vegetation. Always look for and follow label directions regarding impact on bees and refer to the *Protecting pollinators* section for more information.
- **Working with your neighbours.** Pests and beneficials do not recognise farm boundaries. Working with your neighbours to better coordinate planting, farm hygiene and crop spraying can provide benefits for the management of pests such as SLW on an area-wide basis. In some regions growers meet regularly at area wide management (AWM) meetings to discuss pest issues and work towards shared solutions. Talk with your nearest CottonInfo Regional Extension Officer (REO) about any AWM groups in your valley.

How do I implement IPM?

The great thing about IPM is that it does not have to be complicated – it's an evolving process that builds on taking practical steps to reduce the survival of pests. For example, a simple first step could be improved on-farm hygiene. This might be followed by a decision to avoid the use of a particular type of disruptive insecticide. See Table 1 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 familiar with pest management principles, consider challenging your boundaries by asking yourself some simple 'WHY' questions such as "Why were silverleaf whitefly higher or lower than last season?" or "Why am I using this particular insecticide?" The answers might provide insight into the most appropriate next steps for your management program. These types of questions are also good starting points in discussions with your advisor.

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

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

Useful resources:

***Pest and Beneficial Insects in Australian Cotton Landscapes*. Available from www.cottoninfo.com.au**

CottonInfo videos:
What is IPM? https://youtu.be/BdQRLx4hN5o
IPM in action https://youtu.be/k5-0XrzBEeg

TABLE 1: Seasonal activity plan for IPM

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

Protecting beneficials

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

Building and/or conserving beneficial populations is at the heart of integrated pest management (IPM). Pest management decisions need to be well informed and supported by effective sampling and valid control thresholds. Knowledge of the beneficials present, their activity on pests (see Table 2 for common examples), and the potential impacts of other pest control measures helps ensure the best management decisions are made for your crop.

Choose insecticides wisely to conserve beneficials

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

- Efficacy on the pest.
- Impact on beneficials, including bees (see Tables 3 and 4).
- Allowable usage in the cotton industry's Insecticide Resistance Management Strategy (IRMS).

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

Some insecticides are very selective and have little impact on beneficial insects (often referred to as 'soft'), while others are highly disruptive to beneficial populations ('broad-spectrum or 'hard'). Knowing the selectivity of an insecticide helps to assess the risk that following its use, populations of other pests may 'flare' (increase rapidly). The relative selectivity of insecticides available for use in cotton can be found in Tables 3 and 4 (which have been largely based on industry-funded research).

In addition to general impact, Table 4 lists the product's selectivity to specific types of beneficials. For example, if mealybugs are present, look for insecticides that have less effect on parasitic wasps and key mealybug predators such as lacewings and ladybird beetles. When products are registered for a range of rates, using lower rates may provide sufficient efficacy against some target pests, while minimising impact on beneficials. Note that these ratings are based on results after a single application, and multiple applications of a product with a low rank can still have a cumulative disruptive impact.

When selecting an insecticide, refer to the IRMS (pages 56-57) to reduce the risk of resistance, and follow the product's label directions.

CottonInfo video on conserving beneficials https://youtu.be/g3GYrt6QoN8

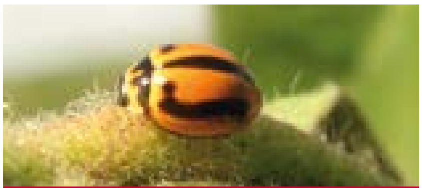
TABLE 2: Key beneficials and their activity on pest groups

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

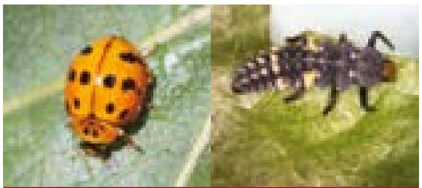
Examples of beneficial species

Predatory beetles

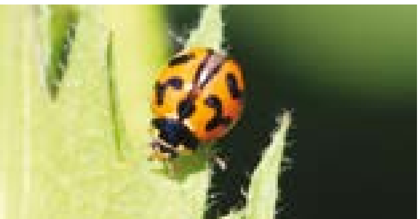
Red and blue beetle adult. 5 mm. (D. McClenaghan)



Striped ladybird. 4 mm. (L. Wilson)



3 banded ladybird. 8 mm. (P. Grundy)
Lava on right. (T. Grundy)

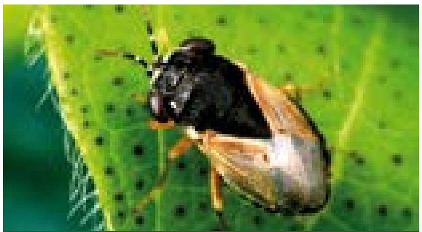


Variable ladybird. 5 mm. (P. Grundy)

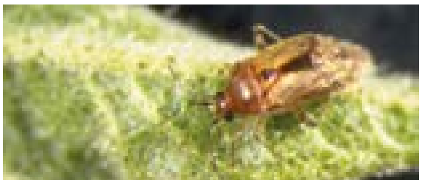
Predatory bugs

Apple dimpling bug (also known as yellow mirid). 3 mm. (J. Wessels)

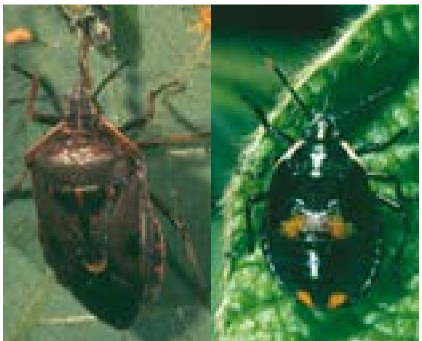
Damsel bug. 8 mm. (D. McClenaghan)
Nymph on right. (J. Wessels)



Big-eyed bug. 3 mm. (M. Dillon)

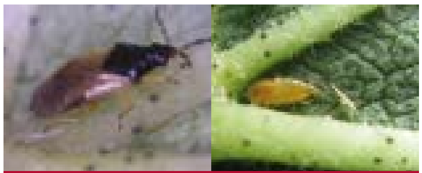


Brown smudge bug. 4 mm. (C. Mares)

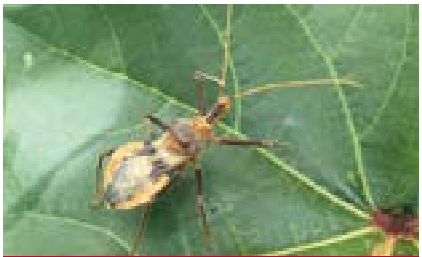


Glossy shield bug. 12 mm. (J. Wessels)
Nymph on right. (J. Wessels)

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

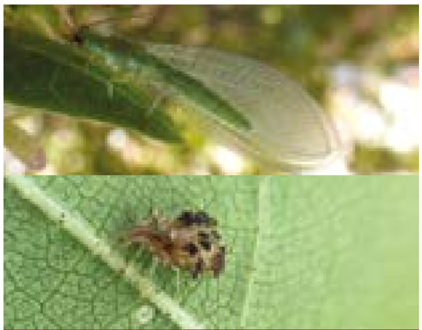


Minute pirate bug adult. 3 mm. (T. Grundy)
Minute pirate bug nymph feeding on adult thrips on right. 1–2 mm. (L. Wilson)



Assassin bug. 25 mm. (L. Wilson)

Lacewings



Adult green lacewing (larval stage is predatory). 12 mm. (T. Grundy)
Green lacewing larva below. 6 mm. (M. Miles)

Lacewing brown adult (8 mm) with larvae below. Both stages are predatory. (J. Wessels)

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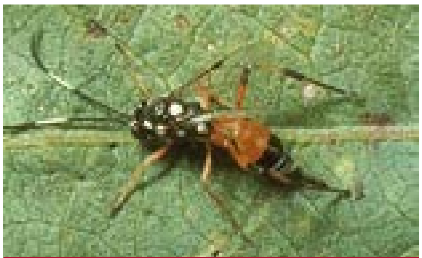
Examples of beneficial species (continued)

Parasitoid wasps


Two-toned parasite. 20 mm. (P. Reid)


The Microplitis wasp pupae is attached to this medium Helicoverpa larvae. 6–7 mm. (M. Dillon)


The banded caterpillar wasp is a pupal parasite capable of locating 'under-ground' pupal chambers. 14 mm. (P. Reid)


This Lysiphlebus wasp has recently emerged from the aphid 'mummy'. 2–3 mm. (M. Miles)

Spiders


Christmas spider. 15 mm. (P. Grundy)


Tangle web spider. 5 mm. (P. Grundy)

Others


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


Thrips feeding on a spider mite. (L. Wilson)

TABLE 3: Impact of insecticides at planting or as seed treatments on natural enemies in cotton

Active	MoA group	Rate	Target pest(s)					Persistence[1]	Impact on beneficials [2]	
			Wireworm	Mites	Mirids	Aphids	Thrips		Thrips	Others[3]
At planting (rate = g ai/ha)										
Phorate	1B	600	Y	Y	Y	Y	Y	Medium-long	Very high	Very low
Chlorpyrifos	1B	250-750	Y					Medium	—	Very low
Seed treatments (rate = g ai/100 kg seed)										
Imidacloprid + Thiodicarb + Fipronil	4A + 1A + 2B	350 + 250 + 50	Y				Y	—	—	—
Thiodicarb	1A	500					Y	Short	High	Very low
Thiodicarb + Fipronil	1A + 2B	259 + 12	Y				Y	Short-medium	High	Very low
Imidacloprid	4A	525	Y			Y	Y	Medium	Very high	Very low
		700	Y			Y	Y	Medium	Very high	Very low
Thiamethoxam	4A	280	Y			Y	Y	Medium	Very high	Very low

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.

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TABLE 4: Impact of insecticides and miticides on predators, parasitoids and bees in cotton

Insecticides (in increasing rank order of impact on beneficials)	MoA group	Rate (g ai/ha)	Target pest(s): *Helicoverpa*	Target pest(s): Mites	Target pest(s): Mirids	Target pest(s): Aphids	Target pest(s): Thrips	Target pest(s): Silverleaf whitefly	Persistence[3]	Beneficials[1]: Overall ranking	Predatory beetles: Total[4]	Predatory beetles: Red & blue beetle	Predatory beetles: Minute 2-spotted ladybird beetle	Predatory beetles: Other ladybird beetles	Predatory bugs: Total[5]	Predatory bugs: Damsel bug	Predatory bugs: Big-eyed bug	Predatory bugs: Other predatory bugs	Predatory bugs: Apple dimpling	Lacewing adults	Spiders	Hymenoptera: Total (wasps)	Hymenoptera: *Eretmocerus*[6]	Hymenoptera: *Trichogramma*	Hymenoptera: Ants	Thrips[7]	Pest resurgence[2]: Mites	Pest resurgence[2]: Aphids	Pest resurgence[2]: *Helicoverpa*	Toxicity to bees[8]
Bt[9]	11A		✔						Very short	Very low	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL				VL
NPV[10]	31		✔						Very short	Very low	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL				VL
Pirimicarb	1A	250				✔			Short	Very low	VL	VL	VL	VL	L	L	M	VL	VL	VL	VL	VL	M	M	VL	L				VL
BioPest®[11]		2-4%				✔			Short	Very low	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	L	—	L	M	VL				VL
Canopy®[11]		2%	✔		✔[16]	✔			Short	Very low	VL[17]	L	L	VL	VL	VL	VL	VL	VL	VL	L	VL	—	VL	H	VL				VL
Pyriproxyfen	7C	50						✔	Long	Very low	M	—	M	M	VL	—	—	—	—	L	VL	VL	L	VL	VL	VL				L
Parachute®[11]		2%	✔		✔	✔		✔	Short	Low	VL	L	VL	VL	VL	VL	VL	VL	VL	VH	VL	VL	—	M	M	L				VL
Sero-X®	UN	800	✔		✔			✔	Short	Low	VL	VL	M	L	VL	VL	VL	—	L	VL	VL	L	—	L	VH	VL				VL
Etoxazole	10B	38.5		✔					Short	Low	VL	VL	—	L	VL	VL	VL	VL	VL	VL	M	L	—	VL	VL	L				VL
Buprofezin	16	440						✔	Long	Low	L	H	VL	VL	VL	L	L	VL	VL	H	VL	L	—	L	VL	VL				VL
Indoxacarb (low+/-salt, oil)	22A	60			✔				Medium	Low	L	L	H	M	VL	L	—	L	H	M	VL	VL	—	VL	H	VL		+ve		H
Chlorantraniliprole	28	52.5	✔						Long	Low	L	M	M	L	VL	VL	VL	L	VL	VH	VL	L	—	L	L	VL		+ve		VL
Dicofol[12]	UN	960		✔					Long	Low	L	—	—	—	L	—	—	—	L	—	L	—	M	—	—	VL				VL
Afidopyropen	9D	10				✔			Medium	Low	L	L	H	M	VL	VL	VL	—	H	VL	L	L	H	H	VH	VL	+ve			VL
Spinetoram	5	48	✔				✔		Long	Low	M	M	H	H	VL	VL	VL	VL	VL	VL	VL	M	—	H	VH	VH	+ve			H[18]
Diafenthiuron	12A	350		✔		✔		✔	Medium	Low	M	H	VL	M	L	M	VL	L	H	VL	L	L	H	VL	H	L			+ve	VH
Pymetrozine	9B	150				✔			Short	Low	M	M	M	M	L	L	L	VL	H	M	L	L	L	L	M	VL				M
Indoxacarb	22A	127.5	✔		✔				Medium	Low	H[19]	L	VH	VH	L	M	L	L	VH	M	VL	L	—	VL	VH	VL		+ve		H
Cyantraniliprole	28	60	✔			✔[16]		✔	Long	Moderate	M	M	VL	L	M	M	M	H	L	VH	M	VL	—	VL	VL	H	+ve			VH
Sulfoxaflor (low)	4C	48			✔	✔			Medium	Moderate	L	L	L	M	L	VL	L	M	VH	H	VL	M	—	M	H	H	+ve		+ve	VH
Spirotetramat	23	96				✔		✔	Medium	Moderate	M	L	H	H	VL	VL	VL	VL	M	VH	M	M	M	M	M	M				H[18]
Flonicamid	9C	70			✔	✔			Medium	Moderate	VL	VL	VL	VL	H	H	VH	H	H	VL	M	M	L	H	VL	H				H[18]
Sulfoxaflor (mid)	4C	72			✔	✔			Medium	Moderate	M	L	M	H	L	VL	L	M	VH	H	VL	M	M	H	H	H	+ve		+ve	VH
Dinotefuran (low)	4A	18			✔			✔	Medium	Moderate	M	M	M	VL	M	VL	VH	M	H	VL	L	M	—	VH	H	M	+ve			VL
Abamectin	6	5.4	✔[20]	✔					Medium	Moderate	L	M	H	VL	M	L	M	M	H	VL	M	M	H	M	H	M				VH
Emamectin benzoate	6	8.4	✔						Medium	Moderate	L	VL	M	VL	H	H	H	H	H	L	M	M	H	M	VL	M				VH
Propargite	12C	1500		✔					Medium	Moderate	M	H	H	M	M	H	VL	VL	L	VL	M	M	L	H	H	M		+ve	+ve	VH
Acetamiprid	4A	22.5			✔	✔			Medium	Moderate	M	M	VH	H	M	M	H	M	VH	L	VL	L	VH	H	VH	VH				H
Clothianidin (low)	4A	25			✔				Medium	Moderate	M	VL	—	H	L	M	VL	VL	H	H	M	M	H	M	VH	VL			+ve	H
Amitraz	19	400	✔	✔[16]		✔[16]			Medium	Moderate	H	M	VH	H	L	—	—	—	H	VL	M	M	H	L	H	M				H
Skope® (low)[13]	4A+6				✔	✔		✔	Medium	Moderate	H	H	VH	VH	M	—	—	—	VH	M	VL	VL	VH	VH	VH	H				L

Fipronil (low)	2B	12.5			✔		✔		Medium	Moderate	L	L	H	L	L	H	L	L	VH	L	M	M	—	M	VH	VH	+ve	+ve	+ve	M
Chlorfenapyr (low)	13	200	✔	✔					Medium	Moderate	M	L	VH	VL	M	VL	H	H	VH	L	L	M	—	VH	H	M				VH
Sulfoxaflor (full)	4C	96			✔	✔		21	Medium	Moderate	H	L	M	H	L	VL	L	M	VH	H	L	M	—	H	VH	H	+ve		+ve	L
Fipronil (high)	2B	25			✔		✔		Medium	Moderate	L	L	H	L	M	H	H	L	VH	L	M	M	M	M	VH	VH	+ve		+ve	VH
Imidacloprid	4A	49			✔	✔			Medium	Moderate	H	L	VH	H	H	M	H	L	VH	L	L	L	VH	M	H	H	+ve		+ve	H
Clothianidin (high)	4A	50			✔				Medium	Moderate	H	VL	—	VH	M	M	L	VL	H	H	M	M	VH	H	VH	VL	+ve		+ve	H
Dinotefuran (high)	4A	75			✔			✔	Medium	Moderate	H	H	H	VL	H	M	VH	M	H	VL	L	M	—	VH	VH	H	+ve		+ve	VH
Methomyl	1A	169	✔						Very short	High	H	L	VH	VH	M	L	VH	L	VH	M	M	M	VH	H	H	H	+ve			VH
Thiodicarb	1A	750	✔						Long	High	VH	M	VH	VH	M	M	L	L	VH	VL	M	M	—	M	M	H	+ve	+ve		M
Dimethoate	1B	200		✔[22]	✔	✔[22]	✔		Short	High	M	M	H	H	M	H	—	H	H	VH	M	H	H	H	VH	M	+ve		+ve	VH
Chlorfenapyr (high)	13	400	✔	✔					Medium	High	H	M	VH	L	H	H	H	H	VH	L	M	M	—	VH	VH	M		+ve		VH
Skope® (high)[13]	4A+6		✔		✔			✔	Medium	High	VH	H	VH	VH	H	—	—	—	VH	H	L	VL	VH	VH	VH	VH				H[18]
OPs[14]	1B		✔	✔	✔	✔	✔		Short-medium	High	H	M	H	H	H	M	H	H	VH	L	M	H	VH	H	VH	H	+ve			M[18]
Carbaryl[12]	1A		✔						Short	High	H	—	—	—	H	—	—	—	—	—	—	—		—	—	H	—	—	—	H
Pyrethroids[15]	3A		✔	✔	✔			✔	Long	Very high	VH	—	—	—	VH	—	—	—	VH	VH	VH	VH	VH	VH	VH	VH	+ve	+ve	+ve	H

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

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

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Managing key insect and mite pests

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

Crop damage

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

CottonInfo video: What is causing my squares to shed? https://youtu.be/XMQr2mC25zc

Sampling and thresholds

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

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

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

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

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

Registration of a pesticide is not a recommendation for the use of a specific pesticide in a particular situation. The pesticide chosen should be the best one for the crop, pest and current circumstances. Individual insect control tables in this publication focus on in-crop applications. See Table 3 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 54-60 for more information). Insecticides can be costly, so follow industry thresholds (when available) to prevent unnecessary spraying.

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

Important – avoid spray drift

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

KEY INSECT PESTS

Transform® WG

Isoclast® active

INSECTICIDE

Cotton pests can suck the profitability right out of your crop. That's why switched on growers have been turning to Transform® WG Isoclast® active insecticide as part of a strategic Integrated Pest Management program.

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

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Aphids

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

Cotton aphid is the most common aphid pest in cotton. While the use of IPM practices have reduced the incidence of cotton aphids in most fields, occasional outbreaks may appear later in the season. Green peach aphid and cowpea aphid are relatively rare pests of young cotton, and populations of both species decline as temperatures increase (generally early December).

Damage symptoms

Nymphs and adults of cotton aphid feed on the undersides of leaves, in the terminals, on young stems and on developing fruit. They may cause stunting and downward cupping of the leaves, and in severe cases portions of a damaged leaf's upper surface will turn red. Feeding on terminals and fruit can also cause stunting. Populations of aphids that develop early and increase quickly can inhibit photosynthesis and reduce yield. The sugary 'honeydew' excreted by aphids can promote sooty mould. Cotton aphids have also been shown to transmit the disease cotton bunchy top (CBT; see page 105). Once bolls begin to open, the honeydew can contaminate the lint, which is why sampling at this stage of crop development is still critical. Green peach aphid causes more severe damage to plant growth than cotton aphid.

Aphids indirectly damage crops by transmitting cotton diseases.
(Lewis Wilson)

Sampling

Aphid populations are sampled visually. Focus on non-winged adults and nymphs. Winged adults may be transitory, while the presence of non-winged adults together with their nymphs indicates that a population has settled in the crop.

Species identification

As the different aphid species differ in their potential to damage cotton or spread CBT, identification is important. Verify which aphid species is present (particularly early in the season) before implementing any management strategies. Note that the species composition may change during the season. Aphid species can be distinguished by close examination with a hand lens. Green peach aphids are pale green and more oval than cotton aphids, 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 don't have tubercles (the head is smooth between the antennae) and the siphunculi are shorter. Adults of cowpea aphid are shiny black and nymphs are always dusky matt grey, while adults and nymphs of cotton aphid are matt and vary widely from yellow, green, olive, brown to dull black. The siphunculi of adult cotton aphids are always black. If you are unable to make a determination, or suspect more than one species could be present, contact your nearest cotton REO to arrange an identification. Contact details are provided at the end of this publication.

CottonInfo video on aphid identification https://youtu.be/Vi07GhSoQtg

Methods

Check the population at least weekly: Begin aphid sampling at seedling emergence and continue until defoliation. Sample for non-winged adults and nymphs on the underside of mainstem leaves 3-4 nodes below the plant terminal. If a high proportion of plants have only the winged form, recheck within a few days to see if they have settled and young are being produced.

Seedling to first open boll: Use a 0-5 scoring system based on the number of aphids/leaf (see page 20). If hotspots of cotton aphid are found early season, monitor cotton in these areas for symptoms of CBT.

First open boll to harvest: Use a presence/absence scoring system. Check one leaf/plant. Choose a recently expanded leaf, from the 3rd, 4th or 5th node below the terminal. If necessary, mites can be sampled using the same leaf. Sample at least 20 leaves per location. Score a plant as infested if the leaf has 4 or more wingless aphids in any 2 cm^2 area. As wingless females surround themselves with their offspring, the indication of a growing aphid population is the clumping of differently sized aphids in a small area. Aphids are most abundant on the edges of fields so ensure some perimeter sampling occurs. Also assess plants for the presence of honeydew.

Thresholds

Cotton aphid

From the seedling stage until first open boll, thresholds are based on the potential for feeding damage of the aphid population to reduce yield. These thresholds are dynamic and consider the value of the crop and the cost of control as part of the decision. After first open boll, the thresholds aim to protect the quality of the lint by avoiding contamination of open bolls with honeydew and possible discolouration from sooty moulds. Since penalties for honeydew contamination are severe, thresholds aim to avoid lint contamination and discolouration.

CottonInfo video on sampling and management https://youtu.be/L9N64u1yi8E

Yield loss due to aphid vectored CBT is not considered by this threshold. 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 or within the field.

For situations where nearby weeds or ratoon cotton may act as a source for CBT infection, monitor for the presence or spread of aphids intensively (twice weekly). If aphids become established (evident by increasing numbers of mixed sizes) control may be required to prevent a subsequent CBT outbreak. Choose a selective option to conserve beneficials. Removing cotton ratoons/volunteers and weeds in and around fields well before cotton planting will reduce winter survival of aphids and carryover of CBT.

SEEDLING TO FIRST OPEN BOLL	FIRST OPEN BOLL TO HARVEST
Calculate the Cumulative Season Aphid Score (see page 20), and use to determine an estimate of yield loss	50% plants infested or 10% if trace amounts of honeydew present

Green peach aphid

This species can severely stunt young cotton plants. As it is more damaging than cotton aphid, the threshold for control is lower: 25% of plants infested. Populations can occasionally occur on seedling cotton. However as populations usually decline naturally when temperatures increase, it is unusual for control to be necessary.

Cowpea aphid

This species can also occur occasionally on seedling cotton crops, however populations usually decline quickly as temperatures increase. Control would only be needed if cowpea populations persisted (e.g. cooler temperatures) and plants were showing signs of damage and stunting.

Key beneficials

Predators – ladybird beetle adults and larvae, red and blue beetles, damsel bugs, big-eyed bugs, lacewing larvae, hoverfly and silverfly larvae (*Chamaemyiids*).

Parasitoids – (cause mummification) *Aphidius colemani, Lysiphlebus testaceipes.*

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

Selecting an insecticide

The insecticide products registered for the control of aphids in cotton in Australia are presented on page 22 (check label for target species). If aphid control is required early season, use a selective option to help conserve beneficial populations, in accordance with the IRMS (pages 56-57). These beneficials can assist in controlling any survivors from the insecticide.

Resistance profile

Aphids reproduce asexually. All the progeny of a resistant individual will be resistant. Once resistance is selected for in a population, it can quickly dominate and give rise to new, entirely resistant populations.

Resistance profile – cotton aphid

Neonicotinoid resistance was once widespread and is now essentially under control but there remains cross-resistance between acetamiprid, thiamethoxam, clothianidin and imidacloprid.

Resistance is being inadvertently selected in two ways. The first has been through the widespread use of neonicotinoid seed treatments and the second is through the use of foliar-applied products targeting mirids. Even when aphids are present at very low levels, resistance is being selected.

It therefore remains critical to follow the recommendations of the IRMS and rotate insecticide chemistries, taking into account the insecticide group of any seed treatment at-planting insecticide (see Table 3 on page 12). For example, phorate has cross-resistance with pirimicarb and dimethoate.

In the early 2000s, cross-resistance in cotton aphid between pirimicarb and dimethoate rendered these compounds ineffective. In recent years, resistance to these compounds has declined in southern growing regions but has re-emerged in northern tropical growing regions. Re-selection of resistance is a risk, and the IRMS stipulates that omethoate/dimethoate should not be used in rotation with pirimicarb, or vice versa.

When choosing an aphicide, consider previous insecticide choices for mirids as well as for aphids and rotate chemical groups. If a phorate side dressing was used then pirimicarb or dimethoate/omethoate should not be used as the first foliar spray since there is cross-resistance between them. Dimethoate/omethoate use will re-select for catastrophic pirimicarb resistance in aphids so do not use pirimicarb and dimethoate/omethoate in the same field.

Overwintering habit

Aphids don't have an overwintering form, but cool temperatures slow their growth rate dramatically. In cotton growing areas, aphids persist through winter on whatever suitable host plants are available, including cotton volunteers and ratoons, and ornamental garden species.

Alternative hosts

Cotton aphid has a broad host range, including many common weeds. Winter weed hosts include: marshmallow, capeweed and thistles. Ratoon or volunteer cotton is a host and can act as a green bridge for CBT. Some legume crops such as faba beans are also potential winter hosts. Spring and summer weed hosts include: thornapples, nightshades, paddymelon, bladder ketmia and Bathurst burr. Sunflower crops and volunteers also accommodate cotton aphid.

Cowpea aphid is more abundant in winter and has a broad host range. Populations in winter can be found on burr medic, marshmallow, dwarf amaranth, caustic weed and volunteer cotton, while summer hosts include hogweed, cathead, volunteer cotton, cobbler's peg, thornapples, tarvine, small crumbleweed, paddy melon and sowthistle.

Winter weeds that support green peach aphids include turnip weed and marshmallow. Spring germinations of peach vine and thornapples also host green peach aphid. Canola is an attractive host crop through late winter and early spring.

Further information:

CSIRO Agriculture and Food, Narrabri
Simone Heimoana: 02 6799 1592 or 0427 992 466.

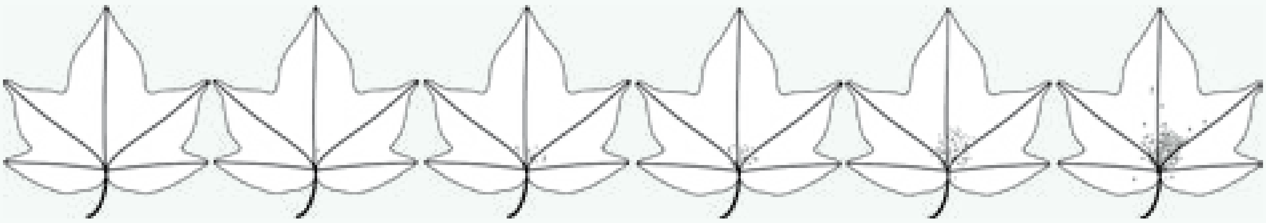
NSW DPI, Tamworth
Lisa Bird: 02 6763 1128.

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

STEP 1: Collect and score leaves.

Collect 20 leaves from each of several locations, taking only one mainstem leaf per plant from 3, 4 or 5 nodes below the terminal (these leaves can also be used for mite scoring). Sample regularly, as yield loss estimates will be most accurate when using the time aphids first arrive in the crop.

Estimate the number of aphids on the leaf and allocate each leaf a score of 0 to 5 (ignore pale brown bloated aphids as these are parasitised). Sum the scores and divide by the number of leaves to calculate the **Average Aphid Score.**



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

STEP 2: Calculate the cumulative season aphid score.

Convert the Average Aphid Score calculated in Step 1 to a **Sample Aphid Score** using the look-up table below to account for the length of time the aphids have been present in the crop. Find the value where the Average Aphid Scores from 'this check' and the 'last check' intersect, and multiply by the number of days that have lapsed between checks to calculate the Sample Aphid Score. If aphids are found in the first assessment of the season, assume the 'Score last check' was '0' and that it occurred 5 days ago.

As the season progresses, add each check's Sample Aphid Score to the previous value to give the **Cumulative Season Aphid Score**. Note that aphids can disappear due to predation by beneficials, changes in the weather or insecticide application. When aphids are sprayed, or if the Average Aphid Scores return to '0' in 2 consecutive checks during the season, reset the Cumulative Season Aphid Score to '0'.

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

STEP 3: Estimate the yield loss.

Use the Cumulative Season Aphid Score to estimate the **percentage yield loss** that aphids have already caused (excluding risks of yield loss from CBT) in the table below. The 'Days remaining' in the season is determined using the first time aphids are found in the crop, based on 165 days from planting to 60% open bolls.

For example, if aphids are first found 9 weeks (63 days) after planting, the days remaining would be ~100. When aphids are sprayed, or if they disappear from the crop then reappear later in the season, reassess the days remaining based on the number of days left in the season from the time of their reappearance.

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

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

TABLE 5: Control of aphids (refer to label for target species)

Active ingredient	MoA group	Cotton aphid resistance	Overall impact on beneficials*	Comments#
Paraffinic oil	No group	Unknown	Very low	Apply by ground rig using a minimum of 80 L/ha of water. If populations exceed 20 aphids per terminal shoot, in a mixture with another aphicide.
Pirimicarb	1A	Very low in southern growing regions. High in northern WA and north Qld. Cross-resistance to dimethoate/phorate	Very low	Thorough spray coverage essential for best results. Maximum 2 applications per season. Do not use as consecutive applications.
Afidopyropen	9D	Unknown	Low	Will disrupt insect behaviour and feeding. Provides a slow knockdown. Maximum 4 applications per season.
Diafenthiuron	12A	Very low	Low	Apply before damage occurs. Lower rate for ground rig application only. Maximum 2 applications per season.
Pymetrozine	9B	Unknown	Low	Apply prior to row closure on an actively growing crop with a developing population before honeydew damage has occurred. Maximum 2 applications per season.
Cyantraniliprole	28	Unknown	Moderate	Suppression only. Maximum 2 applications per season.
Chlorantraniliprole/ Thiamethoxam	28/4A	Cross-resistance between all the neonicotinoids	Moderate	Apply in early stages of population development. Maximum 2 applications per season. If a neonicotinoid seed treatment has been used, do not use as first foliar spray.
Spirotetramat	23	Unknown	Moderate	Use the higher rate when periods of high pest pressure or rapid crop growth are evident, when longer residual control is desired or when crops are well advanced. Do not re-apply within 14 days of a previous spray. Maximum 2 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 an aphid population in the early stages of development before honeydew is evident or aphid damage occurs. Thorough spray coverage is essential. 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 under sustained heavy pressure. Do not use as first foliar if neonicotinoid seed treatment used. Maximum 2 applications per season. If repeat applications are required, alternate with products from a different insecticide group.
Amitraz	19	Unknown	Moderate	Suppression when used for controlling *Helicoverpa* (*Helicoverpa* rates). Maximum 4 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 at 0.2% v/v (2 mL/L water) or equivalent organosilicon surfactant. Do not use as first foliar if neonicotinoid seed treatment used. Apply early in the establishment of an aphid infestation. Maximum 2 applications per season.
Dimethoate	1B	Very low in southern growing regions. High in northern WA and north Qld. Dimethoate is cross resistant to pirimicarb and phorate	High	Do not use where resistant strains are present. Do not harvest for 14 days after application. Do not graze or cut for stock feed for 14 days after application. Maximum 2 applications per season.
Chlorpyrifos	1B	Occasional – low	High	Use higher rates on heavy infestations. Maximum 3 applications per season.

Phorate (1B) is also registered for application at planting (Qld, NSW and WA only).
#For all control options always refer to the label for instructions.
*For more details about impact on beneficial insects (including bees), refer to Table 4 in this guide.

Armyworm

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

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

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

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

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

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

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

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

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

For chemical control options for armyworm species, search the PubCRIS and Permits databases at the APVMA website (https://apvma.gov.au/).

Lesser armyworm. (Melina Miles, Qld DAF)

Fall armyworm. (Melina Miles, Qld DAF)

Cluster caterpillar eggs. (Paul Grundy, Qld DAF)

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Green vegetable bug (and other stink bugs)

Nezara viridula

Several species of stink bug can be found in cotton, but the most common and most damaging is the green vegetable bug (GVB; *Nezara viridula*). There are also several species of predatory shield bugs that can be present, so correct identification is essential to making the most appropriate management decisions.

Damage symptoms

Both adult and nymph green vegetable bugs (GVB) cause dull to black shiny spots on the outer boll, warty growth inside the carpels and brown staining of lint in developing bolls. Severe cases may result in tight lock and yield loss. Damage symptoms cannot be distinguished from those caused by mirid or other boll-piercing bugs. Bolls aged up to 7 days old are usually shed. Bolls 8 to 24 days old can suffer significant damage resulting in incomplete development of one or more sectors (locks), stained lint and reduced yield. Older bolls are not susceptible to damage.

Sampling

Sample for adults and nymphs and monitor fruit retention at least weekly from the start of squaring, more often if numbers are close to threshold. The crop is most susceptible to damage from flowering through until one open boll/m. Smaller instars are less damaging than older instars so it is important to note the size of nymphs in order to use the thresholds correctly.

GVB are most visible early to mid morning. Visual sampling and beat sheets are equally effective checking methods from the start of squaring until flowering. However, from flowering onwards, beat sheeting is twice as efficient at detecting GVB, although it may still underestimate the actual field population, as the first and second instars tend to hide in the bracts and may be difficult to dislodge. Bug distribution is often uneven - increasing the number of samples will give more accurate results.

Thresholds

Sampling method	Adult GVB thresholds from flowering to harvest
Visual	0.5 adults/m
Beat sheet	1.0 adult/m
Damage to small bolls (14 days old)	20%

Converting GVB nymphs and other stink bugs to GVB adult equivalents

Other stink bugs that cause damage similar to that of GVB occasionally occur in cotton. However, their damage potential is less than that of GVB so their counts (and those of medium GVB nymphs) need to be multiplied by the appropriate GVB adult equivalent adjustment:

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

Green stink bug. (Joe Wessels)

Red banded shield bug. (Joe Wessels)

Brown stink bug. (Joe Wessels)

Harlequin bug. (Tonia Grundy, Qld DAF)

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)

Key beneficials

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

Parasitoids – *Trissolcus* is a wasp that inserts its eggs inside GVB eggs. After hatching, *Trissolcus* larvae remain inside the GVB egg and continue to feed and mature. *Trichopoda* is a fly which parasitises later instar nymphs and adults of GVB, laying its eggs on the outside of the bugs. The hatched larvae bore into the host, dramatically reducing the bug's feeding and egg production and ultimately killing them.

Selecting an insecticide

Insecticide products registered for the control of GVB in Australian cotton are presented in Table 6. Avoid mid-season use of dimethoate for GVB control if possible as this compound also selects for organophosphate/carbamate resistance in aphids, particularly if using an OP/carbamate in early season furrow treatments for thrips control.

Resistance profile

No GVB resistance to insecticides has been detected in Australia.

Overwintering habit

A high proportion of GVB adults enter a dormant phase (bronze colour) during late autumn and overwinter in a variety of sheltered locations such as 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.

Alternative hosts

In Queensland there are two GVB generations during the warmer part of the year. The preferred weed hosts of the first (spring) generation include turnip weed, wild radish, variegated thistle and early mungbeans. The second generation breeds in late summer and early autumn, with pulse crops (particularly soybeans and mungbeans) and blackberry nightshade (*Solanum nigrum*) as key hosts. GVB populations are usually much lower in mid summer, mainly due to a lack of suitable hosts. In NSW the two generations occur a little later compared to Queensland.

Further information:

CottonInfo video on GVB https://youtu.be/U9bCoVTgsN8

Qld DAF, Paul Grundy: 0427 929 172

Additional images of stink (podsucking) and predatory bugs can be found in the Beatsheet's resources pages https://thebeatsheet.com.au

ALERT: EXOTIC BUG THREAT

Brown marmorated stink bug.
(Kristie Graham, USDA ARS, Bugwood.org)

Brown marmorated stink bug (BMSB)

An exotic pest that could cause damage to crops including cotton, BSMB has been associated with cargo imports from shipping containers and machinery to household goods (including shoes and barbie dolls).

Monitor and report

If you spot any unusual stink bugs, Catch (if possible) and call the Exotic Plant Pest Hotline: 1800 084 881.

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

TABLE 6: Control of green vegetable bug

Active ingredient	MoA group	Overall impact on beneficials*	Comments#
Fipronil	2B	Moderate	Apply when pests appear. Use higher rate when higher infestations are present. Avoid repeated use 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 still be on plant 2 or 3 days after application but will have stopped feeding. Maximum 2 applications per season.
Acetamiprid	4A	Moderate	Apply with adjuvant as per label recommendations. May only provide knockdown and residual control for 7 days under heavy/sustained pest pressure.
Emamectin benzoate/Acetamiprid	6/4A	Moderate	Use higher rate on heavier populations and for a faster knockdown. Use non-ionic surfactant or organosilicone adjuvant as per label. Maximum 2 applications per season.
Dinotefuran	4A	Moderate	Apply when thresholds are reached. Ensure thorough spray coverage of the crops. 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	Apply when pests appear. Use higher rates for heavier infestations. Do not harvest for 14 days after application. Do not graze or cut for stock feed for 14 days after application. 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 4 in this guide.

Helicoverpa

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

Helicoverpa larvae are major pests of conventional cotton, capable of dramatically reducing yield. Widespread industry adoption of Bt cotton has dramatically reduced the need to control these larvae with insecticides, however even Bollgard 3 crops may have *Helicoverpa* present, and the risk of resistance requires careful management.

Damage symptoms

Larvae attack all stages of plant growth. In conventional cotton (non-Bt varieties), larval feeding can result in seedlings being tipped out, chewing damage to squares and small bolls causing them to shed, and chewed holes in maturing bolls, preventing normal development and encouraging boll rot. In any year an average of 15% of Bt cotton area may carry *Helicoverpa* larvae at or above the recommended threshold levels at some point during peak to late flower. In Bt cotton, chewing damage is mostly confined to fruit and may lead to yield loss.

Sampling

Visually sample the whole plant for *Helicoverpa* from seedling emergence in both conventional and Bt cotton crops. Check at least 2 times/week until the crop has 30-40% open bolls.

Sample at least 30 plants or 3 separate metres of row for every 50 ha of crop. Fields may not be uniform (e.g. lush areas may occur in head ditches that are more attractive to insects), and variability within the field may determine the minimum number of sampling points required. Larger samples will give more accurate estimates.

Note the individual egg and larval growth stages of the pest:

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

Eggs are laid on plant terminals, leaves, stems and the bracts of fruit. Larvae may be found on terminals, the upper or lower surface of leaves, inside squares, flowers and bolls and along stems. Note the species where possible.

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

Once squaring begins, note fruit retention or fruiting factors, to gauge what level of damage is being caused to the crop.

Also sample key beneficials to allow the beneficial to pest ratio to be applied (see page 28). Collect brown eggs to check for parasitism by *Trichogramma* spp. (the eggs will turn black).

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

Thresholds

Helicoverpa thresholds are based on the assumption of potentially mixed populations of *H. armigera* and *H. punctigera*.

Conventional cotton

Larval thresholds are preferable as not all eggs hatch. Early in the season eggs are particularly prone to desiccation and being washed or blown from the small plants. Natural mortality can be as high as 80% early season, 75% mid season and 60% late season.

Parasitism and predation can dramatically reduce egg survival (*Trichogramma* parasitoids have the potential to reduce egg survival by over 90%), and larval thresholds are also affected by beneficial insects. It is important to assess beneficial insect numbers when making pest control decisions. Also consider fruit retention when determining whether *Helicoverpa* have caused, or are at risk of causing economic damage.

SEEDLING TO FLOWERING	FLOWERING TO CUT-OUT
2 larvae/m or 1 larvae >8 mm/m	2 larvae/m or 1 larvae >8 mm/m or 5 brown eggs/m

CUT-OUT TO 15% OPEN BOLLS	15% TO 40% OPEN BOLLS
3 larvae/m or 1 larvae >8 mm/m or 5 brown eggs/m	5 larvae/m or 2 larvae >8 mm/m or 5 brown eggs/m

Bt cotton

Objectively assess larval size and exclude any very small larvae (<3 mm). There are no egg thresholds in Bt cotton, as research has shown no effect on yield from high egg lays (over 100/m).

SEEDLING TO 40% OPEN BOLLS
2 larvae >3 mm/m in 2 consecutive checks or 1 larvae >8 mm/m

Where larvae between 3 and 8 mm 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 3-8 mm larvae are above threshold on a given check, chances are that a large portion of these will ingest a sufficient dose of the toxin and die before the next check.

Using the beneficial to pest ratio

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

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

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

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

The beneficial to pest ratio incorporates parasitoids, particularly *Trichogramma*, in the calculation. The level of egg parasitism should be deducted from the number of *Helicoverpa* eggs before the beneficial to pest ratio is calculated. Levels of egg parasitism can vary greatly from farm to farm, region to region and from season to season. Generally levels decline as the season progresses. To assess parasitism, keep collected brown eggs at 25°C until they hatch (healthy) or turn black (parasitised).

Key beneficials

Predators of eggs – red and blue beetle*, damsel bug*, green lacewing larvae*, brown lacewing*, ants, yellow night stalker spiders, ladybird beetles and apple dimpling bugs.

Predators of larvae – glossy, brown* and predatory shield bugs, big-eyed bug*, damsel bug*, assassin bug*, red and blue beetle*, brown lacewing*, common brown earwig, lynx, tangleweb and jumping spiders.

Predators of pupae – common brown earwig.

Predators of moths – orb-weaver spiders and bats.

Parasitoids of eggs – *Trichogramma* spp., *Telenomus* spp.

Parasitoids of larvae – *Microplitis demolitor*, orange caterpillar parasite, two-toned caterpillar parasite.

Predators of late instar larvae – wolf spiders and carabids.

Parasitoids of pupae – banded caterpillar parasite.

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

Selecting an insecticide

Insecticides registered for the control of *Helicoverpa* in cotton are presented in Table 7 on page 30. The use of more selective insecticide options will help to conserve beneficial insects (see Table 4).

Be aware of resistance status in *H. armigera* and follow the insecticide resistance management strategy (IRMS) (pages 56-57).

Resistance profile

H. armigera

Conventional insecticides

With the introduction of Bt cultivars, *H. armigera* is no longer front of mind as a major pest of concern, however maintaining effective control is critical for conventional cotton and other crops such as pulses. Importantly, large plantings of Bt cotton do not change the overall frequencies of insecticide resistance genes in the *Helicoverpa* population and is unlikely to influence the rate at which *H. armigera* will develop resistance to conventional insecticides if significant selection pressure is imposed.

Results from an industry-wide resistance surveillance program, implemented by NSW DPI and supported by CRDC and GRDC, shows industry-wide resistance to indoxacarb in *H. armigera* are about 6%. Importantly, populations of *H. armigera* in Central and Northern Qld had levels of indoxacarb resistance 2.4-fold higher than Southern Qld and NSW during 2018-19, although resistance in most regions declined during the 2019-20 and 2020-21 seasons. Research suggests that indoxacarb resistant *H. armigera* are less likely to survive diapause which may partly explain why resistance has increased in regions where overwintering does not occur to any large extent.

Chlorantraniliprole resistance is stable (>0.5%) and there has been no recent detection of emamectin benzoate resistance. The industry has ceased monitoring broad-spectrum chemistry for resistance. However, field failures are likely for synthetic pyrethroids and carbamates if used to target *H. armigera.*

The use of conventional insecticides for control of *H. armigera* in conventional and Bt cotton crops should be based on relevant thresholds and the IRMS. As well as the cotton IRMS, it is important to adhere to the resistance management strategy (RMS) for the grains industry. www.ipmguidelinesforgrains.com.au/ipm-information/resistance-management-strategies/#heli

Adoption of resistance management tactics in grains will be critical for maintaining efficacy of indoxacarb, particularly in Central and Northern Qld where resistance risk is highest.

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

Bt cotton

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 the protein or 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 61-71.

H. punctigera

Conventional insecticides

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

Bt cotton

Several genes are currently present in field populations of *H. punctigera* that confer resistance to the discrete proteins in Bollgard cotton, however none confer cross-resistance to the other proteins. Individuals must carry two copies of these resistance genes to survive the protein or 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. These pupae can contribute to carry-forward of resistance from one season to the next. Diapause initiation is caused by falling temperatures and shortening day length. The proportion of pupae entering diapause increases from 0% in late February to over 90% in late April – early May, depending on the region. Diapause termination is based on rising soil temperature beginning in mid to late September in most regions. Emergence from diapause usually occurs over a 6 to 8 week period.

Though *H. punctigera* has always had the capacity to over-winter as diapausing pupae, extensive research conducted in the early 1990s found this species was rarely found late season and diapausing pupae were scarce.

Spring migrations from western inland have largely been thought to be the main source of this species in the eastern cropping regions, and *H. punctigera* have historically never shown any trends towards insecticide resistance in the past. However, in recent times this species has been persisting throughout the whole cotton-growing season, with significant overwintering now taking place.

Migration flights also appear to have lessened, reducing the natural genetic dilution factor. Research continues to investigate whether *H. punctigera* is more likely to develop resistance in the future.

Alternative hosts

Spring host crops of *H. armigera* include: faba beans, chickpeas, safflower, linseed and canola. Pastures and weed flushes also sustain emerging spring populations. Summer host crops include: soybeans, mungbeans, pigeon pea, sunflower, sorghum and maize. *H. armigera* will attack flowering crops of sorghum and maize preferentially over most other crop hosts.

H. punctigera moths are able to utilise a vast selection of host plants (mostly broad-leaved) and do not appear to be as closely associated with crop hosts as *H. armigera*. Though favourable weather and non-crop hosts such as daisies appear to be critical for the early successful survival of *H. punctigera*, spring crops such as chickpea, canola, faba beans and linseed can be heavily infested by this species. Summer crop hosts can include pigeon pea, sunflower and various legume crops (mungbean, soybean etc).

Further information:

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Helicoverpa larva damaging a maturing boll. **(Paul Grundy, Qld DAF)**

TABLE 7: Control of *Helicoverpa*

MoA	MoA group	Resistance *(H. armigera)*	Overall impact on beneficials*	Comments#
Bacillus thuringiensis	No group	None detected	Very low	Restrictions apply – refer to Bt cotton resistance management plan.
Helicoverpa NPV	No group	None detected	Very low	Use alone or with compatible larvicide. Target application to coincide with egg hatching.
Paraffinic oil	No group	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	Group 22A	Widespread – moderate	Low	Maximum 3 applications per season.
Clitoria ternatea extract (Sero-x)	No group	Unknown	Low	Ensure good coverage. Treatment effects may not be seen for 3 or more days. Applications should be timed to coincide with egg hatch and when small larvae are present. Maximum 5 applications per season.
Amorphous silica	No group	Unknown	Low	Apply during egg lay to egg hatch. Best results are obtained from two sequential applications 6-7 days apart.
Chlorantraniliprole	28	Occasional – low	Low	Target brown eggs or hatchling to 2nd instar larvae before they become entrenched in squares, flowers and bolls. Use high rate where the potential is for >2 larvae/m and to achieve longer residual control. Maximum 3 applications per season.
Spinetoram	5	Occasional – low	Low	Use the higher 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 and hatchlings to 2nd instar larvae before they become entrenched in hidden feeding sites. Maximum 2 applications per season.
Chlorantraniliprole/ thiamethoxam	28/4A	Occasional – low Cross-resistance between all the neonicotinoids	Moderate	Apply at brown egg to 2nd instar larvae before becoming entrenched in squares, flowers and bolls. Use high rate where the potential is for >3.5 larvae/m and to achieve longer residual control. Maximum 2 applications per season.
Abamectin	6	Occasional – low	Moderate	Use the higher rate alone or the lower rate with a suitable mixing partner. Some labels indicate control of *H. punctigera* only. Maximum 2 applications per season.
Emamectin benzoate	6	Occasional – low	Moderate	Apply at or just prior to hatching. Use non-ionic surfactant as per label. Maximum 4 applications per season.
Emamectin benzoate/ acetamiprid	6/4A	Occasional – low Cross-resistance between all the neonicotinoids	Moderate	Apply at or just prior to hatching. Use non-ionic surfactant as per label. Maximum 2 applications per season.
Amitraz	19	Unknown	Moderate	Apply as an ovicide with larvicide when eggs or very small larvae are detected. Repeat treatments at 5 and 7 day intervals, when necessary. May suppress mites. Maximum 4 applications per season.
Methomyl	1A	Widespread – moderate	High	Higher rate of larvicidal rate may cause reddening of foliage. Do not use more often than every 14 days, if excessive use an alternative. Do not apply during periods of plant stress. Maximum 2 applications per season.
Thiodicarb	1A	Widespread – moderate	High	This product has ovicidal and larvicidal activity. See label for details. Lower rate is on light to moderate infestations and the higher rate on heavier infestations. 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	Widespread – moderate Cross-resistance	Very high	Time spray to coincide with egg hatch. DO NOT apply to larvae >5 mm. Use higher rate when pest pressure is high, conditions favour pest development and when increased residual protection is required. *H. armigera* resistance to bifenthrin has increased. Field failures are likely. 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	Group 3A	Widespread – high	Very high	Use low rate as ovicide and high rate when egg lay is heavy and/ or *H. punctigera* >10 mm and/or *H. armigera* <5 mm. Maximum 1 application per season.
Lambda-cyhalothrin	Group 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 4 in this guide.

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Mealybug

Phenacoccus solenopsis

Ratoon cotton stubs are a major source of solenopsis mealybug infestation in following 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 infestations lead 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.

Infestation with mealybug up to the early boll setting stage has 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.

Honeydew excreted onto the leaves is high in melezitose sugar, which is very sticky and can promote the development of black sooty mould and render seed cotton un-ginnable.

Sampling

Mealybug 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. Mealybug 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 mealybug.

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

CottonInfo videos:

Solenopsis mealybug in cotton https://youtu.be/vOTJ2XkAsug

Mealybug hotspots https://youtu.be/r4aeGPcVHk0

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

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.**
- **Drones can be useful in identifying hotspots.**
- **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 mealybug with passage of people and machinery.**

Solenopsis mealybug adults and crawlers. (Tonia Grundy, Qld DAF)

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

Management strategy

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.

Adhere strictly 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.

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

Management options until early flowering

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

Insecticidal options for specifically targeting mealybug include sulfoxaflor, spirotetramat and buprofezin. Consider the presence of other pests:

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

Management options from late flowering to defoliation

Mealybug hotspots in mid-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 (e.g. mirids, SLW), insecticidal control of mealybug is generally not recommended. Allow beneficials to build and control mealybug.

If mirids and/or SLW are present, aim to control them SLW without flaring mealybug 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 mealybug (head, tail drains, sides) to minimise mealybug 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 mealybug.

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.

Parasitic wasps – *Aenaisus bamabwalei*, a parasitoid of solenopsis mealybug that attacks adult females is effective in suppressing populations.

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

Key features that influence survival and pest status

Mealybug 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. Mealybug shelter in protected positions on the cotton plant; 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. Mealybug 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 mealybug can be found in the root zone of weed hosts during winter. In spring, breeding and dispersal begins.

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.

Further information: Qld DAF, Richard Sequeira 0407 059 066, Paul Grundy 0427 929 172.

The pupal stage (top) and adult wasp stage (bottom) of *Aenasius bambawalei* which is a parasitoid of the solenopsis mealybug.
(Zara Hall, Qld DAF)

TABLE 8: Control of solenopsis mealybug

Active ingredient	MoA group	Overall impact on beneficials*	Comments#
Buprofezin	16	Low	Aim application at early nymph stages. Thorough spray coverage is essential. Maximum of 2 applications per crop.
Spirotetramat	23	Moderate	Do not re-apply within 14 days of a previous Movento spray. Do not apply more than 2 applications per crop. The re-application of spirotetramat presents a risk for SLW resistance management.
Sulfoxaflor	4C	Moderate	Thorough spray coverage is essential. 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 4 in this guide.

Mirids

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

Green and brown mirids look similar, but brown mirids are slightly larger with darker pigmentation. Both species cause similar damage at the boll stage, however green mirids do more damage during squaring. Green mirids are usually more abundant in cotton and they move into crops earlier than brown mirids. The apple dimpling bug (ADB) is about 1/3 the size of other mirids, and can damage small squares (4 ADBs do equivalent damage to 1 adult green mirid). ADB is also a predator of mites, silverleaf whitefly adults, nymphs and eggs, and *Helicoverpa* eggs.

Damage symptoms

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

Square loss depends upon where the mirids are feeding and size of the squares. Feeding on small or medium sized squares is very likely to directly damage the developing ovules and anthers, resulting in shedding. Feeding on large squares may not result in shedding but still damage the developing ovules, resulting in poor fertilisation and seed development in several locks. The resulting misshapen bolls are commonly referred to as being 'parrot beaked', a deformity that can also be caused by high temperatures, hence good pest monitoring is important to avoid unnecessary sprays.

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

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

The relationship between mirid numbers and square loss is influenced by both the development stage of the squares and mirid feeding patterns (which can change in response to factors such as temperature and the presence of natural enemies). Therefore, consider both square retention and mirid numbers when making a control decision.

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.

CottonInfo video on mirid identification and damage https://youtu.be/FdCtVONjh_Y

Sampling

Mirids are mobile and are easily disturbed so care must be taken during sampling, otherwise numbers may be underestimated (discussed later in this section). It is 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).

Frequency

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

Methods and sample size

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

When beat sheeting, place the sheet against the base of a row of plants and drape across the furrow and up over the adjacent row. Vigorously shake a section of row with a 1 m stick onto the area of beat sheet lying across the furrow. Quickly count the number of adult mirids dislodged onto the beat sheet. Look also for mirid nymphs, which can easily be confused with other small green insects. The easiest way to identify them is by their noticeably long antennae and fast movement across the beat sheet.
CottonInfo video on using a beatsheet https://youtu.be/vl-Y8qj_xXs

Accurate estimation of mirid numbers is closely linked to sample size – more is better. A minimum of 12-15 beat sheet samples are required per management unit (approximately 50 ha) to obtain reasonable estimates of the mirid density. Crop sampling protocols should aim to get as close to the recommended sample number as possible.

When 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 (approximately 50 ha) 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.
CottonInfo video on mirid sampling and thresholds https://youtu.be/iK63neuw7rU

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. However this is only an estimate of the true cost of deciding to spray, which includes 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.

A recent review has reconsidered the historical basis for mirid thresholds in the context of modern high-yielding Bollgard 3 production systems, allowing existing mirid threshold data to be interpreted in a way that better reflects current economics and production practices.

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

For example, previous work suggests that at squaring, the crop will incur a loss of ~0.026 bales/ha/mirid, while at flowering it will incur a loss of ~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 9).

Deciding when to spray

Under field conditions, the link between mirid density and damage is not straightforward. Sometimes few mirids seem to be causing a lot of damage, while at other times, large populations of mirids cause little damage.

When making a mirid management decision, it is also important to consider:

- **The crop's ability to compensate for damage,** which 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 the commencement of flowering. 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 presence of other pests (mirids may preferentially feed on insect eggs), and temperature effects. There are also a range of other factors that might be relevant for mirid management such as 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 9 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.

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Key beneficials

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

Selecting an insecticide

Insecticide products registered for the control of mirids in cotton in Australia are presented in Table 10. The use of more selective insecticide options will help to conserve beneficial insects (see Table 4 on pages 14-15). 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.

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

CottonInfo video on 'soft' options for mirids https://youtu.be/zmz70fX4v5U

Resistance profile

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

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

Overwintering habit

Mirids survive on weeds and native plant hosts surrounding cotton fields. They also breed on native hosts in inland (central) Australia in winter and can migrate to cotton growing areas in spring in a similar way to *Helicoverpa punctigera*. Understanding 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 soybeans, mungbeans, pigeon pea, safflower and sunflowers. It is assumed that mirids migrate between these crops. Weed hosts include turnip weed, Noogoora burr, yellow vine, variegated thistle and volunteer sunflowers.

Further information:

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CSIRO, Narrabri – Simone Heimoana: 0427 992 466.

NSW DPI, Tamworth – Lisa Bird: 02 6763 1128.

TABLE 9: Mirid thresholds

Economic factors		Thresholds (adults or nymphs/m)	
Product value	**Cost of control (1:1 cost benefit)**	**Planting to 1 flower/m**	**Flowering to 1 open boll/m**
$450	$15	1.5	1
$550		1	0.5
$650		1	0.5
Consider reducing the thresholds if:		• No plant compensation time (e.g. short, cool season) • <60% retention up to 1st flower • >50% light tip damage (black embryo leaves within terminal) • >20% heavy tip damage (terminal and 2-3 nodes dead) • <60-70% retention 1st flower to 4 NAWF • >20% boll damage	
Economic factors		**Thresholds (adults or nymphs/m)**	
Product value	**Cost of control (1:1 cost benefit)**	**Planting to 1 flower/m**	**Flowering to 1 open boll/m**
$450	$45	4	2.5
$550		3	2
$650		2.5	1.5
Consider raising the thresholds if:		• Time for plants to compensate (e.g. long, warm season) • Many beneficials • High levels of retention (~80%) • High threat of whitefly damage (raises the cost of control)	
Economic factors		**Thresholds (adults or nymphs/m)**	
Product value	**Cost of control (1:1 cost benefit)**	**Planting to 1 flower/m**	**Flowering to 1 open boll/m**
$450	$60	5	3
$550		4	2.5
$650		3.5	2

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

TABLE 10: Control of mirids

Active ingredient	MoA group	Overall impact on beneficials*	Comments#
Paraffinic oil	No group	Very low	Apply low rate for suppression of fewer than 0.5 mirids/m. Apply high rate if population reaches threshold of 0.5 mirids/m or apply 2 successive low rate sprays not more than 7 days apart.
Clitoria ternatea extract	No group	Low	Apply as indicated by field checks and pest presence. 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	Under high populations suppression only may be observed. Maximum 3 applications per season.
Indoxacarb + salt	22A	Low	For controlling green mirids ONLY. Use the higher rate on infestations exceeding economic spray threshold levels and/or large canopy crops. Maximum 3 applications per season.
Chlorantraniliprole/ Thiamethoxam	28/4A	Moderate	If pest pressure remains high additional control measures may be required from 7 days after application. Do not use as first foliar if neonicotinoid seed treatment used. Maximum 2 applications per season.
Sulfoxaflor	4C	Moderate	Use lower rate when infestation is predominately nymphs. Maximum 4 applications per season.
Fipronil	2B	Moderate	Apply spray to achieve thorough coverage. Use higher rate under sustained heavy pressure, 3-4 days to reach full effectiveness. Compatible with early season IPM with lower rate having less impact on beneficials. Avoid repeated use of this insecticide group.
Flonicamid	29	Moderate	Thorough spray coverage is essential. Maximum 2 applications per season.
Emamectin benzoate	6	Moderate	For suppression only. Apply to developing populations that are predominantly nymphs. Use non-ionic surfactant at label rate. Maximum effect may take 5 to 7 days. 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.
Acetamiprid	4A	Moderate	Apply with 0.2% Incide penetrant. Target nymphs and/or adults when they reach economic thresholds. On above threshold or increasing populations, suppression only when they reach economic thresholds. Maximum 2 applications per season.
Clothianidin	4A	Moderate	Apply when numbers reach threshold levels requiring treatment. Maximum 2 applications per season.
Imidacloprid	4A	Moderate	Do not use as first foliar if neonicotinoid seed treatment used. Maximum 2 applications per season.
Dinotefuran	4A	Moderate	When mirids and SLW are present and SLW is at or above threshold levels, use SLW. 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.
Dimethoate (high rate)	1B	High	Do not use where resistant strains are present. Do not harvest for 14 days after application. Do not graze or cut for stock feed for 14 days after application. Maximum 2 applications per season.
Gamma-cyhalothrin	3A	Very high	Apply at recommended threshold levels as indicated by field check. Maximum 1 application per season.
Lambda-cyhalothrin	3A	Very high	Apply at recommended threshold levels as indicated by field checks. Maximum 1 application per season.
Alpha-cypermethrin	3A	Very high	Apply at recommended threshold levels as indicated by field checks. Use the higher rate when pest pressure is high and increased residual protection is required. Maximum 1 application per season.
Bifenthrin	3A	Very high	Apply at recommended threshold levels as indicated by field checks. Use the higher rate for increased pest pressure and longer residual control. 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 4 in this guide.

Sponsored by CGS Growing Success

Mites

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

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

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

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

Damage symptoms

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

Two-spotted mite damage appears as brownish areas on the lower leaf surface, usually starting at the junction of the petiole and leaf blade or in leaf folds. On the upper leaf surface, these damaged areas show up as red patches. At high mite densities, leaves become completely red and fall off. Diapausing two spotted mites turn bright orange.

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

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

Bean spider mite. 0.5 mm. (M. Hill)

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

Strawberry spider mite. 0.3 mm. (C. Mares)

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

Broad mites. 0.2 mm. (T. Grundy)

Sampling

Sampling protocols for spider mites in cotton are presented on page 40. There is currently no sampling protocol for broad mites, but they tend to infest terminals rather than older leaves, so visually check for broad mite symptoms in the upper canopy.

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

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

Look for the presence of any mite stages on the underside of leaves. Use a hand lens, especially if there is doubt about the species present. In young plants, sample the oldest leaf. As plants grow, sample leaves from node 3, 4 or 5 below the terminal. Also look for fine webbing that protects the developing mite population.

Determine the mite species present. Two-spotted spider mite is a pale yellowish-green with one dark spot on either side of its body. Strawberry spider mite is also pale yellowish-green but has three dark spots on each side, which may merge with age, however the adults are only about half the size of adult two-spotted spider mites. Bean spider mite is the same size as two-spotted mite but is dark red.

With nymphs of all ages present, identification can be challenging. It is therefore important to also consider any other signs of damage. For example, leaf reddening is a good indication of two-spotted spider mite.

Frequency

Sample at least weekly, beginning at seedling emergence. Sample more frequently if mite populations begin to increase, if conditions are hot and dry, or if sprays that impact natural enemy abundance are used.

Methods

Presence/absence sampling allows many plants to be sampled quickly, thus increasing the likelihood of finding mites if they are present. 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.

Thresholds for two-spotted mites

The thresholds and yield loss charts on page 39 have been developed for two-spotted mite only. These thresholds should NOT be applied to bean spider mite or strawberry spider mite. Bean spider mite causes half the damage of two spotted mite, and strawberry spider mite does not cause significant damage.

A general threshold of 30% of plants infested is advocated through the bulk of the season (squaring to first open boll). Yield loss due to mites depends on when mite populations begin to increase and how quickly they increase. Use Table 11 to determine whether the rate of increase in two-spotted mite populations warrants control (adjust for bean spider mite if required).

Seedling emergence to squaring: Mites are normally suppressed by predators (particularly thrips) during this period. Mite populations only need to be controlled if they begin to increase, which indicates that natural controls are not keeping them in check.

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% of plants infested per day).

Crop exceeds 20% open bolls: Control is no longer warranted.

Two-spotted spider mite yield reduction charts

A simple relationship allows prediction of yield loss from two-spotted spider mites, based on knowledge of the rate of population increase and the time remaining until defoliation. These 'look-up' charts have been provided in Table 11 for areas with different season lengths.

The rate of increase of the mite population is calculated 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 charts

1. Select the chart appropriate for your region.
2. Go to the section 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.

This value is the predicted percentage yield loss that the mite population is likely to cause if left uncontrolled. It must be stressed that these charts only provide a guide for potential yield losses caused by mites.

You will need to take into account the vigour of the crop, other pests (you may be about to spray with a pyrethroid which may flare mites) and the conditions (e.g. mite populations develop faster in hot dry conditions). The effect of beneficials is also 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 – 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, tangleweb spiders.

Selecting a miticide

The miticide products registered for the control of spider mites in cotton in Australia are presented in Table 12 on page 40. There are currently no registrations for control of broad mites. Amitraz, used for the control of *Helicoverpa* early in the season, will tend to slow, or suppress, the development of mite populations that may also be in the field. Conversely, 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 (OP). This occurs because those sprays kill key beneficial species and allow resistant mite populations to flourish (see Table 4 for the impact of pesticides on key beneficials).

Two-spotted mite causes economic damage and has a long history of developing resistance to miticides. While current resistance levels are low for all products excluding OPs, abamectin and pyrethroids, resistance can be selected very quickly. Avoid consecutive sprays of the same miticide. If mite numbers rebuild after a miticide application, rotate to a product from a different chemical group. 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.

Abamectin resistance has occasionally been detected at high levels in two-spotted mite in horticulture, and frequencies in cotton have been elevated in recent years. Bifenthrin and chlorfenapyr resistance in mites occurred largely due to the use of these compounds against other pests. This is true also for abamectin when used in combination with mirid sprays to prevent mite flare.

Overwintering habit

While the lifecycle slows in cool temperatures, mites are adapted to exploit a wide range of plant hosts and to produce large numbers of offspring, especially as conditions warm up in spring. Control of winter hosts on farms will reduce carry-over of mites between seasons.

Alternative hosts

Spider mites have a wide host range and can survive through the year on a wide range of broad-leafed weeds. In summer, two-spotted spider mite can also attack sorghum, maize, pulses, sunflowers and many horticultural crops. Preferred winter weed hosts are turnip weed, marshmallow, deadnettle, medics, wireweed and sowthistle, although they can be found on almost any broad-leafed weed species. Alternative winter and spring host crops include safflower, faba beans and field peas. Broad mites also have a wide host range, including many horticultural crop and ornamental species.

Further information:

CSIRO Narrabri, Simone Heimoana: 02 6799 1592 or 0427 992 466.

NSW DPI Narrabri, Lisa Bird: 02 6763 1128.

CottonInfo videos:
Spider mites in cotton https://youtu.be/oUcatfAOOQM
Sampling spider mites https://youtu.be/2hB84S7p6vY
Broad mites in cotton https://youtu.be/PexkYjLQnoU

TABLE 11: Yield reduction caused by two-spotted spider mites

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

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

SAMPLING PROTOCOLS FOR SPIDER MITES IN COTTON

Population monitoring

1. Walk into the field about 40 m. Early in the season also sample near the field edges to see if significant influxes of mites have occurred.
2. Take a leaf from the third, fourth or fifth main-stem node below the terminal of the first plant. If the plant has less than three leaves, sample the oldest. Early in the season until the plant has about five true leaves, it is simplest to pull out whole plants.
3. Walk five steps and take a leaf from the next plant, on your opposite side and so on until you have 50 leaves.
4. Once all the leaves have been collected, score each leaf by turning it over and looking at the underside, firstly near the stalk, then scanning the rest of the leaf. If mites of any stage (including eggs) are present, score the leaf as infested. A hand lens will be needed as mite eggs cannot be seen with the naked eye.
5. Repeat at several widely separated places in the field to allow for differences in mite abundance. Depending on the field size, 4-6 sites are needed to obtain a good estimate of mite abundance.
6. Calculate the percentage of plants infested in the field. Continue presence/absence sampling until 20% open bolls.

Additional recommendations for mites in seedling cotton

On seedling cotton (up to 6-8 true leaves) sample regularly to determine the level of infestation using the presence/absence technique above.

When more than 5% of plants are infested also count the numbers of mites on plants, and score the damage level (i.e. estimate the percentage of total leaf area per plant that is damaged by mites). Continue to monitor mite numbers, damage levels and infestation levels at least weekly, or more frequently if >30% of plants are infested.

If the level of infestation, damage level or mite number per plant declines then control is unnecessary, but monitoring should continue.

If mite numbers per plant do not decline after about 6 weeks, if damage levels exceed an average of 20% of plant leaf area, or if infestation levels increase, then predators are not abundant enough to control mites and a miticide should be applied.

Miticide resistance monitoring

1. If mites are being collected after a miticide application, ensure sufficient time has lapsed for the miticide to be fully activated. Depending on the product, this may take 7 to 10 days. Avoid making collections and sending samples on Thursdays or Fridays.
2. Collect 50 infested leaves from different areas across the field. Keep samples from different fields separate. If mite numbers per leaf are very low, consider collecting up to 100 leaves.
3. Phone Lisa Bird (see below) to let her know you are sending the sample.
4. Clearly label samples with the following information:

Farm Name ....

Field ....

Region (e.g. Gwydir) ....

Collector's Name...

Phone No..

Fax No...

Email address ....

Date of collection........../........../..........

Comments (e.g. details of the problem if a control failure has occurred).

Samples for testing

5. Pack the leaves loosely in a paper bag, fold and staple the top. Pack this in a 6-pack esky. Attach the sample details and send by overnight courier to:

Lisa Bird
Department of Primary Industries
Tamworth Agricultural Institute
4 Marsden Park Rd
Calala NSW 2340
Ph: 02 67631128 or 0438 623 906

TABLE 12: Control of two-spotted spider mites

Active ingredient	MoA group	Mite resistance	Overall impact on beneficials*	Comments#
Etoxazole	10B	Occasional – low	Low	Good coverage is essential. Refer to label for no-spray zones and record keeping. Best on low to increasing populations. Maximum 1 application per season.
Dicofol	2B	No data	Low	NSW registration only. Apply by ground rig at first appearance of mites before row closure. Maximum 2 applications per season.
Diafenthiuron	12A	No resistance	Low	Treatment at higher infestation levels may lead to unsatisfactory results. Maximum 2 applications per season.
Abamectin	6	Widespread – med/high	Moderate	Best results will be obtained when applied to low mite populations. Maximum 2 applications per season.
Emamectin benzoate	6	Cross-resistance to abamectin	Moderate	When applied for *Helicoverpa* control will reduce the rate of mite population development. Suppression only. Maximum 2 applications per season.
Propargite	12C	Occasional – low	Moderate	Apply spray before mite infestations reach damaging levels as maximum efficacy is not reached until 2 weeks after spraying. Maximum of 2 non-consecutive applications per season.
Amitraz	19	No data	Moderate	Suppression when used for controlling *Helicoverpa*. Maximum 4 applications per season.
Dimethoate	1B	No data	High	Will not control organophosphate-resistant mites. Do not harvest for 14 days after application. Do not graze or cut for stock feed for 14 days after application. Maximum 2 applications per season.
Bifenthrin	3A	Widespread – med/high	Very high	Applications against *Helicoverpa* will give good control of low mite populations. Maximum 1 application per season.
Deltamethrin	3A	Cross-resistance to bifenthrin	Very high	Suppression only. Maximum 1 application per season.

Phorate (1B) is also registered for application at planting (Qld, NSW and WA only).
#For all control options ALWAYS refer to the label for instructions.
*For more details about impact on beneficial insects (including bees), refer to Table 4 in this guide.

Stainers

Pale cotton stainer – *Dysdercus sidae*
Red cotton bug – *D. cingulatus*

Pale cotton stainers are occasional pests in southern regions. Red cotton stainers occur in northern Australia and their pest status is not yet known, but expected to be similar. Other *Dysdercus* spp. are included on the high priority exotic pests list (see Biosecurity chapter). 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 is likely to cause economic damage.

Damage symptoms

Pale cotton stainers can penetrate the boll wall of young and mature bolls to feed on cotton seeds and will also feed on seeds in open bolls. Seed weight, oil content and viability all decline as a result. Loss of seed viability should be a consideration in seed production crops.

Bolls up to 20 days old develop small black marks on the outer surface and may have warty growths on the inner boll wall. Damage to older bolls causes small dark marks on the inside of the boll wall, usually without external symptoms. Damage reduces seed size and lint production. Tight lock can result around damaged seeds, preventing the lint from fluffing out as the boll opens, and damaged locks are often yellow or stained.

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

Sampling

Where adults and nymphs are observed feeding, monitor the percentage of damaged bolls. Sample at least weekly once bolls are present, and more often if pale cotton stainer numbers approach threshold.

Distribution through the field and through the canopy can be quite patchy, as adult females lay eggs in clusters in the soil or sometimes in open bolls. Sample with a beat sheet at multiple sites spread throughout the field. Search visually for younger instars in the lower canopy.

Cut open bolls of varying ages to monitor for signs of damage. Examine seeds for browned, dried damage areas. A week after damage the lint may begin to yellow and locks will be stuck to the boll wall.

The mild, wet conditions that favour the survival of pale cotton stainers in cotton will also favour the occurrence of 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 stainers.

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

Thresholds

Boll development: When stainers are observed in the crop and damage to developing bolls is detected, an action threshold of 3 pale cotton stainers/m is recommended (based on beat sheet sampling – see GVB adult equivalents on page 25). Adults and older nymphs (3rd to 5th instars) cause similar levels of damage.

After first open boll: When stainers are observed feeding in open bolls, consider the potential for quality downgrades of the lint as well as the loss of seed weight and seed viability. Where staining is observed, use a threshold of 30% affected bolls to prevent a colour downgrade.

Key beneficials

The role of natural enemies in Australia has not been studied.

Selecting an insecticide

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

Worldwide, there are few records of resistance to insecticides developing in the field, however cotton stainers will react to selection pressure under laboratory conditions.

Overwintering habit

As 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

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 stainer's access to alternative food sources.

Further information:
CSIRO, Narrabri
Simone Heimoana: 02 6799 1592 or 0427 992 466

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

Sampling

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

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

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

CottonInfo video on sampling for soil insects https://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.

Larvae attack germinating seeds, the hypocotyl and roots of young cotton plants resulting in seedling death, young plant 'felling' and patchy

True wireworm larva. (Tonia Grundy, Qld DAF)

plant stands. The adult beetles can also damage seedlings by chewing at or just above ground level.

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

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

Black field earwigs

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

Black field earwigs are about 15 mm long. They are an occasional pest of seedling cotton, predominantly feeding 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 have been defined for cotton, but thresholds used for maize and sorghum suggest that control maybe warranted when more than 50 earwigs are found across 20 baits or 2-3 earwigs per bait sample.

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

Symphyla

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

Symphyla generally feed on decomposing organic matter but can feed on rootlets and root hairs and have been associated with crop establishment issues in some fields, often as part of a broader complex of soil pests. Damage is more likely in dry soil conditions. They can move up and down in the soil profile and distribution within a field is generally patchy. If plants show symptoms of damage, conduct a basic soil survey, keeping a close

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

eye on newly broken-apart clods for movement. Symphyla are fast moving and will rapidly shift to avoid sunlight.

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

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

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

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

Other soil pests

Black field cricket. (J. Wessels)

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.

Cutworm larvae. (P. Room)

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

Whitegrub attacking peanut. (J. Wessels)

Whitegrubs are the larvae of scarab beetles and 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 13: Control of wireworm (refer to label for target species)

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

#For all control options ALWAYS refer to the label for instructions.
*For more details about impact on beneficial insects (including bees), refer to Table 4 in this guide.
Assessment of impact on beneficials is based on contact, which is unlikely to occur for pesticides applied at planting.

Thrips

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

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

Damage symptoms

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

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

CottonInfo video on thrips identification and damage: https://youtu.be/e8B0wpimUvA

Sampling

Sample seedlings and count the number of thrips/plant. Adults thrips can migrate into the crop from surrounding vegetation, however presence of larvae in crops that have had an insecticide seed treatment or in-furrow insecticide treatment indicates that the population is actively breeding and the early insecticide offered poor control. No larvae and little plant damage indicates that the insecticide is effectively controlling the thrips.

Score the severity of damage to the seedlings by estimating the percentage reduction in leaf area.

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

Thrips nymph on underside of leaf and adult in cotton flower.
(Tonia Grundy, Qld DAF)

Frequency

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

Methods

Use a hand lens to count the number of adult and larval thrips on 20-30 separate seedlings for every 50 ha of crop. Also assess leaf damage (if the damaged young leaves are less than 1 square centimetre then the reduction in seedling leaf area is usually greater than 80%).

If thrips are present in high numbers (>30/plant), check the plant terminal. Complete blackening of the embryonic leaves means the terminal has died.

CottonInfo video on thrips sampling and management: https://youtu.be/FKkwWID4iQA

Thresholds

As thrips occur in cotton in most years the most effective management option is to use a seed treatment or an at-planting insecticide applied with the seed. This protects plants during the establishment phase and has the advantage of minimal negative effects on beneficial species compared to an insecticide applied to the crop after emergence (see Tables 3 and 4).

Severe damage to leaves can result in delayed maturity or yield loss. In northern and central regions with warmer climates, the risk is lower because plants can outgrow and compensate for damage, so yield loss is only likely to occur about one year in 10.

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

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

Thrips populations will normally naturally decline 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 thresholds below.

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

Thresholds

SEEDLING TO 6 TRUE LEAVES
80% reduction in leaf area + 10 thrips/plant (adults and larvae)

Thrips found in cotton in the mid and late season are usually *Frankliniella* spp. Adult thrips feed on pollen, but are unlikely to affect pollination or fruit set. Eggs are laid on leaves and the hatching larvae may cause damage to the undersides, resulting in distorted, smaller leaves. As these larvae are also predatory, high levels of damage would be required to affect yield, and control should not be considered unless >30% of leaf area is damaged in the top 6 nodes in pre-cut-out crops or more than 50% of leaf area damaged after the crop has cut-out.

CottonInfo video on whether thrips are friends or foes:
https://youtu.be/UsWxHB94NN4

Key beneficials

Predators – minute pirate bug, green lacewing larvae, brown lacewing, ladybird beetles.

Selecting an insecticide

Insecticide products registered for the control of thrips in cotton in Australia are presented in Table 14. Insecticide seed treatments will provide protection from thrips during crop establishment. A neonicotinoid seed treatment should not be used if resistance to neonicotinoids in thrips is suspected. Consider the benefit of thrips as predators of spider mites when deciding whether to control thrips in cotton with an insecticide. **It should be noted that every western flower thrips tested in Australia since resistance screening commenced has been pyrethroid resistant, so insecticides in that mode of action group (3A) must be avoided.**

In Australia, pyrethroid and OP resistance has been detected in some tobacco thrips associated with bulb onion but resistance in tomato thrips has not been detected.

Overwintering habit

Thrips prefer milder temperatures. Populations decline at temperatures greater than 30°C. Thrips are active and common through winter on a range of hosts.

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.

Further information:

CSIRO Agriculture, Narrabri –
Simone Heimoana: 02 6799 1592 or 0427 992 466
Lisa Bird: 02 6763 1128.

TABLE 14: Control of thrips

Active ingredient	MoA group	Overall impact on beneficials*	Comments#
Tobacco thrips (*Thrips tabaci*) and tomato thrips (*Frankliniella schultzei*)			
Fipronil	2B	Moderate	Fipronil will take 3-4 days to reach full effectiveness. Use higher rates under high pressure. Avoid repeated use of this insecticide group.
Dimethoate	1B	High	Do not harvest for 14 days after application. Maximum 2 applications per season.
Western flower thrips (*Frankliniella occidentalis*)			
Spinetoram	5	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 4 in this guide.

Whitefly

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

Silverleaf whitefly (SLW) is a major pest that infests mid to late-stage cotton. If populations build up, their honeydew becomes a serious contaminant of cotton lint. SLW also have a track record of developing insecticide resistance, increasing the difficulty of their management. Greenhouse whitefly is an infrequent pest of cotton.

Damage symptoms

Both adults and nymphs excrete honeydew, which dries to a matte, non-sticky consistency on lint, making contamination difficult to detect visually. The sugar composition, in particular the high concentration of trehalulose, makes SLW-contaminated lint 'sticky' and more difficult to process at gins and textile mills compared to aphid honeydew-contaminated cotton, usually leading to downgrading or rejection. Whitefly honeydew can also promote the growth of sooty mould.

CottonInfo video on implications for lint quality and colour https://youtu.be/uVSSIqUg5q0

Sampling

Sample for species and population

While SLW can be visually differentiated from greenhouse whitefly by the wing shape in adults and the absence of hairs on the nymphs (see photographs on page 50), they cannot by easily distinguished from endemic *Bemisia* species that are occasionally present in cotton crops. These endemic species are less common and tend to have slower population growth so are rarely important in pest management decisions.

Effective sampling is the key to successful management. Keep an eye out for SLW while sampling for other pests pre-flowering to assist in making decisions about product selections; conservation of beneficial species may help delay build-up of SLW or other pests. Begin sampling between 1000 and 1300 day degrees (DD) and continue for several weeks to record changes in nymph abundance in relation to cotton development.

SLW sampling aims to monitor changes in the nymph population density over time. SLW densities naturally fluctuate and during hot and dry conditions populations can rapidly increase, so sample twice weekly.

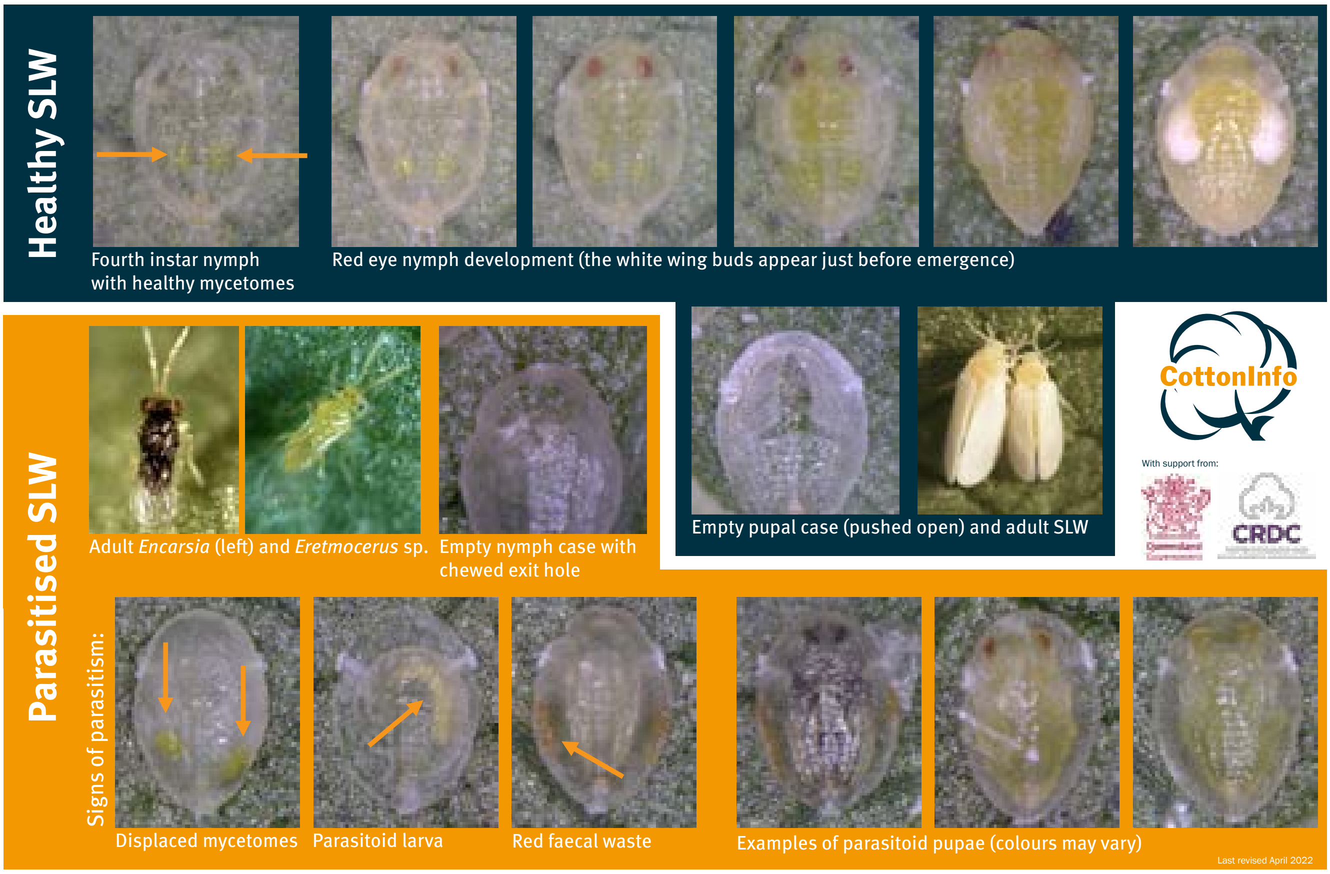
Sampling protocol

A management unit can be a whole field or part of a field. Start at least 20 metres from the field edge and collect one leaf per plant from the lower canopy (11-14 nodes down from the main stem terminal shoot), gathering at least 30 main stem leaves per management unit from plants 3-5 metres apart.

CottonInfo video on sampling SLW nymphs https://youtu.be/gWkTKMmJYLw

Count the total number of large nymphs on each leaf, and note the number that are viable ('red eye') versus non-viable (dead or parasitised). Nymph density on leaves is easier to assess prior to significant wilting and with magnification (e.g. hand lens). A phone app that can be used to image and record nymph densities is under development.

Silverleaf whitefly: healthy vs parasitised late stage (4th instar) nymphs



The new SLW decision support tool

An industry-developed decision support tool (DST), pictured below, is available from www.cottoninfo.com.au/silverleaf-whitefly-decision-support-tool to guide control decisions. The DST generates two population density profiles showing viable (red symbol) and total (black symbol) nymphs, plotted against crop development (which is predicted using daily temperature data). The magnitude of difference between the red and black dots is an indicator of mortality factors (such as parasitism) that may continue to suppress the SLW nymph population growth.

To use the DST:

1. Count the total number of large nymphs (3rd & 4th instar with red eyes) including nonviable for each leaf and determine the number of viable (healthy) nymphs. Ignore empty pupal cases.
2. Input the total and viable nymph counts for each leaf into the DST spreadsheet.
3. Enter the accumulated day degrees (base 12) for each check.

Late season considerations

SLW management involving late season mass-immigration of adults into crops with open bolls should be based on (a) expected time to defoliated leaf drop, (b) lint contamination level, and (c) prior chemical use from a resistance management perspective (i.e. avoid multiple applications from the same mode of action). During defoliation, adult SLW will leave the crop, while falling leaves will take the nymphs with them to the ground. These displaced adult SLW relocate to nearby host crops and the nymph-based DST method will be of limited value for crops in this situation.

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

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

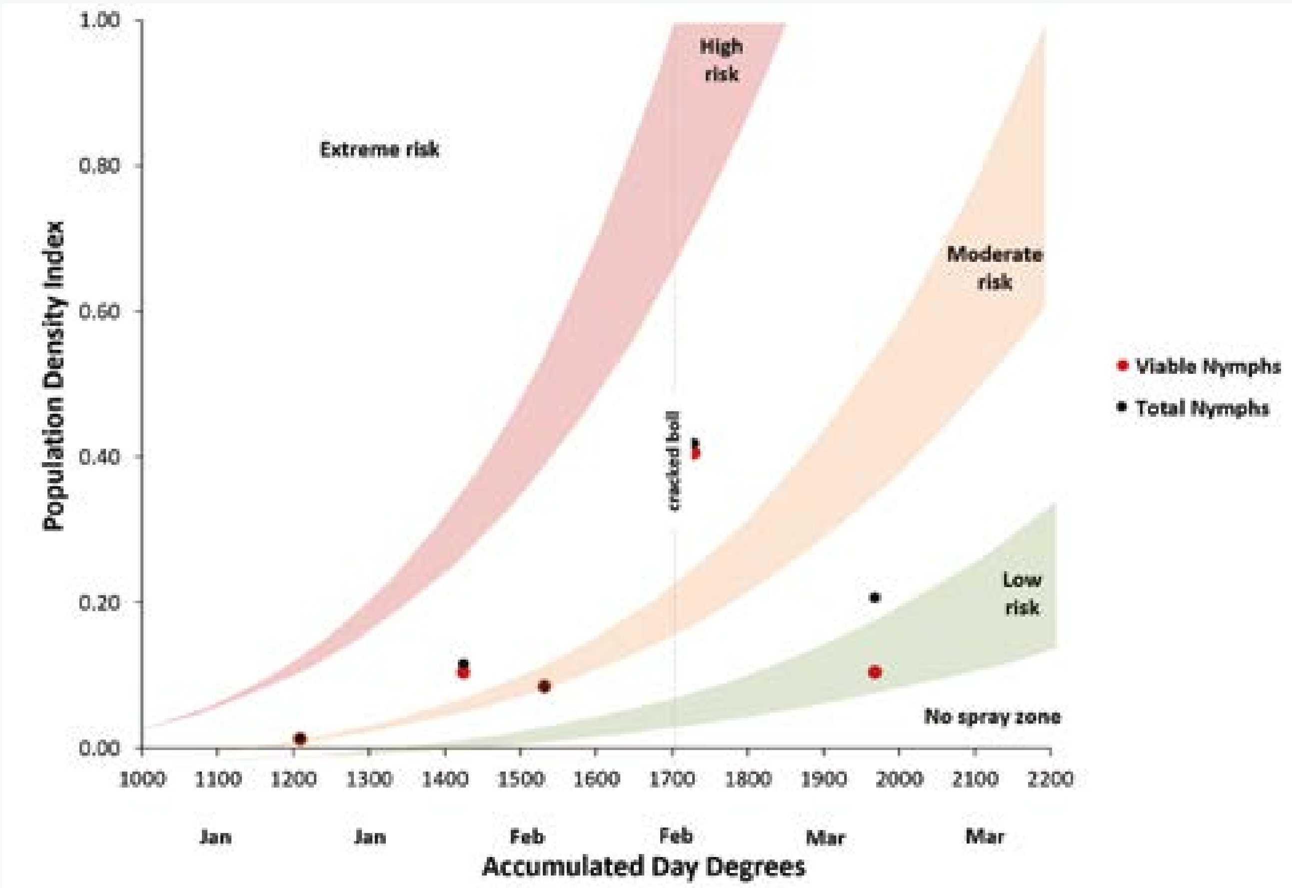
Key beneficials

The tiny wasps, *Encarsia* and *Eretmocerus* are important parasitoids of SLW nymphs. Predators of nymphs include big-eyed bugs, pirate bugs, lacewing larvae, apple dimpling bugs, brown smudge bugs and ladybird beetles.

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

Find out how to identify parasitised SLW nymphs in this CottonInfo video https://youtu.be/SOOcedrGIQI

SLW DECISION SUPPORT TOOL (DST)



Large 'red eye' nymphs (3rd or 4th instar) are used in the SLW decision support tool. (Tonia Grundy, Qld DAF)

Selecting an appropriate insecticide

The insecticides registered for control of SLW are presented in Table 15. One of the challenges in SLW management is the timing of insecticide application as it's often a compromise between delaying treatment to reduce the risk of re-infestation (to avoid the cost of additional sprays), versus the need to control populations prior to open cotton (reducing the risk of sticky cotton).

Considerations when applying insecticides to control SLW include:

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

NOTES		
Sampling protocol	The minimum sample size per management unit is 30 leaves collected between nodes 11-14 from the terminal.	
Day degrees	Daily day degrees (DD) are calculated using the formula; DD = [(Max °C – 12) + (Min °C – 12)] ÷ 2. More accurate day degree calculations can be made using the online calculator at www.csd.net.au/ddc	
PATHWAY		**CHEMISTRY**
Green	The green pathway is a conservative indicator of low population density. Due to inherent variability associated with sampling, one or two data points slightly above the upper boundary of the green pathway does not constitute a 'breakout' and cause for concern that the population is increasing rapidly. These populations still require regular checking as a sharp increase in viable nymph density above the green pathway for two or more consecutive checks (spanning 7 days) is deemed a breakout population.	**1250-1450 DD** Insecticide use is not warranted for fields with low SLW densities. **1600+ DD** If SLW are in the upper portion of the green pathway and you are targeting other pests, consider choosing products with modes of action effective against SLW activity: • Diafenthiuron (vapour activity) • Dinotefuran (high rate) (knockdown) • Acetamiprid/emamectin (knockdown) • Spirotetramat (use adjuvant as per label).
Amber	A population tracking within or above the bounds of the amber pathway for two (spanning 7 days) or more checks is likely to require control action. The exact timing of control should take into account crop stage and the insecticide mode of action. If the crop is at 1250-1450 DD, a slower acting Insect Growth Regulator (IGR) product would be an appropriate choice. These products have a low impact on beneficial insects that can continue to exert biological control after the efficacy of the insecticide residues have degraded. If the crop is nearing or has open bolls (1600+ DD), a faster acting insecticide would be a more appropriate choice. A follow up treatment for SLW may be necessary during the late stages of boll opening if natural enemies are disrupted and SLW populations recur. The difference between viable and total SLW nymphs will provide an estimate of natural mortality of which biological control is a component.	**1250-1450 DD** Partial selectivity • Pyriproxyfen (IGR) (Refer to recommended regional 30 day window) • Spirotetramat (use adjuvant as per label) • Buprofezin **1600+ DD** • Diafenthiuron (vapour activity) • Dinotefuran (high rate) (knockdown) • Acetamiprid/emamectin (knockdown) • Spirotetramat (use adjuvant as per label).
Red	Red pathway populations represent the highest risk of lint contamination, but they are the simplest to manage because: • High SLW numbers occurring well before boll opening allow time for control action without the immediate risk of lint contamination. • Insecticides such as IGRs, that have a slower mode of action and reduce population recruitment, can be used to best effect prior to canopy closure thereby improving spray penetration. • The efficacy provided by early IGR usage can then be reinforced by natural enemies that are largely undisrupted by these products, suppressing populations for much longer.	**1250-1450 DD** Partial selectivity • Pyriproxyfen (IGR) (Refer to recommended regional 30 day window) • Cyantraniliprole (if used twice in succession within 10-15 days) • Spirotetramat (use adjuvant as per label) • Buprofezin **1600+ DD** Partial selectivity to broad-spectrum • Diafenthiuron (knockdown) • Acetamiprid/emamectin (knockdown) • Spirotetramat (control nymphs).

Note: Products are listed in order of selectivity based on Table 4 (pages 14-15).

Resistance profile – SLW

When silverleaf whitefly was first identified in Australia in 1994 it already possessed resistance to many older insecticide groups, including pyrethroids (SP) and organophosphates (OPs). Selection of resistance in SLW populations can happen very quickly. Currently there is widespread, low level resistance to imidacloprid and bifenthrin. Rare instances of resistance to acetamiprid has been detected in previous seasons.

Resistance to pyriproxyfen is a significant concern for industry with increase in number of regions where resistance was detected with some reports of field failures. In an effort to maintain product efficacy Transgenic & Insect Management Strategy (TIMS) has recommended a continuation of the regional 30 day pyriproxyfen window and restrictions on pyriproxyfen use in open cotton. Rare and low level resistance to spirotetramat is of concern due to the dominant target site resistance mechanism. This means resistance could develop rapidly and reversal of resistance is unlikely.

Compliance with the IRMS (see pages 56-57) will ensure the products available for SLW control will 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. It relies on alternative host plants to survive. Generation times are temperature dependent, slowing down during winter months. In central Queensland, the winter generation time is 40-45 days while in the Macintyre, Gwydir and Namoi valleys, generation time increases to 65-70 days. At Griffith in southern NSW, development during winter takes just over 100 days.

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 gerkin 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 soybeans, sunflowers and all cucurbit crops. Spring plantings of these crops may provide a haven for SLW populations to build up in and then move into cotton. Autumn plantings of these crops may be affected by large

Adults and nymphs of SLW (left) and greenhouse whitefly (right). (Richard Lloyd, Qld DAF) populations moving out of cotton. Do not plant cotton near preferred SLW host crops such as melons. Destroy crop residue from all susceptible crops immediately after harvest.

Minimising winter hosts, particularly sowthistle and volunteer cotton, is important in reducing 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.

Further information – SLW Factsheet available: www.cottoninfo.com.au

Qld DAF, Toowoomba
Jamie Hopkinson: 07 4529 4152 or 0475 825 340 (resistance enquiries).
Paul Grundy: 0427 929 172.

Qld DAF, Emerald – Richard Sequeria: 07 4991 0810 or 0407 059 066.

Natural enemies play a vital role in the successful management of whitefly. Minimise impact on these beneficials by using thresholds for all pests and consider the impact on beneficials when selecting an insecticide.

TABLE 15: Control of silverleaf whitefly

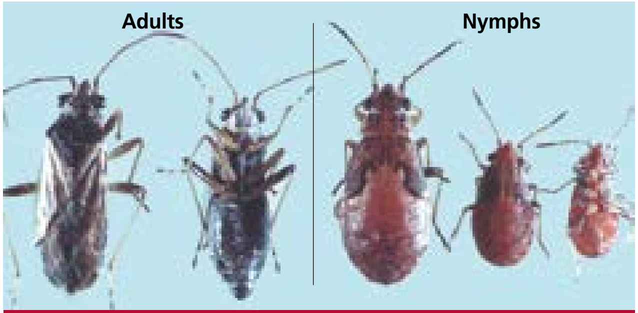
Active ingredient	MoA group	SLW resistance	Overall impact on beneficials*	Comments#
Paraffinic oil	No group	Unknown	Very low	Most effective when targeting low, early season populations. Apply in a minimum of 100 L/ha for ground applications. Use in combination with another registered insecticide when applying from the air. Multiple applications are more effective.
Pyriproxyfen	7C	Widespread – low	Very low	An IGR with translaminar movement that disrupts egg hatch, and interferes with moulting from 4th instar nymph to adult. Adult female fertility is reduced by contact with pyriproxyfen. Ensure thorough coverage. Maximum 1 application per season.
Clitoria ternatea extract	No group	Not detected	Low	Apply as indicated by field checks and pest presence. 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. Application should be aimed at the early nymph stages of whitefly. Spray in sufficient volume to provide adequate penetration and coverage. Maximum 1 application per season. Thorough spray coverage is essential.
Diafenthiuron	12A	Not detected	Low	Provides suppression of SLW. Apply when population densities are low to moderate. Suppression may not be satisfactory once population densities exceed moderate infestation, or when high numbers of adults are invading from nearby fields. Maximum 2 applications per season.
Afidopyropen	9D	Not detected	Low	Registered to provide suppression of both adult and nymph stages of whitefly, however it is recommended to target the nymph stage. Ground rig application only.
Cyantraniliprole	28	Not detected	Moderate	Target early developing populations. Maximum 2 applications per season.
Spirotetramat	5	Very rare	Moderate	Use the higher rate when periods of high pest pressure or rapid crop growth are evident, and when crops are well advanced. Do not re-apply within 14 days. Spirotetramat controls nymphs and has a sterility effect on female SLW. Maximum 1 application per season. Ensure thorough coverage and use of adjuvant as specified on label. Has translaminar and systemic mobility in both phloem and xylem.
Acetamiprid	4A	Very rare – low	Moderate	Apply with adjuvant as per label recommendations. 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	Acetamiprid – very rare -– low	Moderate	Use prior to heavy populations becoming established in the crop. Activity primarily on nymphs and therefore evidence of activity will be slower than typical contact insecticides. Use adjuvant as per label. Maximum 2 applications per season and use an insecticide from another mode of action between applications.
Dinotefuran	4A	Not detected	Moderate	When mirids and SLW are present and SLW is at or above threshold levels, use SLW rate. 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 and use an insecticide from another mode of action between applications.
Bifenthrin	3A	Widespread – low Cross-resistance with other SPs.	Very high	The adult stage should be targeted. Do not spray crops with a high population of the juvenile stages. Thorough coverage of the crop canopy is essential. 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 4 in this guide.

Other insect pests

Rutherglen bug (RGB) – *Nysius vinitor*

RGB's wide host range includes fruits, vegetables, oilseeds and grains, and many common weeds. Adult RGBs are often found in cotton, sometimes in large numbers, but generally do not feed and can't reproduce in the crop. Starving nymphs migrating from maturing sunflower or canola crops may damage border areas of adjacent cotton.

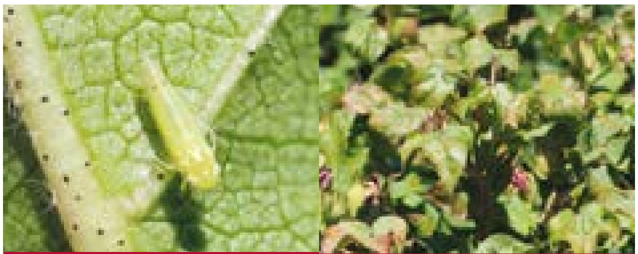


Adult Rutherglen bugs are 3-4 mm long; nymphs are reddish-brown. (Qld DAF)

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

Leafhoppers (jassids)

Several species of leafhoppers are occasional pests of cotton. Seedling damage or leaf stippling is unlikely to reduce yield unless extreme (e.g. damage to >50% of the leaf surface just before cut-out). Lucerne leafhopper is suspected to have caused leaf chlorosis in some fields in the 2021-22 season. Unnecessary sprays for leafhoppers may adversely affect beneficial species and flare other pests.



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

Redshouldered leaf beetle – *Monolepta australis*

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

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

Bollworms

While this term 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 18mm long and their favoured host is the weed, bladder ketmia. (Lewis Wilson)

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

Pink spotted bollworm moths and larva (moth – right 12mm). (P. Room)

Damaged lint due to pink spotted bollworm feeding and the entry of boll-rotting fungi. (D. Ironside)

Insecticide Resistance Management Strategy (IRMS) for 2022-23

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

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

The IRMS aims to assist users to:

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

The cotton industry IRMS seeks to manage the risk of resistance in all major pests of cotton including aphids, mites, SLW and *Helicoverpa* spp. in both conventional and Bt cotton (note that in this document, the term 'insecticide' refers generally to pesticides used for insect or mite control). Additional resistance management requirements are also in place for managing the risk of *Helicoverpa* developing resistance to Bt cotton (pages 61-71).

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 highlights for the 2022-23 cotton season

- **Fipronil bee risk.** While bees are susceptible to many insecticides used on cotton, fipronil risk to managed hives has been highlighted due to the extended residue risk. The industry recommends fipronil should not be used on flowering crops. Refer to label for statement about bees.
- **Incidental resistance from fall armyworm spraying.** Use of insecticides for fall armyworm in other crops may inadvertently select for resistance in cotton pests. Apply resistance management principles to FAW management.
- **Continuation of pyriproxyfen window.** Resistance to pyriproxyfen in SLW is a significant concern for industry with an increase in the number of regions where resistance was detected and field failures reported. In an effort to maintain product efficacy, TIMS has recommended a continuation of the regional 30 day pyriproxyfen window and restrictions on pyriproxyfen use in open cotton. After consultation, appropriate window dates will be published on CottonInfo and Cotton Australia websites. Limit pyriproxyfen use to no more than ONE application per season.
- **SLW products.** With the move from the SLW threshold matrix to the DST, SLW products are listed against the pathways as examples only. The SLW management fact sheet (available from the CottonInfo website) should be consulted when making decisions regarding SLW products. There is rare and low level resistance to spirotetramat in most regions. The dominant target site resistance mechanism means resistance can develop rapidly and reversal of resistance is unlikely. With pyriproxyfen resistance remaining a concern, and increased reliance on spirotetramat, TIMS has recommended usage be limited to one application per season. The `double knock' use for mealybug – 2 applications 14 days apart is an allowable exception.
- **Northern IRMS.** To avoid confusion, the previous 'Northern Regions' IRMS has been renamed Central Qld IRMS. An IRMS strategy has not been yet been developed for cotton regions in Northern Australia (NQ, NT, WA).

Principles underlying the IRMS

- **Monitor pest and beneficial populations. Consider species as well as abundance.**
- **Monitor fruit retention and determine if losses are likely to be 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.**

IRMS in grains

Resistance management strategies have also been developed for key grains pests and should be used in conjunction with the Cotton IRMS. They are available at https://ipmguidelinesforgrains.com.au/ipm-information/resistance-management-strategies

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

CRDC COTTON RESEARCH AND DEVELOPMENT CORPORATION

Insecticide Resistance Management Strategy 2022/23

Best Practice Product Windows and Use Restrictions to Manage Insecticide Resistance in Insect Pests of Australian Cotton

CENTRAL QLD REGIONS: Belyando, Callide, Central Highlands, Dawson

INCREASING — SELECTIVITY — DECREASING

CONSIDER IMPACT ON BENEFICIALS & BEES (TABLE 4 CPMG)

Stage 1	Stage 2	Stage 3	Stage 4	
	1-Nov	1-Dec	1-Jan	
Helicoverpa viruses (Vivus)				
Pirimicarb Group 1A				Note 1
Paraffinic Oil (Canopy, Biopest)				
	Pyriproxyfen Group 7C		Use an alternative from open cotton	Note 3
Sero-X				
Etoxazole				
Buprofezin (Applaud) Group 16				Note 3, 9
GROUP 28: Max 4/season	Chlorantraniliprole (Altacor) Group 28			Note 10
Afidopyropen (Versys) Group 9D				Note 3
Spinetoram (Success Neo) Group 5				
start date = canopy closure	Diafenthiuron Group 12A			Note 3
Pymetrozine Group 9B				
Indoxacarb Group 22A			Dec-31	Note 10
GROUP 28: Max 4/season	Cyantraniliprole (Exirel) Group 28			Note 3
Spirotetramat (Movento) Group 23				Note 3, 8
Flonicamid (MainMan) Group 29				
Abamectin Group 6			GROUP 6: Max 3 / season	Note 7
Emamectin Group 6				
start date = squaring	Propargite Group 12C			
Amitraz Group 19				
Sulfoxaflor (Transform) Group 4C				Note 2
Fipronil Group 2B	Do not apply to flowering crops			Note 11
Neonicotinoids (acetamiprid, clothianidin, dinotefuran, imidacloprid, thiamethoxam) Group 4A				Note 2, 3, 4, 11
	Chlorantraniliprole + Thiamethoxam (Voliam Flexi) Group 4A + Group 28			Consider risk to each group
Acetamiprid + Emamectin (Skope) Group 4A + Group 6				Consider risk to each group
Phorate	Note 1	Carbamates (methomyl, thiodicarb) Group 1A		Note 5
		Feb-01 Dimethoate Group 1B		Note 1
		OPs (chlorpyrifos, methidathion) Group 1B		
		Synthetic pyrethroids Group 3A		Note 3, 6

Green	Avoid repeated use of same group
Orange	No more than 1 application
Blue	No more than 2 applications
Purple	No more than 3 applications
Pink	No more than 4 applications

Note 1 If a phorate side dressing is used at planting then do not use a pirimicarb or dimethoate first foliar spray as there is cross resistance between them all. Dimethoate use will select catastrophic pirimicarb resistance in aphids so do not use pirimicarb and dimethoate in the same field.

Note 2 Failures of neonicotinoids against aphids have been confirmed. DO NOT follow a neonicotinoid seed treatment with a foliar neonicotinoid when aphids are present. If there is an alternative do not follow a neonicotinoid with sulfoxaflor.

Note 3 Refer to CottonInfo SLW fact sheet for additional guidance www.cottoninfo.com.au/publications/insects-managing-silverleaf-whitefly-australian-cotton

Note 4 Imidacloprid (neonicotinoid) resistance in cotton seedling thrips is likely. If resistance is suspected, phorate is an appropriate at-planting alternative. Consider non-neonicotinoid alternatives for first foliar spray.

Note 5 Additional applications can be made if targeting *Helicoverpa* moths using Magnet.

Note 6 High SP resistance is present in *Helicoverpa armigera* populations. Expect field failures. Low resistance is present in SLW.

Note 7 Addition of abamectin to mirid sprays has caused high level resistance in mites. Base miticide decisions on thresholds only.

Note 8 Rare and low level resistance to spirotetramat has been detected in most regions. The dominant target site resistance mechanism means resistance can develop rapidly and reversal of resistance is unlikely.

Note 9 Where buprofezin usage is targeting mealybugs, maximum of 2 sprays per field.

Note 10 Use of insecticides for fall armyworm in other crops may inadvertently select for resistance in cotton pests. Apply resistance management principles to FAW management.

Note 11 Refer to label statement about bees.

ALWAYS FOLLOW LABEL DIRECTIONS
CONSIDER IMPACT ON BENEFICIALS & BEES; (TABLE 4, COTTON PEST MANAGEMENT GUIDE)
IMPLEMENT AN IPM STRATEGY INCLUDING GOOD FARM HYGIENE AND CONTROL OF OVERWINTER HOSTS.
PUPAE BUST CONVENTIONAL COTTON CROPS AFTER HARVEST

Insecticide Resistance Management Strategy 2022/23

Best Practice Product Windows and Use Restrictions to Manage Insecticide Resistance in Insect Pests of Australian Cotton

CENTRAL & SOUTHERN REGIONS: Balonne, Bourke, Darling Downs, Gwydir, Lachlan, Upper & Lower Namoi, MacIntyre, Macquarie, Murrumbidgee, Murray

INCREASING — SELECTIVITY — DECREASING

CONSIDER IMPACT ON BENEFICIALS & BEES (TABLE 4 CPMG)

Stage 1	Stage 2 (15-Dec)	Stage 3 (15-Jan)	Stage 4 (15-Feb)	
Helicoverpa viruses (Vivus)				
Pirimicarb Group 1A				Note 1
Paraffinic Oil (Canopy, Biopest)				
	Pyriproxyfen Group 7C Regional 30 day window		Use an alternative from open cotton	Note 3, 8
Sero-X				
Etoxazole				
Buprofezin (Applaud) Group 16				Note 3, 10
GROUP 28: Max 4/season	Chlorantraniliprole (Altacor) Group 28			Note 11
Afidopyropen (Versys) Group 9D				
Spinetoram (Success Neo) Group 5				
start date = canopy closure	Diafenthiuron Group 12A			Note 3
Pymetrozine Group 9B				
Indoxacarb Group 22A		Jan-31		Note 11
GROUP 28: Max 4/season	Cyantraniliprole (Exirel) Group 28			
Spirotetramat (Movento) Group 23				Note 3, 9
Flonicamid (MainMan) Group 29				
Abamectin Group 6			GROUP 6: Max 3 / season	Note 7
Emamectin Group 6				
start date = squaring	Propargite Group 12C			
Amitraz Group 19				
Sulfoxaflor (Transform) Group 4C				Note 2
Fipronil Group 2B	Do not apply to flowering crops			Note 12
Neonicotinoids (acetamiprid, clothianidin, dinotefuran, imidacloprid, thiamethoxam) Group 4A				Note 2, 3, 4, 12
	Chlorantraniliprole +Thiamethoxam (Voliam Flexi) Group 4A + Group 28			Consider risk to each group
Acetamiprid + Emamectin (Skope) Group 4A + Group 6				Consider risk to each group
Phorate / Note 1		Carbamates (methomyl, thiodicarb) Group 1A		Note 5
		Feb-01 / Dimethoate Group 1B		Note 1
		OPs (chlorpyrifos, methidathion) Group 1B		
		Synthetic pyrethroids Group 3A		Note 3, 6

Green	Avoid repeated use of same group
Orange	No more than 1 application
Blue	No more than 2 applications
Purple	No more than 3 applications
Pink	No more than 4 applications

Note 1 If a phorate side dressing is used at planting then do not use a pirimicarb or dimethoate first foliar spray as there is cross resistance between them all. Dimethoate use will select catastrophic pirimicarb resistance in aphids so do not use pirimicarb and dimethoate in the same field.

Note 2 Failures of neonicotinoids against aphids have been confirmed. DO NOT follow a neonicotinoid seed treatment with a foliar neonicotinoid when aphids are present. If there is an alternative do not follow a neonicotinoid with sulfoxaflor.

Note 3 Refer to CottonInfo SLW fact sheet for additional guidance www.cottoninfo.com.au/publications/insects-managing-silverleaf-whitefly-australian-cotton

Note 4 Imidacloprid (neonicotinoid) resistance in cotton seedling thrips is likely. If resistance is suspected, phorate is an appropriate at-planting alternative. Consider non-neonicotinoid alternatives for first foliar spray.

Note 5 Additional applications can be made if targeting *Helicoverpa* moths using Magnet.

Note 6 High SP resistance is present in *Helicoverpa armigera* populations. Expect field failures. Low resistance is present in SLW.

Note 7 Addition of abamectin to mirid sprays has caused high level resistance in mites. Base miticide decisions on thresholds only.

Note 8 Resistance to pyriproxyfen is now widespread. To avoid complete loss of product efficacy, adhere to the 30 day regional window. Limit pyriproxyfen use to no more than 1 application per season.

Note 9 Rare and low level resistance to spirotetramat has been detected in most regions. The dominant target site resistance mechanism means resistance can develop rapidly and reversal of resistance is unlikely.

Note 10 Where buprofezin usage is targeting mealybugs, maximum of 2 sprays per field

Note 11 Use of insecticides for fall armyworm in other crops may inadvertently select for resistance in cotton pests. Apply resistance management principles to FAW management.

Note 12 Refer to label statement about bees

ALWAYS FOLLOW LABEL DIRECTIONS

CONSIDER IMPACT ON BENEFICIALS & BEES; (TABLE 4, COTTON PEST MANAGEMENT GUIDE)

IMPLEMENT AN IPM STRATEGY INCLUDING GOOD FARM HYGIENE AND CONTROL OF OVERWINTER HOSTS.

PUPAE BUST CONVENTIONAL COTTON CROPS AFTER HARVEST

Using the IRMS

Region

The IRMS aims to reduce the chance that highly mobile pests would be repeatedly exposed to the same insecticide group by limiting the timing of insecticide availability. The two strategies accommodate the different growing seasons: from southern Queensland through to southern NSW, and in Central Queensland where the different stage dates account for early planting and quicker crop development.

A specific IRMS strategy has not been yet been developed for cotton regions in northern Australia. Apply the IRMS principles in these regions.

Stage

The dates shown on the strategy charts indicate the start of each stage. Specific start &/or end dates are listed for individual insecticides and miticides that start or end outside window boundaries. All windows start at 12 am.

Selectivity

The products in the IRMS 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 insecticides.

Use restrictions

Colours represent the maximum number of applications per crop per season for any given product or product group. Additional restrictions can be found to the right of the table, with links to specific footnotes.

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 5 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 pyriproxifen 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 and aphids: 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

While ideally the window length would be 42 days (average time from egg to moth), 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

It is possible that resistance could develop and 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. Refer to CottonInfo (www.cottoninfo.com.au) or Cotton Australia (https://cottonaustralia.com.au) websites for details of the current Cotton Grower Association (CGA)-nominated voluntary pyriproyfen application window.

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).

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Bollgard 3 Resistance Management Plan (RMP)

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

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

Current status of Bt resistance in Australia

While field resistance to Cry1Ac 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 3%. Additionally, the expression of Cry1Ac and Vip3A varies throughout the season and is not always high enough for each insecticidal protein to individually control susceptible insects. None of the resistance genes identified confer cross-resistance to the other insecticidal proteins.

The data for current frequencies is sourced from Bayer's 2021-22 monitoring program. Unless otherwise stated, other information around trends in resistance frequencies draws on data collected over time from CSIRO and Bayer. The frequencies of these recessive resistance genes are currently not at a level that impacts performance of the technology (there is currently no resistance to Bollgard 3 that affects its performance against *H. armigera* or *H. punctigera*).

Cry1Ac: A gene present in field populations of *H. armigera* has the potential to confer high-level resistance to Cry1Ac. This largely recessive gene occurs at a low frequency – probably less than 5 in 10,000 (<0.05%).

***H. armigera*. (Melina Miles, Qld DAF)**

It also has a high fitness cost (i.e. resistant individuals develop slowly and are more likely to die) but this disadvantage is unlikely to greatly impact on the development of resistance.

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

Cry2Ab: A recessive gene that confers high level resistance to Cry2Ab is present in field populations of *H. armigera*. The mechanism is likely to be an alteration of a binding site in the gut of the insect. The current estimate of resistance frequency is approximately 3 in 100 (3%) 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 by CSIRO and Bayer suggests that the frequency of all Vip3A resistances is around 1 in 100 (1%).

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

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

How is resistance monitored?

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

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

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

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

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

H. punctigera. **(Melina Miles, Qld DAF)**

between the two to minimise the movement of large larvae from the refuge to the crop.

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

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

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

The productivity of refuges will vary considerably across regions and seasons. Improving the production potential of each individual refuge is an integral component of the RMP. Growers must ensure that on farm refuge management is a priority. Looking after refuges, including nutrition, weed control, timely irrigation and all factors that make the refuge 'attractive' to female moths laying eggs, is the key to ensuring that they are effective. Guidelines on refuge management are provided in the RMP and the following unsprayed pigeon pea refuge agronomy guide (page 72).

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

2. Controlling volunteers and ratoons

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

3. Planting windows

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

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

4. No Bt sprays

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

5. Pupae destruction

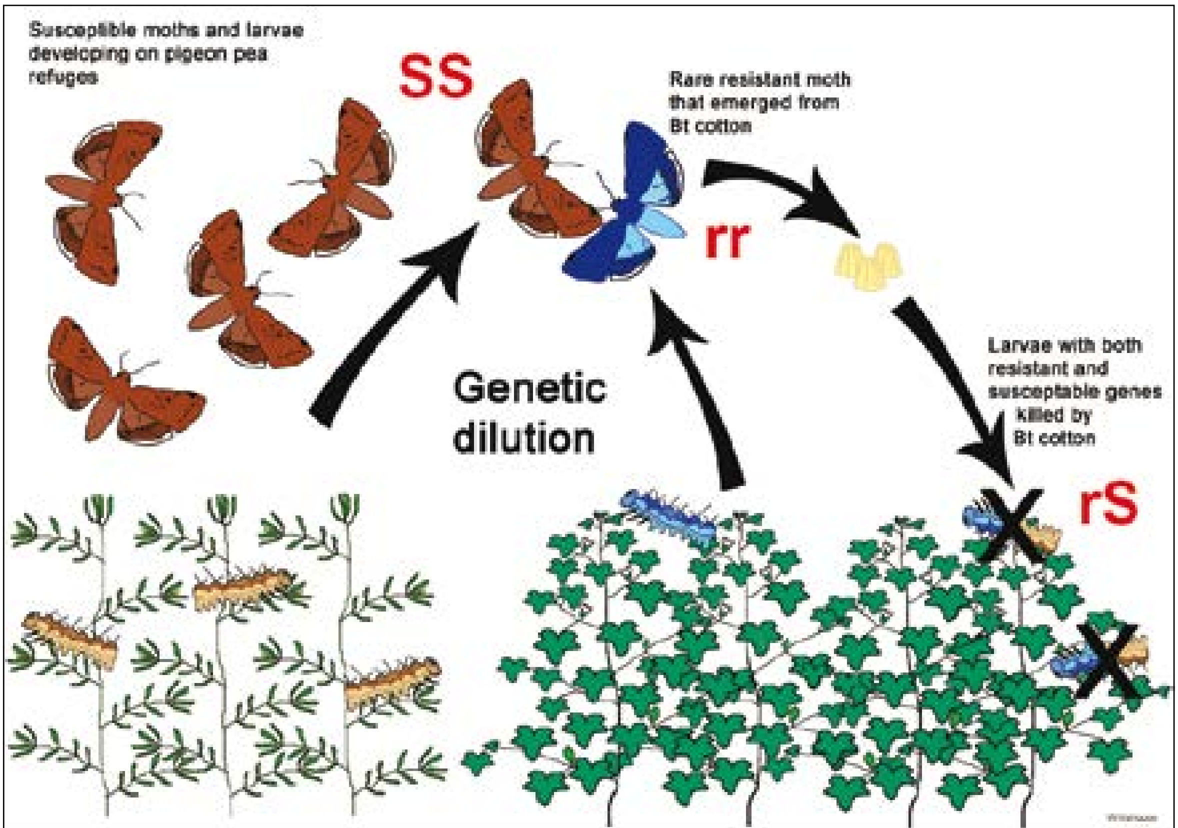
Pupae busting is a highly effective mitigation tactic for reducing resistance risk in areas where *Helicoverpa* have a diapause stage, provided it is performed well and at the right time. Although minimal larvae are expected to survive in Bollgard 3 cotton, those that do are most likely carrying resistance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

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

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

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

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



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

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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 late-flowering and included *H. armigera* and *H. punctigera*.

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

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

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

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

- **Sharon Downes: 0427 480 967 or**
- **Kristen Knight: 0429 666 086**

Insecticide selection for Bollgard 3 crops

When controlling *Helicoverpa* within Bollgard 3 crops, insecticide selection should comply with the cotton industry's Insecticide Resistance Management Strategy (pages 56-57). The beneficial/pest ratio (described on page 28) should also be given careful consideration before applying insecticides. If an insecticide is required, choose the most effective product that is the least disruptive to the beneficial complex (refer to Table 4). While foliar Bt can be used on Bollgard 3 crops, it is a requirement of the Bollgard 3 cotton Resistance Management Plan that foliar Bt not be used on any refuge crops.

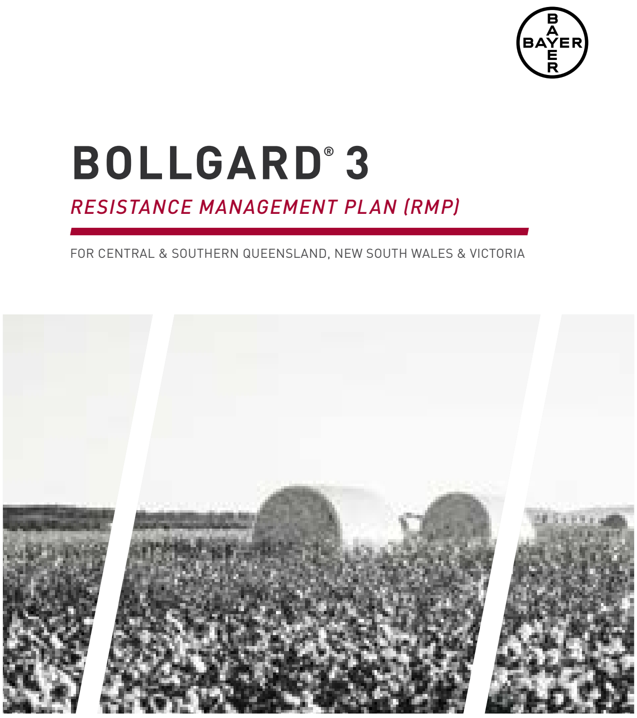
Helicoverpa thresholds

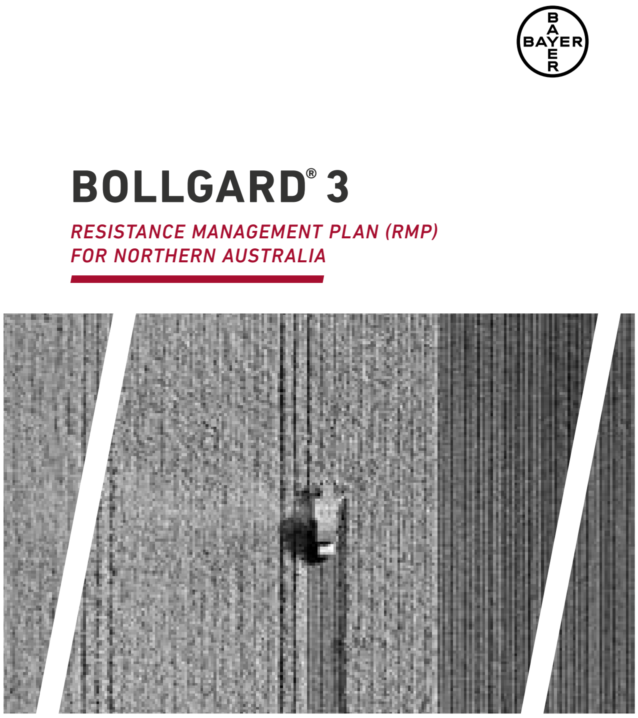
Do not include eggs or any larvae <3 mm long in spray threshold counts. For economic management of *Helicoverpa*, larval populations should be controlled with an insecticide if a threshold of:

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

Application of these thresholds requires careful and accurate assessment. Checks should be made over the whole plant including the terminals, squares and especially flowers and small bolls. Be sure to objectively assess larval size. A complete description of the sampling protocols for *Helicoverpa* can be found on page 27.

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





The RMP for Central and Southern growing regions is included in this publication.
The Northern RMP can be downloaded from www.bollgard3.com.au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RESISTANCE MANAGEMENT PLAN

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 1st to October 31st 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 the 1 August that only has an associated 5% unsprayed cotton refuge (or its equivalent) must be completely destroyed by 18 March.
- Any Bollgard 3 cotton that is planted in planting window 1 and is grown for greater than 230 days with only a 5% unsprayed cotton refuge (or its equivalent) will be recorded as non-compliant and be issued with a Resistance Risk Management Plan (RRMP).

Planting Window 2:

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

2. REFUGES

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

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

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

Table 1. Irrigated Bollgard 3 cotton refuge options

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

Table 2. Dryland Bollgard 3 cotton refuge options

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

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

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

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

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

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

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

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

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

General conditions for all refuges:

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

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

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

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

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

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

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

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

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

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

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

3. CONTROL OF VOLUNTEER AND RATOON COTTON

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

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

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

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

4. PUPAE DESTRUCTION/ TRAP CROPS

Victoria, New South Wales and Southern Queensland

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

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

Option for an alternative pupae destruction management

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

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

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

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

Central Queensland

Crop destruction

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

End of season management of refuges/trap crops

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

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

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

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

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

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

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

Failed crops – all regions

Bollgard 3 crops that will not be grown through to harvest for various reasons and are declared to, and verified by, Monsanto as failed must be destroyed within two weeks after verification, in such a way that prevents regrowth. Crops that are abandoned before February 28 should be slashed and mulched within 4 weeks.

5. SPRAY LIMITATIONS

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

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

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

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

For further background information on the various components of this plan see the "Bollgard 3 Resistance Management Plan" section in the current *Cotton Pest Management Guide*.

The Resistance Management Plan (RMP) for Northern Australia can be found at www.bollgard3.com.au

Managing unsprayed pigeon pea refuges

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

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

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

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

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

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

Seed bed preparation and planting

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

Pre-irrigation

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

Crop nutrition

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

Weed management

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

As well as herbicides, 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 to reduce the risk of waterlogging on heavy soils. 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 the first in-crop irrigation as the plants begin to develop flower buds. On lighter loamy soil types with lower moisture holding capacity (<140 mm PAWC) or in hotter climates, two irrigations prior to flowering may be required. Sunrise™ should be exhibiting signs of budding by the time it reaches 50-70 cm in height. After the initiation of buds, Sunrise™ can be irrigated on a similar schedule to the adjacent cotton to prolong flowering and ensure rapid regrowth after insect attack.

Larvae in pigeon pea refuge. (Johnelle Rogan)

Destruction and harvest of pigeon pea refuge crops

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

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

Do not feed crop product or crop residue to livestock.

TABLE 16: Herbicides available for use in pigeon pea

Active ingredient	MoA group	Comment
Prometryn*	C (5)	Apply up to the maximum rate pre planting and incorporate, or as a post-emergent directed spray towards the base of established plants.
Butroxydim*	A (1)	Apply the specified rate as a post-emergence spray over the top of the pigeon pea crops. Refer to label as rates are different depending on weed being controlled.
Fluazifop-p*	A (1)	
Haloxyfop*	A (1)	
Sethoxydim*	A (1)	Apply specified rate as a post-emergence spray over the top of the pigeon pea crops.
Clethodim*	A (1)	Always apply with D-C-trate at 2 L/100 L or Hasten or Kwickin at 1 L/100 L. Uptake at 500 mL/100 L spray volume. The lower doses will provide effective control if applied under ideal conditions to weed that are smaller, actively growing and free from temperature or water stress.
Quizalofop*	A (1)	Refer to permit for growth stages of species and critical comments.
Trifluralin	D (3)	Apply up to the maximum rate pre planting and incorporate. NSW and ACT only.
Diquat	L (22)	Harvest aid
Diquat/paraquat	L (22)	Apply pre-sowing, in minimum 50-100 L water. Apply specified rates for certain weeds at particular growth stages, refer to label.
Pendimethalin	D (3)	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	C (5)	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.

*Use in pigeon pea trap crops is under permit PER13758 (valid until 31 August 2026). Only apply to pigeon pea crops that are to be destroyed at the end of the season or to be harvested for seed for refuge replanting. Do not feed crop product or residues to livestock. Unless otherwise stated in the permit, use must be in accordance with the product label.

Integrated Weed Management (IWM)

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

Develop a strategy

Having good records on crop rotations, herbicides and other tactics used as well as weed species present will help in developing a plan that identifies where there are particular risks in the system and also where there might be opportunities to incorporate additional tactics. The Herbicide Resistance Management Strategy (HRMS pages 88-89) can help to inform the effectiveness of combinations of tactics on reducing the weed seed bank as well as the risk of herbicide resistance.

Know your enemy

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

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

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

WEEDpak www.cottoninfo.com.au/publications/weedpak

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

Time your tactics

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.

Think about the whole farming system

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

Consider crop competition

An evenly established, vigorously growing cotton crop can compete strongly with weeds, especially later in the season. Delaying planting on weedy fields until last gives more opportunity to control weeds that emerge prior to planting, and better conditions for cotton emergence and early vigorous growth. In irrigated crops, weed-free periods of 8-9 weeks from planting provide enough time for cotton to out-compete most later emerging weeds and significantly reduce weed seed production. Refer to critical periods for weed control (page 68, 2022 ACPM) for more information.

The Australian modes of action (MoA) classification system for herbicides changed from letters to numbers in 2021. For your convenience, both old and new MoA groups are included in this edition.

Plan weed management to fit with other operations

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

Consider the wider impacts of weeds

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

Mix it up with rotation crops

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

Don't forget non-crop areas

Weeds in non-crop areas on the farm such as channels, tail drains, fence lines and roadsides can develop and introduce herbicide resistance into the farming system. Manage these areas as a fallow, using a range of tactics including residual herbicides, cultivation and chipping of weeds. Do NOT rely on glyphosate only to manage weeds in non-crop areas.

TABLE 17: Control of weeds in dry channels

Active ingredient	Mode of Action group
Amitrole + ammonium thiocyanate	Q(34)
Glyphosate	M(9)
Imazapyr + glyphosate	B(2) + M(9)
Pendimethalin	D(3)
Flumioxazin	G(14)

Dryland cotton

Moisture is the key ingredient for dryland cotton and weeds are very efficient at robbing the soil of vital moisture and nutrients. Controlling weeds in winter crops pre-cotton and maintaining a clean winter fallow are crucial in providing sowing opportunities for dryland cotton. Running the weed seed bank down in the previous winter crop or fallow is vital to keep in-crop weed management costs at a minimum. Including residual herbicides in fallows and ensuring that pre-emergent herbicides are used at planting will provide ongoing in-crop weed control and reduce the reliance on glyphosate.

Rotating to other modes of action (MoA) for knockdown weed control is an important management strategy to prolong the life of glyphosate. The development of new Group G(14) herbicides also provides additional control options pre-sowing. Cultivation is often seen as detrimental in dryland systems due to moisture losses from cultivation passes.

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

Come Clean. Go Clean.

To minimise the entry of new weeds into fields, clean down boots, vehicles, and equipment between fields and between properties. Pickers and headers require special attention. Eradicate any new weeds that appear while they are still in small patches. Monitor patches frequently for new emergences. More biosecurity information is available at www.cottoninfo.com.au/biosecurity

Irrigation water can be a source of weed infestation with weed seeds being carried in the water. Control weeds that establish on irrigation storages, supply channels and head ditches.

Control survivors before they set seed

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

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

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

Manual chipping

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

Spot spraying

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

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

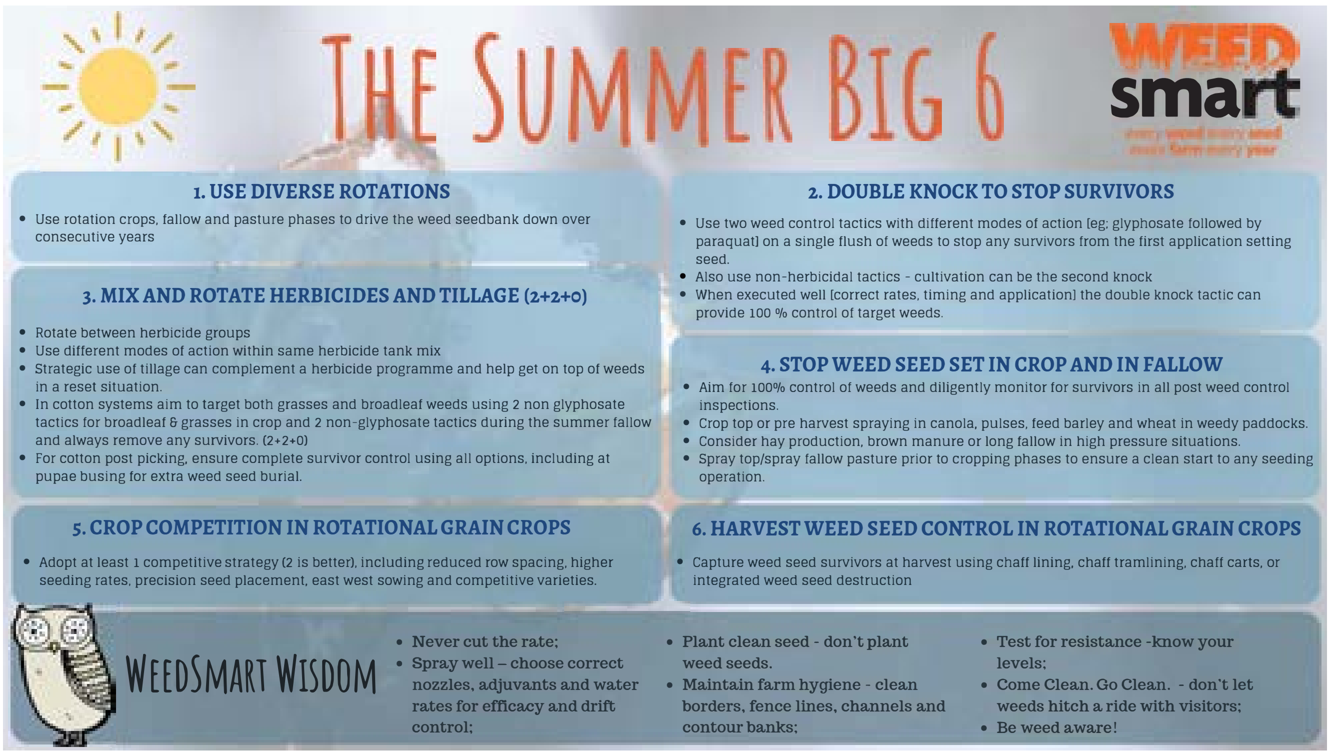

TABLE 18: Herbicide plant-backs from rotation crops to cotton

Active ingredient	MoA	Plant-back to cotton	Notes
Aminopyralid + fluroxypyr	I(4)	9 months	Plant-back interval on black cracking clay soils. When rainfall is less than 100 mm for a period of 4 months or greater the plant-back period may be significantly longer.
Aminopyralid + picloram + 2,4-D	I(4)	12 months (northern NSW, Qld)	Plant-back periods for rotational crops and fallow following application of FallowBoss Tordon Herbicide up to 20 months (Southern NSW) 700 mL/ha. Plant-back periods are based on normal rainfall pattern. During drought conditions (or when rainfall is less than 100 mm for a period of 4 months or greater) the plant-back period may be significantly longer. Under such circumstances a bioassay is required, before planting the next crop.
Atrazine	C(5)	6 months	Following treatments of up to 1.4 kg/ha.
		18 months	Following treatments of 1.4 kg/ha to 3.3 kg/ha.
Atrazine + S-metolachlor	C(5) + K(15)	6 months	When rates up to 3.2 L/ha are used.
		18 months	When rates up to 3.2 L/ha are used. On alkaline soils, a bioassay or analytical test should be undertaken.
Chlorsulfuron	B(2)	18 months	Where soil pH is 6.6-7.5 and 700 mm of rain has fallen.
			For soil pH >7.5 only grow cotton after growing a test strip.
Clopyralid	I(4)	3 months	When rates up to 30 g/ha are used.
		6 months	When rates of 30-120 g/ha are used
		24 months	When rates above 120 g/ha are used. For all rates at least 100 mm rain required during plant-back period.
Diuron	C(5)	Refer to label	Do not replant treated areas within 2 years of application of diuron except when otherwise stated on the label.
			Do not replant treated areas to any crop within 1 year after last spray except cotton (along with corn or grain sorghum) which may be planted in the spring following year.
Flumioxazin	G(14)	0 months	For zero plant-back for knockdown spike rates of 45 g/ha or below.
		2 months	For residual rates above 210 g/ha.
Flumetsulam	B(2)	2 years	For NSW and Qld a minimum of 50 mm and preferably 100 mm rain or more must have fallen over the warm months of the year.
Imazamox	B(2)	10 months	Must have 800 mm of rainfall or irrigation
Imazamox + imazapyr	B(2)	Unknown	Registered for use in Clearfield crops (all other – 34 months).
Imazethapyr	B(2)	22 months	Dryland cotton.
		18 months	Irrigated only. (Providing rainfall and irrigation exceeds 2000 mm)
Isoxaflutole	H(27)	7 months	350 mm rainfall (do not include flood/furrow irrigation) between application and planting the subsequent crop.
Mefenpyr-diethyl + iodosulfuron-methyl sodium	B(2)	12 months	Rainfall of less than 500 mm may result in extended re-cropping intervals for summer crops sown in the following season.
Metsulfuron methyl	B(2)	Unknown	Registered for use in cereal crops: wheat, barley, triticale. Legume crops: chickpeas (desiccant).
Metribuzin	C(5)	6 months	Rates <1.5 L/ha. This could be longer if there have been long dry periods between crops.
		12 months	Rates >1.5 L/ha.
Metsulfuron-methyl + mefenpyr-diethyl	B(2)	12 months	Rainfall of less than 500 mm following application may result in extended re-cropping intervals for summer crops sown in the following year.
Pyroxasulfone	K(15)	5 months	+ 150 mm rainfall. Less total rainfall between application and planting of the following crop than 150 mm may require extended plant-back period.
Picloram + 2,4-D	I(4)	12 months	(Nth NSW & Qld). Do not use on land to be cultivated for growing susceptible crops within 12 months of application. Based on normal rainfall.
Simazine	C(5)	9 months	When up to 2.5 kg/ha are used. When rates exceed 2.5 kg/ha, plantings may not be possible for very long periods of time afterwards.
Sulfosulfuron	B(2)	Unknown	Registered for use in cereal crops: wheat, triticale.
Tribenuron methyl	B(2)	Unknown	Registered for use in fallows.
Triasulfuron	B(2)	15 months	Soil pH <7.5, 700 mm rainfall between application and sowing the plant-back crop.
		18 months	Soil pH 7.6-8.5.
Triclopyr + picloram + aminopyralid	I(4)	4 months	0.2 L/ha. During drought conditions (<100 mm rainfall in a 4 month period) the plant-back is significantly longer.
		6 months	0.4 L/ha.

This is a guide only – always read and follow product label directions.
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.

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 herbicide is used for weed control poses the greatest risk to glyphosate resistance developing. The continued use of glyphosate for controlling summer weeds means that these weeds are only exposed to one mode of herbicide action. The Herbicide Resistance Management Strategy recommends at least two non-glyphosate tactics in summer fallows in addition to two non-glyphosate tactics in the cotton crop. Residual herbicides and double knock tactics provide good alternatives to a glyphosate-only fallow herbicide (see Table 18). To control larger weeds that may be tolerant to herbicides, a strategic cultivation or manual chipping is recommended. Field activities such as fertiliser placement and bed cultivators should be set up to have adequate soil disturbance to eradicate weeds during these mechanical tasks, and this will lessen the pressure to control weeds with further actions.

In-crop tactics

Pre-plant/at planting

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

Herbicides from Groups C(5), G(14), I(4), L(22), M(9), N(10) and Q(34) can be used to target weeds that have emerged in the field (see the Integrated weed management diagram). 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 C(5), D(3) or K(15).

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

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

The persistence of residual herbicides needs to be considered in order to avoid impacts on rotation crops. Persistence is determined by a range of factors including application rate, soil texture, organic matter levels, soil pH, rainfall/irrigation, temperature and the herbicide's characteristics. It can be quite complex. For example, it is not usually the volume of rain, but the length of time the soil is moist that is the critical factor. Microbes that degrade many herbicides live near the soil surface and require moist soil to flourish. A couple of storms, where the soil surface dries out quickly won't contribute as much to residue breakdown as a period of rain that moistens the soil surface for days. Refer to product labels for more information. If you suspect that a residual may still be active in the lead up to planting, look for the presence of susceptible weeds in the treated paddock or pot up soil from treated and untreated areas, sow the susceptible crop and compare emergence. Where there is a concern, consider planting an alternative crop that is tolerant of the herbicide, or if cotton is to be used, plant the paddock last and pre-irrigate if it is to be irrigated. Always ensure that best practice is followed in terms of capture and management of runoff water.

Post-emergence

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

When targeting the over the top (OTT) application of glyphosate (Roundup Ready Flex®), aim to treat actively growing weeds, and do not allow weeds to become too large. Avoid using the same herbicide to control successive generations of weeds, and ensure survivors are not able to set seed. Do not apply more than the allowable number of OTT applications. Refer to the *Herbicide tolerance technology* section (page 91) for more information.

TABLE 20: Efficacy of knockdowns in winter fallows measured 6 weeks after treatment

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

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

TABLE 19: Plant-backs to cotton for herbicides used in seedbed preparation

Active ingredient	2,4-D amine 700 g/L (2,4-D amine 300 g/L)			dicamba 700 g/kg (dicamba 500 g/L)			fluroxypyr 200 g/L (fluroxypyr 333 g/L)			triclopyr 600 g/L
Rate L or g/ha	0.5 (1.1)	0.5-1.0 (1.1-2.3)	1.0-1.5 (2.3-3.4)	140 (200)	200 (280)	400 (560)	0.375 (0.225)	0.75 (0.45)	1.5 (0.9)	0.16
Plant-back[1] (days)	10	14	21	7	7	14	14	14	28	14

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

Integrated weed management tactics

NON GLYPHOSATE WEED TACTICS FOR THE COTTON FARMING SYSTEM

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

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

NON-GLYPHOSATE TACTICS

Fallow
Strategic cultivation
Double knock
Optical sprayers
Patch management
Cover crops

Non Glyphosate options[2]
Group C/5 (bromoxynil, terbuthylazine)
Group G/14 (flumioxazin, pyraflufen, saflufenacil)
Group H/27 (isoxaflutole)
Group L/22 (paraquat, paraquat/diquat)
Group L-22/Q-34 (amitrole/paraquat)
Group N/10 (glufosinate)
Group I/4 (2,4-D, dicamba, fluroxypyr)

Rotation Crops[4]
Crop competition
Rotate MoA
Plant back restrictions
Cover crops

Pre/at plant
Cultivation

Knockdown MoA
Group C/5 (bromoxynil)
Group D/3 (chlorthal dimethyl)
Group G/14 (pyraflufen, flumioxazin, saflufenacil, oxyflurofen, carfentrazone)
Group I/4 (dicamba, fluroxpyr)
Group L/22 (paraquat, paraquat/diquat)
Group L-22/Q-34 (amitrole/paraquat)
Group N/10 (glufosinate)

Residual MoA[4]
Group C/5 (fluometuron, prometryn, terbuthylazine, diuron)
Group D/3 (pendimethalin, trifluralin)
Group K/15 (S-metolachlor, metolachlor)

Post-emergent[1]
In-crop cultivation
Manual chipping
Rogueing

Post-emergent OTT MoA
Group A/1[3] (sethoxydim, clethodim, butroxydim, propaquizafop, haloxyfop)
Group K/15 (S-metolachlor[5])
Group Z/0 (MSMA)

Lay-by, directed or shielded spray
Group C/5 (fluometuron, prometryn, terbuthylazine, diuron)
Group D/3 (pendimethalin)
Group G/14 (flumioxazin[5])
Group K/15 (S-metolachlor)
Group J/0 (2,2-DPA)

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

NO SURVIVORS

Survivors – aim for 100% control

In fallow survivor control
Cultivation, chipping or spot spraying
Refer above for NON glyphosate options
Optical sprayer

Pre-plant survivor control
Cultivation, chipping or spot spraying
flumioxazin
pyraflufen-ethyl
carfentrazone-ethyl
bromoxynil

Post-emergent
Inter-row cultivation, chipping or spot spraying

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

Comments

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

[1] Mix full rates of different MoA, and rotate to alternative MoA in following years.
[2] APVMA permits: 12941, 88120 for fallow use.
[3] Group A/1 herbicides already exhibit widespread resistance in several species. Controlling survivors is essential.
[4] Refer to label for plant-back restrictions to following crop.
[5] Limited formulations are registered for this use. Please check label.

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Grass selective herbicides (Group A/1) can be applied over the top of cotton, however repeated use is likely to lead to the development of Group A(1) resistance. It is important that in managing glyphosate resistance, that resistance to other herbicides doesn't develop. Use Group A(1) 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 C(5), D(3), G(14), K(15) and J(15). Check label to confirm usage is allowed for each product in your situation and for crop safety directions.

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

Post-harvest

Some weeds are likely to be present in the crop later in the season – even in the cleanest crop. These weeds will produce few seeds in a competitive cotton crop, but can be very problematic in skip-row configurations and can take advantage of the open canopy created by defoliation and picking. Removing crop residues and weeds as soon after picking as practical greatly reduces the opportunity for these weeds to set seed. See also *Management of volunteers and ratoons* (page 94).

Notes on herbicide use

Registration of a herbicide is not a recommendation for the use of a specific herbicide 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, and note any specific instructions relating to the rate, timing, application and safety.

IMPORTANT – avoid spray drift

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

- Plan your crop layout to avoid sensitive areas.
- Ensure spray contractors have details of any nearby sensitive areas.
- Consult with neighbours to minimise risks from spraying near property boundaries (refer to SataCrop).
- Carefully follow all label directions.
- Pay particular attention to weather conditions before application.
- Use buffer zones to reduce the impact of spray drift or over-spray.
- Keep detailed records.
- Adhere to relevant 2,4-D application regulations.

See the *Spray application* section (page 126) for more details.

For more information:

Refer to IWM tactics diagram on page 78.

SataCrop website satacrop.com.au

The *Australian Cotton Production Manual* also includes information on weed control tactics.

CottonInfo videos:
Late season weeds https://youtu.be/4gqLpEu5uTE
Integrated weed management https://youtu.be/AH3jwf0TY60
Sources of weed seed https://youtu.be/TLSpFIZZaqU

TABLE 21: Cotton herbicide plant-backs to rotation crops

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

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

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

Key weeds

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

Graham Charles, NSW DPI

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

Graham Charles, NSW DPI

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

Graham Charles, NSW DPI

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

Graham Charles, NSW DPI

Eric Koetz, CottonInfo/NSW DPI

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

Graham Charles, NSW DPI

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

Eric Koetz, CottonInfo/NSW DPI

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

Eric Koetz, CottonInfo/NSW DPI

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

Tonia Grundy, Qld DAF   Eric Koetz, CottonInfo/NSW DPI

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

Herbicide resistance management

The Australian lettering mode of action (MoA) classification system for herbicides changed in 2021 to match the international numbering system to allow for expansion as new chemistries enter the market. Both systems are included in this edition for ease of reference. The alignment mobile App is available to cross reference the current Australian letter system with the new numbering format. hracglobal.com/tools/classification-lookup

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

There are currently 509 unique cases (species x mode of action) of herbicide resistant weeds globally across 266 species (153 dicots and 113 monocots). Weeds have evolved resistance to 21 of the 23 known herbicide sites of action and to 164 different herbicides. Costs of weed control in cotton in the US have increased significantly due to the evolution of resistance to glyphosate (Group M/9). While historically the Australian cotton industry has had a strong integrated weed management system, the extensive use of herbicide tolerant (HT) cotton varieties since 2006 has meant that glyphosate now accounts for more than 70% of all herbicide used within cotton – herbicide resistance is a reality in the Australian cotton industry. 21 weed species have now been confirmed as glyphosate resistant (see Table 22), 12 of which occur widely in cotton farming systems. A NSW DPI survey has confirmed the presence of glyphosate resistant sowthistle (*S. oleraceus*) within at least three cotton growing regions.

For more information:

C.Preston, The Australian Sustainability Working Group. March 2020. https://www.facebook.com/AGSWG

I.Heap, The International Survey of Herbicide Resistant Weeds. March 2022. https://weedscience.org

Why the need for an industry-wide strategy?

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

How was the HRMS strategy developed?

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

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

HRMS review

The HRMS is reviewed annually by the Herbicide Resistance Tech Committee in light of weed field surveys, CCA and grower surveys and in consultation with registrants of glyphosate registered for over the top (OTT) use in Roundup Ready Flex.

Why does the HRMS only focus on glyphosate?

The strong reliance on glyphosate in the current farming system and the increasing number of cases of glyphosate resistance has meant that for the first HRMS, glyphosate was the key focus. Tables 23 and 24 show resistance has also been identified in Group L/22 (paraquat) and I/4 (2,4-D)

TABLE 22: Glyphosate resistant weeds in Australia

Weed species	Year first documented	Confirmed populations
Annual ryegrass (*Lolium rigidum*)	1996	854
Awnless barnyard grass (*Echinochloa colona*)	2007	103
Liverseed grass (*Urochloa panicoides*)	2008	4
Flaxleaf fleabane (*Conyza bonariensis*)	2010	64
Windmill grass (*Chloris truncata*)	2010	11
Wild radish (*Raphanus raphanistrum*)	2010	2
Great brome (*Bromus diandrus*)	2011	5
Sowthistle (*Sonchus oleraceus*)	2014	23
Red brome (*Bromus rubens*)	2014	1
Sweet summer grass (*Moorochloa eruciformis*)	2014	1
Prickly lettuce (*Lactuca serriola*)	2014	1
Feathertop Rhodes grass (*Chloris virgata*)	2015	5
Tridax daisy (*Tridax procumbens*)	2016	1
Tall fleabane (*Conyza sumatrensis*)	2017	3
Winter grass (*Poa annua*)	2017	2
Willow-leaved lettuce (*Lactuca saligna*)	2017	2
Northern barley grass (*Hordeum glaucum*)	2018	2
Wild oats (*Avena sterilis* spp.lLudoviciana)	2018	1
Wild oats (*Avena fatua*)	2018	1
Johnson grass (*Sorghum halapense*)	2019	1
Capeweed (*Arctotheca calendula*)	2021	1


CELEBRATING HASTEN
25th
YEAR
ANNIVERSARY
NOT TO BE
TAKEN
READ SAFETY DIRECTIONS
BEFORE OPENING OR USING
HASTEN†
SPRAY ADJUVANT
VICCHEM
CONTENTS
20 LITRES
AUSTRALIAN
eco-care
MADE

herbicides to weeds common in cotton farming systems The HRMS has been updated with notes to address risks from other MoAs, especially the emerging concerns around Group A(1) resistant grass species such as feathertop Rhodes grass, annual ryegrass and windmill grass.

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

A NSW DPI survey has confirmed Group A(1) resistance in windmill grass (*Chloris truncata*), feathertop Rhodes grass (*Chloris virgata*) and barnyard grass (*Echinochloa crus-garli*) in three cotton growing regions. The intent is to continue to expand the HRMS to incorporate other modes of action and multi-trait HR cotton varieties.

How to use the HRMS

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

How do non-cropping areas relate to the HRMS?

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

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

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

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

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

TABLE 23: Species that have developed resistance to paraquat (Group L/22) in Australia

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

Seed bank control/resistance risk

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

Seed bank control key:

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

Do I have to adhere to the HRMS?

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

Assessing your own risk

For a more detailed assessment of the resistance risks for individual paddocks, use Qld DAF's Online Glyphosate Resistance Toolkit, available via www.cottoninfo.com.au. This tool allows you to check what your current level of risk is for developing glyphosate-resistant weed populations on your farm. The tool allows you to enter information on your current practices (including crop rotation, crop density, and weed control tactics) and to identify which weed species you usually have to control. It will then calculate a glyphosate resistance risk score for the paddock, and a level of risk for each weed identified.

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

What does herbicide resistance look like?

Resistance begins with the survival of one plant and the seed that it produces. Early in the development of a resistant population, resistant plants are likely to occur only in isolated patches. These are often surrounded by dead 'susceptible' plants of the same species, or other species usually

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

TABLE 24: Weed species with populations resistant to 2,4-D (Group I/4)

Species	Common Name	Year	State	Situation	Herbicide	Also resistant to MoAs
Raphanus raphanistrum	Wild radish	1999	Western Australia	Winter cereal	2,4-D	
		2006	South Australia	Winter cereal	2,4-D, MCPA	B(2), F(12)
		2009	Victoria	Winter cereal	2,4-D	B(2)
		2010	Western Australia	Winter cereal	2,4-D	B(2), F(12), M(9)
		2011	Victoria	Winter cereal	2,4-D	
		2011	New South Wales	Winter cereal	2,4-D	
		2013	New South Wales	Winter cereal	2,4-D	
		2020	Western Australia	Winter cereal	2,4-D	B92), H(27), K(15)
Sisymbrium orientale	Indian hedge mustard	2005	South Australia	Winter cereal	2,4-D, MCPA	B(2)
		2015	South Australia	Winter cereal	2,4-D	F(12)
		2016	Victoria	Winter cereal	2,4-D	
		2016	Victoria	Winter cereal	2,4-D	B(2), F(12)
Sonchus oleraceus	Sowthistle	2015	Victoria	Winter cereal	2,4-D	
		2015	South Australia	Winter cereal	2,4-D, dicamba, clopyralid	
Arctotheca calendula	Capeweed	2015	South Australia	Winter cereal	2,4-D	

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

Why should I get weeds tested?

Testing a plant population for the presence of herbicide resistant individuals is an important tool for growers and advisors. The results from these tests can confirm if there is still efficacy within some of the MoA groups. Generally, seed is collected from the suspect plants and is sent for testing (see below). Bayer also offers free resistance testing – see page 92 for more details.

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

Collecting seed samples:

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

Collecting plant samples for the Quick Test:

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

Sending samples to resistance testing services

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

Dr Peter Boutsalis (seed or Quick Test)
Plant Science Consulting
22 Linley Avenue,
Prospect SA 5082
Phone: 0400 664 460
Email: info@plantscienceconsulting.com
Website: www.csu.edu.au/weedresearchgroup/herbicide-resistance

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

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

How do I manage glyphosate resistant weeds?

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

Refer to *Integrated weed management* section.

For more information on herbicide resistance visit www.weedsmart.org.au

BYGUM (barnyard grass understanding & management) www.cottoninfo.com.au
Contact: david@innokasintellectual.com.au

CottonInfo videos:
Minimising glyphosate resistance https://youtu.be/cke-mamGe2o
A demonstration of weed resistance https://youtu.be/y7Jj1laiSLk

Herbicide Resistance Management Strategy 2022-23 Explanatory Notes:

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

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

The formula to manage/delay glyphosate resistance
The most effective way to delay resistance is to use:
2 non-glyphosate tactics targeting both grasses and broadleaf weeds during the cotton crop
+
2 non-glyphosate tactics in summer fallow targeting both grasses and broadleaf weeds
and
NO survivors, control survivors of glyphosate applications and do not allow them to set seed.

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

Cropping system – The HRMS models two systems,

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

With many farms now reporting glyphosate resistance, it is important to note that the strategies identified to avoid resistance are similar to those required to manage it. However, recent research has found that to eradicate populations, additional tactics such as patch management are required.

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

In-crop tactics

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

Summer fallow tactics

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

Other management recommendations:

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

Assessing your own risk
Refer to page 86 of this publication for information on how to get weeds tested for resistance. For more information and tools on herbicide resistance and weed management in cotton refer to: **www.cottoninfo.com.au** or **www.weedsmart.org.au**

Irrigated back to back cotton

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

Dryland cotton every second summer

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

Glyphosate (Group M/9) resistance has been confirmed and is widespread in the following cotton weeds:

- Windmill grass
- Fleabane
- Feathertop Rhodes grass
- Awnless barnyard grass
- Sowthistle
- Liverseed grass

- Annual ryegrass is a significant issue in Southern valleys and is emerging as a problem in Northern NSW. There are reports of cross resistance to glyphosate and Group A(1) herbicides.
- Group A(1) resistance is widespread throughout broadacre farming systems and is increasing in cotton farming systems, especially in hard to control weeds such as feathertop Rhodes grass, annual ryegrass and windmill grass.
- Emerging herbicide resistance to Group L(22) (paraquat) has been reported in other farming systems, especially in grasses. Resistance has not been reported in cotton farming systems, however the increase in double knock strategies makes it essential that **all survivors** of a double knock involving paraquat need to be controlled. Two populations of tall fleabane collected during surveys have tested as resistant to a glyphosate + paraquat double knock.
- Increasing use of Group I(4) herbicides in summer fallows is a concern with a population of sowthistle reported as resistant to 2,4-D in winter cereals.
- Hit weeds where it hurts: Use WeedSmart Summer BIG 6 (page 75).

TABLE 25: Resistance risk for herbicides used in cotton

Herbicide active ingredient	Pre plant	At plant	Post plant	Mode of Action	Years to resistance	Resistance status
MSMA	N	N	Y	Z(0)	N/A	Rare
Amitrole + paraquat	Y	N	N	Q(34) + L(22)	>15	Rare
Amitrole + ammonium thiocyanate	Y	N	N	Q(34)	N/A	Rare
Paraquat	Y	Y	Y	L(22)	>15	Occasional
Paraquat + diquat	Y	Y	N	L(22)	>15	Occasional
Glufosinate-ammonium	Y	N	N	N(10)	10-15	Rare
Glyphosate(a)	Y	Y	Y	M(9)	>12	Widespread
s-Metolachlor or Metolachlor (b)	Y	Y	Y	K(15)	>15	Rare
2,4-D (c)	Y	N	N	I(4)	10-15	Occasional
Dicamba (c)	Y	N	N	I(4)	10-15	Rare
Fluroxypyr	Y	N	N	I(4)	10-15	Rare
Fluroxypyr+ aminopyralid	Y	N	N	I(4)	10-15	Rare
Triclopyr	Y	N	N	I(4)	10+	Rare
Triclopyr + picloram	Y	N	N	I(4)	10+	Rare
Triclopyr + picloram + aminopyralid	Y	N	N	I(4)	10+	Rare
Carfentrazone-ethyl	Y	N	N	G(14)	10	Rare
Flumioxazin (d)	Y	N	Y*	G(14)	10	Rare
Oxyfluorfen	Y	N	N	G(14)	10	Rare
Saflufenacil	Y	N	N	G(14)	N/A	Rare
Norflurazon	Y	N	N	F(12)	15+	Occasional
Pendimethalin (e)	Y	Y	Y	D(3)	10-15	Occasional
Trifluralin	Y	Y	N	D(3)	10-15	Occasional
Chlorthal dimethyl	Y	Y	Y	D(3)	10-15	Occasional
Bromoxynil	Y	N	N	C(5)	10-15	Occasional
Diuron	Y	Y	Y	C(5)	10-15	Rare
Fluometuron	Y	Y	Y	C(5)	10-15	Rare
Fluometuron + prometryn	Y	Y	Y	C(5)	10-15	Rare
Prometryn	Y	Y	Y	C(5)	10-15	Rare
Isoxaflutole (c)	Y	N	N	H(27)	10	Rare
Halosulfuron-methyl	N	N	Y	B(2)	4	Widespread
Trifloxysulfuron sodium	N	N	Y	B(2)	4	Widespread
Butroxydim	N	N	Y	A(1)	6-8	Widespread
Clethodim	N	N	Y	A(1)	6-8	Widespread
Fluazifop-p	N	N	Y	A(1)	6-8	Widespread
Haloxyfop	N	N	Y	A(1)	6-8	Widespread
Propaquizafop	N	N	Y	A(1)	6-8	Widespread

Lowest resistance risk
Moderate resistance risk
Highest resistance risk

Group A herbicides already exhibit widespread resistance in several species. Controlling survivors is essential.

Always read the label for detailed use patterns and application rates.
a) Roundup Ready Flex® varieties only.
b) Bouncer® and Dual Gold formulations.
c) See label for rainfall required before plant-back period begins.
d) Valor® formulation only.
e) Rifle® formulations.

Refer to Tables 18, 19 and 21 for plant-back periods.

Herbicide tolerance technology

Roundup Ready Flex® technology

Bayer Crop Science

How does Roundup Ready Flex cotton work?

The primary effect of glyphosate on plants is the inhibition of the production of EPSPS. EPSPS is an enzyme responsible for the production of amino acids essential for protein construction and plant growth.

Bayer Crop Science identified a soil bacterium that produces a modified form of the EPSPS enzyme, the CP4 strain. The CP4 strain of EPSPS is not inhibited by glyphosate. Roundup Ready Flex cotton plants produce the modified form of EPSPS, so are able to continue producing amino acids and proteins after glyphosate has been applied. Roundup Ready Flex cotton contains two copies of the CP4 EPSPS gene and a promoter sequence resulting in expression in both the vegetative and reproductive parts of the plant. Roundup Ready Flex cotton is therefore able to tolerate applications of glyphosate in its vegetative (pre-squaring) and reproductive (squaring, flowering, boll development and maturation) stages. Only glyphosate products registered for us in Roundup Ready Flex cotton can be used over the top (OTT) of Roundup Ready Flex cotton. Usage must be in accordance with the approved label. Glyphosate products registered for use OTT of Roundup Ready Flex cotton may be applied up to four times between emergence and 60% boll open stage. One application is permitted OTT between 60% bolls open and harvest. However, the total amount of herbicide applied to any one crop must not exceed 6 kg/ha of Roundup Ready Herbicide with PLANTSHIELD® in a total of 4 applications as illustrated in the Application Guidelines figure (page 92). Crops that are intended for seed production must not have an application of glyphosate past the 60% bolls open stage.

The whole-plant glyphosate tolerance of Roundup Ready Flex means that applications of glyphosate can be made irrespective of the rate of crop growth or the number of days between applications with no effect on fruit retention, fibre quality parameters or yield.

Weed management in Roundup Ready Flex cotton

Roundup Ready Flex cotton offers growers an increased margin of crop safety, a more flexible window for OTT applications of glyphosate, and the potential to improve the efficacy of weed control, when compared to Roundup Ready cotton. However Roundup Ready Flex cotton should be viewed as a component of an Integrated Weed Management (IWM) system, not as a solution to all weed management scenarios. Repeated glyphosate applications will select for weed species with natural tolerance to glyphosate, resulting in a species shift in the treated areas. The most effective, economic and sustainable weed management system for growers will, therefore, be achieved using an integrated (IWM) approach. Refer to the *Integrated weed management* section for more detailed information.

Know your field history

A combination of the relative effectiveness of previous herbicide programs and other agronomic practices employed on a farm is likely to influence the weed species present in any field. The correct identification and a basic understanding of the biology and ecology of the weeds present in a field are essential elements in the design of a successful weed management program. It is critical that the appropriate herbicide and herbicide rate are chosen for the target weed species. By knowing field history, growers can determine which weed control tools they should use and when they should be employed to achieve the best results.

Pre-plant knockdown

Starting with a 'clean' field provides seedling cotton with the best possible conditions to emerge and to develop, unhindered by the competitive effects of weeds. Pre-plant weed control can be achieved using tillage and/or appropriate registered herbicides. The use of glyphosate tank-mixes or herbicides with other modes of action is encouraged prior to planting to strengthen the IWM program. It is important that any cotton volunteers are controlled at this stage.

The role of residual herbicides

Residual herbicides should be used where appropriate in the Roundup Ready Flex system. The nature of pre-emergence residual herbicides often requires that they be applied in anticipation of a weed problem. Consideration for the use of residual herbicides in a weed control program for any given field should be determined based on the knowledge of the field's history.

The first OTT (over-the-top) application

Cotton is a very poor competitor and is sensitive to early season weed competition. The longer OTT application window with Roundup Ready Flex may tempt growers to delay the first OTT application of a registered glyphosate product in the hope that multiple weed germinations can be controlled with a single spray. While competitive effects will vary according to weed species and weed density, it is commonly recognised that good weed control in the first 6-8 weeks following crop emergence maximises cotton yield potential. Delaying the initial OTT application may result in growers having to target weeds later in the season that are beyond the growth stage for optimum control. After the first spray is completed a thorough check of each field is recommended to note the presence of survivors and evaluate the efficacy of the spray.

Subsequent OTT applications

After the first OTT application, the use of subsequent OTT applications (up to a maximum of four), should be made according to the presence of new weed germinations. In any field, a mix of weed species will commonly exist. Correct identification of weeds is very important as this will have a direct impact on the rate selection and application timing(s) chosen. Select the timing and application rate of the registered glyphosate product based upon the most difficult to control weed species in each field. Refer to label for more information. Scouting of fields after each spray to evaluate the effectiveness of any glyphosate application, and to identify if any weeds have survived the spray is essential for monitoring and managing resistance.

Inter-row cultivation

Inter-row cultivation is a relatively cheap and non-selective method of weed control. In irrigated cotton, it also assists in maintaining furrows to facilitate efficient irrigation. In a Roundup Ready Flex crop, inter-row cultivation contributes to the diversity of weed control methods being employed and, as such, is a valuable component of an IWM strategy.

Lay-by residual application

Growers and their advisors are encouraged to scout fields prior to row closure and to combine these observations with their historical knowledge of individual fields to ascertain the need for a lay-by herbicide application. A lay-by application should be used on fields where there is an expectation of a significant emergence of weeds later in the season.

Pre-harvest application

One application of a registered glyphosate product may be made OTT between 60% boll open and harvest. In most circumstances, good weed control earlier in the crop should render a pre-harvest application unnecessary. However, if late season weeds are present, a pre-harvest application can be used to reduce seed set and improve harvest efficiency. Pre-harvest applications of glyphosate will not provide regrowth control in Roundup Ready Flex cotton.

Post-spray surveillance

Scouting of fields after each spray to evaluate the effectiveness of any glyphosate application and to identify if any weeds have survived the spray is essential for monitoring and managing resistance. Samples should be collected and sent for resistance testing. Surviving weeds should be controlled with an alternative tactic. To assist growers and consultants to confirm the status of suspected resistant weeds on farm, Bayer is offering a free herbicide resistance testing program for Australian cotton growers. The aim of the program is to provide access to free herbicide resistance testing for cotton growers and their consultants to assist decision making and IWM strategy development.

Testing is available to all farmers who have grown Roundup Ready Flex cotton in any of the previous 3 seasons. Growers can test five major weeds (annual ryegrass, awnless barnyard grass, liverseed grass, red pigweed, milk (sow) thistle) present in cotton systems for resistance to any of the key herbicides included in the Roundup Ready PLUS® program.

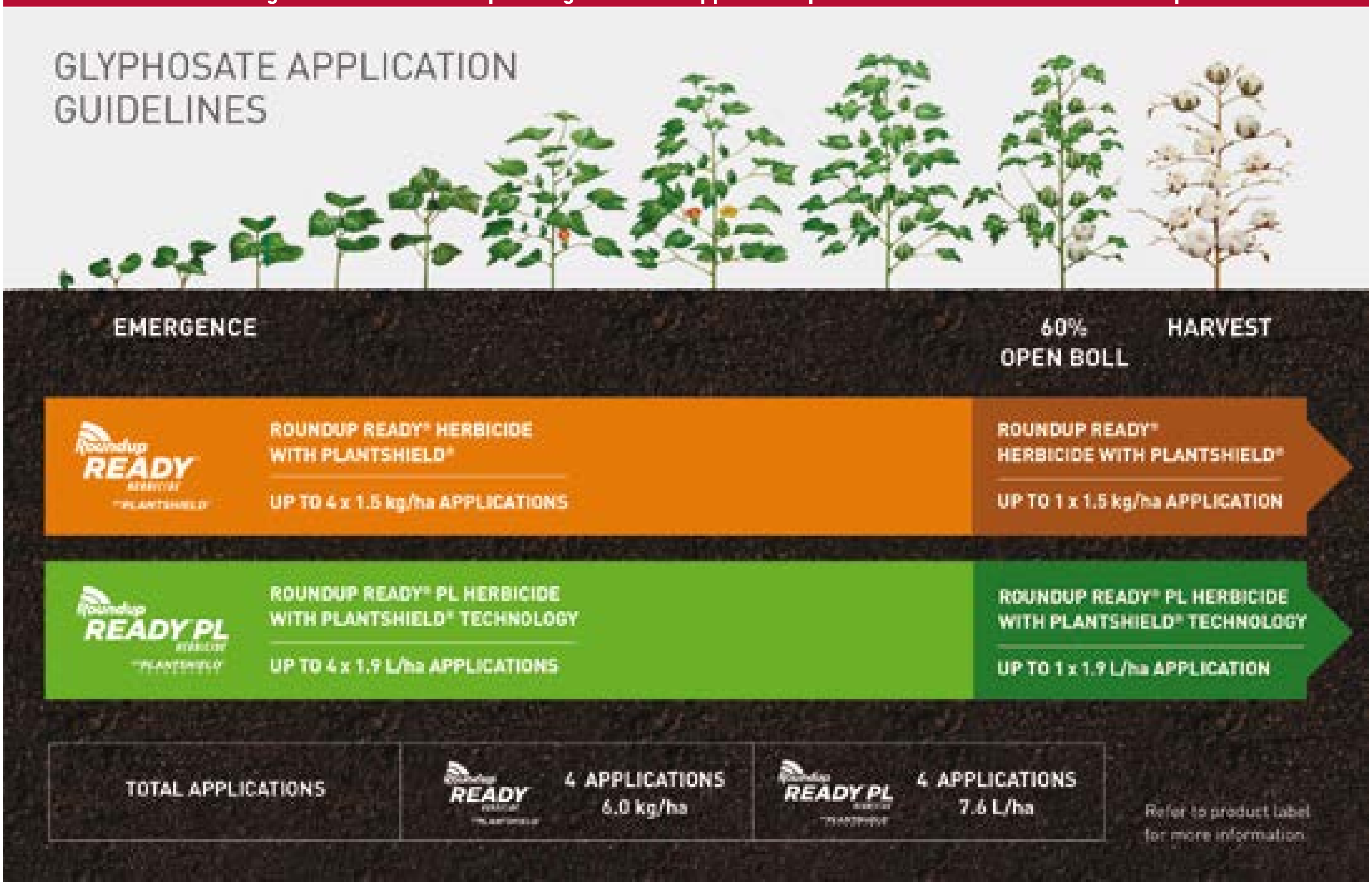
The Roundup Ready PLUS® program is designed to reward cotton growers who use herbicides sustainably and help slow or prevent the development of glyphosate resistance in key weed species. The program encourages growers to use a range of weed control practices through product recommendations, education and stewardship campaigns and financial rebates. Visit www.roundupreadyplus.com.au or email australia.cotton@bayer.com for further information.

Resistance testing is completely anonymous. Bayer is not provided with grower identification information.

Managing Roundup Ready Flex volunteers

A major consideration in the development of an IWM plan for Roundup Ready Flex cotton is the management of herbicide tolerant cotton volunteers. Plans need to be made to use cultural control options and herbicides with alternate modes of action in fallows and subsequent crops to control volunteers. Refer to pages 94-96 for more information.

FIGURE A: Roundup Ready Flex cotton allows you to spray a registered glyphosate product over the top (OTT) of your cotton up to four times between emergence and 60% boll open stage with one application permitted OTT between 60% bolls open and harvest.



Application guidelines

Timing options

The registered labels for Roundup Ready herbicides registered for OTT usage in Roundup Ready Flex cotton permit:

- Applications in fallow, prior to sowing the Roundup Ready Flex crop, with the maximum rate applied dependent on the targeted weed/s. Application may be made by ground rig sprayer or by aircraft.
- Up to four applications of Roundup Ready herbicide with PLANTSHIELD or Roundup Ready® PL herbicide with PLANTSHIELD technology between crop emergence and 60% boll open stage, with a maximum of 1.5 kg/ha or 1.9 L/ha respectively, being applied in any single spray event.
- An option for a pre-harvest application, alone or in tank mix with a registered defoliant, once the crop has a maximum of 60% open bolls. The maximum herbicide rate for pre-harvest use is 1.5 kg/ha of Roundup Ready herbicide with PLANTSHIELD, or 1.9 L/ha of Roundup Ready PL herbicide with PLANTSHIELD. Application may be made by ground rig sprayer or by aircraft.
- Not more than four applications and 6.0 kg/ha of Roundup Ready herbicide with PLANTSHIELD or 7.6 L/ha of Roundup Ready PL herbicide with PLANTSHIELD may be applied through all growth stages of Roundup Ready Flex cotton in any one growing season.

Over-the-top applications

Before each OTT application, it is absolutely essential to thoroughly decontaminate the sprayer of any products which might damage the crop, particularly sulfonylurea and phenoxy herbicides. For ground rig sprayers, a spray volume of 50-80 litres per sprayed hectare is recommended for optimum performance. Nozzles and pressure settings must be selected to deliver no finer than a COARSE spray quality (American Society of Agricultural and Biological Engineers, ASABE S572) at the target. For aerial application, nozzles and pressure settings must also be selected to deliver no finer than a COARSE spray quality at the target. A minimum total application volume of 40 L per hectare needs to be used. Do not apply by aircraft at temperatures above 30°C or if relative humidity falls below 35%.

Other sources of information: Please refer to www.bollgard3.com.au and www.crop.bayer.com.au for further information on stewardship and resistance management.

www.weedsmart.org.au

Management of volunteer and ratoon cotton

Controlling volunteer and ratoon cotton is an essential part of good integrated pest and disease management and general farm hygiene. Maintaining a farm that is free of volunteer cotton (cotton that has established unintentionally) and ratoon cotton (cotton that has regrown from leftover root stock from a previous season) breaks the 'green bridge' that enables pests and pathogens to overwinter between seasons.

Control of volunteers

Cultivation and herbicides are the two most common methods of volunteer cotton control. Both methods require the cotton plants to have germinated and emerged. Planning to control volunteers is a key part of an integrated weed management strategy and should consider issues such as rotational crops and other weeds present in the field. Reducing the amount of viable seed left in fields (through clean pick and stubble management) and around farm (through clean up after module removal and spillages) will reduce the amount of volunteers that germinate. It is also important to remember that volunteers and ratoons that are left to set seed will also contribute to additional volunteers.

Cultural

Broadacre cultivation controls established seedling volunteers as well as larger volunteer cotton plants in a fallow, however effective control only occurs when applied across the entire field (both furrow and hill). Cultivation also manages other weeds, making it an excellent non-chemical option to include within an integrated weed management program. A disadvantage of this control method, particularly in dryland farming systems, is soil moisture loss. Cultivation is also relatively slow and can lead to soil damage if conducted at an inappropriate time.

Best practice…

- **Control volunteer cotton as part of an integrated weed management strategy.**
- **Control volunteer and ratoon cotton plants in crop and non-cropping areas.**
- **Target plants when small, using the appropriate herbicide option applied in a sufficient spray volume to achieve good coverage. Read all labels before use to confirm timing and rates. ALWAYS FOLLOW LABEL DIRECTIONS.**
- **Undertake crop destruction operations as soon as practical after picking to minimise the number of residual stalks that can regrow into ratoon cotton.**
- **Ensure implements are set up to cultivate both hill and furrow, to avoid leaving uncultivated strips.**
- **Manual removal (i.e. chipping) may be necessary where isolated plants remain in non-field areas.**

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

Rotation of crops enables the use of alternate and residual herbicides. Ensure good control is achieved as cotton plants hidden within subsequent crops can continue to host pests and diseases.

Where isolated plants remain in fallow or non-field areas such as along roadsides and fences, physical removal by chipping can be effective.

Chemical

Pre-watering is a method used to encourage volunteer cotton germination prior to planting the next cotton crop, providing a window for appropriate herbicide control.

Most herbicides work best on seedling volunteers. Tables 26 and 27 provide a list of herbicide actives registered for the control of volunteer cotton plants. Not all products containing these actives will have volunteer cotton on the label, so refer to the label for specific use information and ensure all label directions are followed.

When using contact herbicides to control volunteers, excellent spray coverage is essential. Coverage may be compromised by the presence of nearby stubble, lint or other weeds.

For more detailed information on chemical options for controlling volunteer cotton, refer to section F4 in WEEDpak.

Volunteer cotton plants enable pests to survive between seasons. (Lewis Wilson)

Ratoon cotton

Ratoon cotton is normally a product of minimum tillage where either conventional cotton is double-cropped back to a winter cereal, or consecutive cotton crops are grown. Mealybug hotspots are often associated with ratoon cotton plants.

In theory, ratoon cotton should not occur as harvested cotton is required to be controlled with adequate cultivation and soil disturbance as soon as practical after picking (usually mulching and/or root cutting followed by cultivation to destroy the root system).

In conducting this cultivation an additional aim is to destroy overwintering *Helicoverpa* pupae. This pupae control is a strategy in managing insecticide resistance for the cotton industry and is mandatory for

Bollgard 3 crops where the first defoliation occurs after March 31. Thorough crop destruction can be particularly challenging in a zero-till situation, where the only soil disturbance is pupae busting. This operation should be conducted carefully to minimise the number of residual stalks that can regrow the following spring.

Ratoon cotton plants (regrowth/stub cotton) that have survived crop destruction can be difficult to control, having developed a large root system and small leaf surface area. Three herbicide options are available for the control of large volunteer cotton or ratoon cotton amongst stubble or in fallow. These options are registered for both optical booms and broadacre application, enabling all growers to conserve soil moisture. Refer to Table 27 for further information.

ALWAYS FOLLOW LABEL DIRECTIONS

For more information
(see www.cottoninfo.com.au/publications-and-media):

- ***Australian Cotton Production Manual*: Chapter 13, Integrated Disease Management and Chapter 23, Managing cotton stubble/residues.**
- **WEEDpak**
- **Managing ratoons and volunteers**

CottonInfo videos (www.youtube.com/cottoninfoaust):

- **Keep your farm free from pests, weeds and diseases: Come Clean. Go Clean. https://youtu.be/gR8hf8-hYOA**
- **Rogue cotton plants in the farming community https://youtu.be/CJP14_swggE**
- **Checking your farm for volunteer plants https://youtu.be/9C2Utf5mUxk**

Inadequate end of season crop destruction can lead to ratoon cotton. (Murray Sharman, Qld DAF)

TABLE 26: Herbicides for control of volunteer cotton

Active ingredient	MoA group	Comments (always refer to product labels)
Amitrole + paraquat	Q(34) + L(22)	Can be applied after an initial spray of a glyphosate herbicide (double knockdown). Refer to label for spot spray rates.
Bromoxynil	C(5)	Apply in minimum of 80 L/ha water for Roundup Ready cotton. Refer to label for rain-fastness and restrictions on spray quality & condition.
Carfentrazone-ethyl	G(14)	Apply minimum spray volume of 80 L/ha to ensure effective coverage. To broaden weed spectrum may be tank mixed with the recommended rate of a knockdown herbicide. Refer to label for adjuvant recommendation.
Paraquat + diquat	L(22)	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	B(2)	May be banded (>40%) over the row or broadcast. Minimum spray volume 150 L/ha for optimum results.
Flumioxazin	G(14)	Do not apply post-sowing pre-emergent. Do not sow crops for at least one hour after application. Can be tank mixed with glyphosate to control other weeds that may be present. Refer to label for adjuvant details.
Glufosinate-ammonium	N(10)	Good coverage is essential. Do not apply more than three applications per season. Best results are achieved when applied under warm humid conditions.
Metribuzin	C(5)	Registered for control of volunteer cotton in pigeon pea. Refer to label for critical comments.
Fluroxypyr	I(4)	Summer fallow.
Saflufenacil	G(14)	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	G(14)	Prior to sowing summer crop or starting a summer fallow. Apply by ground rig only. Good spray coverage is essential. Do not sow crops for at least 1 hour after application.
For any changes to labels, refer to https://portal.apvma.gov.au/pubcris		

TABLE 27: Herbicides for control of large (15 to 30 node) volunteer cotton and ratoon cotton in fallow

Active ingredient	MoA group	Rates	Comments
Fluroxypyr	I(4)	1 L/ha followed by 1 L/ha OR	For control of large cotton plants or ratoon cotton a sequential application of Comet followed by Comet is required for maximum control. Ensure sufficient leaf regrowth has occurred on the ratoon cotton to maximise chemical uptake.
		1 L/ha followed by Shirquat 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 700/ha	For a single pass operation apply Comet + Amicide Advance 700. Ensure sufficient leaf regrowth has occurred on the ratoon cotton to maximise chemical uptake.
Refer to the Comet 400 registration label for further details on control rates for optical spot spray technologies. Note that control rates are based on L/ha for broadacre application and L/100L (spot spraying rate) for optical sprayers. For any changes to labels, refer to https://portal.apvma.gov.au/pubcris			

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Best Practice

Integrated Disease Management (IDM)

Developing an IDM strategy

A plant disease occurs when there is an interaction between a plant host, a pathogen, and the environment. Effective IDM involves a range of control strategies which must be integrated with management of the whole farming system.

Most disease control strategies should be implemented regardless of whether a disease problem is evident, as the absence of visible symptoms does not necessarily indicate an absence of disease. Effective management can also delay the establishment of diseases in a cropping system.

Effective disease management does not always mean complete control of the disease through eradication of the pathogen, but rather aims at improving the resilience of the farming system. Many strategies may help to reduce the disease burden for subsequent crops and minimise the risk of diseases spreading within and between farms and regions.

IDM at planting

Optimal seed bed conditions

- Check field history for disease problems and avoid back-to-back cotton and rotations that host cotton diseases.
- Prepare firm, high beds to optimise establishment and seedling vigour.
- Position fertiliser and herbicides in the bed to avoid root damage.
- 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. Aim to plant when soil temperatures are 16°C at 8am and rising for the next 7 days. The *Australian Cotton Production Manual* (ACPM) includes information on crop establishment.

Also see the CSD Faststart Cotton Soil Temperature Network for your region www.csd.net.au/soil-temperature

Aerial photo of Fusarium wilt damage.

Best practice...

- **Monitor in-crop and over time for disease symptoms. Identify areas with a history of disease.**
- **Select disease resistant varieties where possible.**
- **Practice IDM at planting, in-crop and post-harvest.**
- **Implement a reporting system for unusual symptoms.**
- **Be aware of and control insect vectors according to industry thresholds.**
- **Implement good farm hygiene and biosecurity practices.**

Variety selection

A number of varieties have some resistance to Verticillium wilt or Fusarium wilt (indicated by higher V rank and F rank respectively). Consider the disease status of each field when selecting varieties. Also consider the variety's seedling vigour, particularly when pre-irrigating or planting early. Refer to CSD's variety notes for more information (www.csd.net.au/disease-ranks).

When black root rot is present, use the more indeterminate varieties that have the capacity to catch up later in the season.

Different seed treatment options are also available and must be chosen when seed is ordered. See the CSD website for more information.

Replanting

Make replant decisions early, based on stand losses, not on seedling size. Refer to the ACPM Crop establishment chapter for more information.

IDM in crop

Fungicides

All cotton seed sold in Australia for planting is treated with a standard fungicide for broad-spectrum disease control. See Table 28 (page 112) for a list of fungicides registered in cotton or available under permit.

Irrigation scheduling

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

Irrigate as required if disease has weakened the root systems and there are signs of water stress, but avoid waterlogging, particularly when temperatures are cool. Manage tail water to minimise the risk of spreading pathogens; if possible water the least infected fields first. General traffic, sprays, and picking should also follow the same order.

Agronomic management

High planting rates can compensate for seedling mortality, but a dense canopy favours development of Alternaria leaf spot, Sclerotinia and boll rots. Optimise nutrition and irrigations and consider the use of growth regulators when required.

If black root rot is present, either manage for earliness to get the crop in on time (short season areas) or manage for delayed harvest to allow catch up (longer season areas).

Balanced crop nutrition

A healthy crop is more able to express its natural resistance to disease. Excessive nitrogen will favour Fusarium and Verticillium wilt, and will also greatly increase the risk of boll rot, particularly in fully irrigated situations. Potassium is important for natural plant defences and a deficiency can lead to the expression of more severe disease symptoms. Refer to NUTRIpak or the ACPM for more information on cotton nutrition.

Conduct your own in-field disease survey

Monitoring and recording the incidence and severity of each disease allows you to make a comparison over time and adjust your management strategies accordingly. The following section includes examples of the key diseases in cotton and their common symptoms.

If disease is suspected, sample healthy plants as well for submission to cotton pathologists. Occasionally, symptoms of nutrient deficiency can be misinterpreted for disease, so if the disease diagnostics turn out to be negative, consider a nutritional analysis.

Early season: Start monitoring when seedlings reach the 2 true leaf stage. Look for plants with signs of poor vigour or unusual symptoms. Examine roots by digging up the seedlings – DO NOT pull seedlings as this may damage the root system or remove characteristic symptoms or infected parts of the roots. Examine multiple plants at multiple locations as diseases are often unevenly distributed.

Compare number of plants established per metre with number of seeds planted. Refer to the ACPM for replanting considerations.

During the season conduct disease surveys as frequently as possible. Look for plants that show unusual symptoms, have poor vigour, or have died.

Cut both diseased and healthy-looking plants in several places along the stem and look for discolouration. Plants infected with Verticillium or Fusarium wilt may display minimal or no external symptoms, particularly in varieties with high disease rankings.

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

Perform a **late season** check after the final irrigation but before defoliation to give an indication of the disease burden that field has been under and assess disease risk in the following years.

If a suspect plant is located, please contact your nearest CottonInfo REO (see inside back cover) for more information or to determine the appropriate pathologist and process for submitting a sample.

IDM post harvest

Control alternative hosts and volunteers

Having a host free period prevents build-up of pathogen inoculum and carryover of disease from one season to the next. The pathogens that cause Verticillium wilt, Fusarium wilt, tobacco streak virus (TSV), Alternaria leaf spot, some rots, and cotton bunchy top can also infect common weeds found in cotton growing areas. Refer to WEEDpak F5 for more details.

It is particularly important to have a host-free period as some diseases, such as cotton bunchy top, can only survive on living plants. Controlling alternative hosts, especially cotton volunteers and ratoons, will help reduce the risk of quality downgrades and yield loss.

Utilise the off-season to rotate herbicide chemistries and explore alternate mechanical means of weed control.

CottonInfo video on checking your farm for volunteer plants https://youtu.be/9C2Utf5mUxkk

Manage crop residues

The pathogens that cause Verticillium wilt, Fusarium wilt, black root rot, boll rots, seedling disease and Alternaria leaf spot can all survive in cotton and some rotation crop residues. Carefully manage crop residues to minimise carryover of pathogens into subsequent crops.

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

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

Use crop rotations to assist in managing disease

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

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

Australian trial work with cotton has shown crop rotations influence the abundance and diversity of soil microbial populations. After two years of rotation, Verticillium wilt disease levels were lowest in cotton following bare fallow compared to corn, 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 corn and sorghum compared to continuous cotton, and these crops are a good rotation option.

Cotton is highly dependent on arbuscular mycorrhiza 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, may result in a severe lack of AMF. A cereal or green-manure crop may restore sufficient mycorrhizal fungi.

Pages 80-81 of the *2022 Australian Cotton Production Manual* list the potential disease implications of rotation crops with cotton and can assist in developing a rotation strategy.

IDM all year round

Manage insect vectors

Diseases caused by a virus or phytoplasma are often preventable by managing the vector that carries the pathogen. Cotton bunchy top (CBT) can be transmitted by aphids feeding on infected plants before migrating to healthy plants. Transmission of TSV to plants relies on the virus from infected pollen entering plant cells through the feeding injury caused by thrips. Several exotic diseases also have insect vectors (see the Biosecurity chapter for more details). Consider integrated pest management principles and resistance risks when managing vectors.

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

On-farm biosecurity and hygiene

Minimise the risk of moving pathogens on or off your farm, from field to field or farm to farm by considering vehicle and machinery movements within the farm. Have a strategy for ensuring clean movement of vehicles and machinery onto and around the farm. 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.

It is recommended to have a written biosecurity plan for each cotton producing farm. This plan will identify biosecurity risks and management options for disease outbreaks.

Useful resources:

www.cottoninfo.com.au and www.mybmp.com.au

CottonInfo video:
Keep your farm free from pests, weeds and diseases: Come Clean. Go Clean.
https://youtu.be/gR8hf8-hYOA

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

Key diseases of cotton

Alternaria leaf spot (ALS)

Pathogen: *Alternaria alternata* and other minor spp.

ALS is the most common cause of leaf spots in cotton. Other fungal pathogens that can promote spotting symptoms include Cersospora, Stemphyllium and Ramulariopsis species.

Symptoms

Cotton plants are prone to infection 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 coalesce to form irregular shapes. Severe infection may result in leaf dessication.

Favoured by

Spores can only germinate when there is several hours of free moisture on the leaf surface. Epidemic development is therefore favoured by either repeated heavy dews or extended periods of wet weather.

- Symptom development is suppressed by periods of very hot weather.
- Symptom development is favoured by physiological or nutritional stress e.g. heavy fruit load or premature senescence.
- Back-to-back fields are at greater risk of developing the disease.

Host range

ALS has a wide host range and is globally distributed. Around 100 plants species have been reported as hosts, however, some strains show host specificity.

IDM tactics

- Avoid planting into fields containing unincorporated infected residues from a previous crop.
- Provide balanced crop nutrition (especially potassium).
- Manage crop to avoid extremely rank growth.
- Apply registered or permitted foliar fungicides according to label.
- Incorporate crop residues as soon as possible after harvest.
- Control alternative weed hosts, volunteer and ratoon cotton plants before, during and post season.

Current research is investigating…

- **Effect of late season foliar fertilisers and fungicides on yield and quality.**
- **Fungicide resistance testing.**
- **Testing efficacy of currently unregistered fungicides.**

Alternaria leaf spot of seedlings. Cotton trash is a common source of Alternaria inoculum.

Typical lesions associated with Alternaria leaf spot of cotton. (Linda Scheikowski, Qld DAF)

Black root rot (BRR)

Pathogen: *Berkeleyomyces rouxiae*
(formerly *Thielaviopsis basicola*)

Symptoms

Affected crops may be slow growing or stunted, especially early season. The disease causes destruction of the root cortex (outer layer), seen as blackening of the roots. Some roots may die but the fungus does not kill seedlings by itself. Severe black root rot can increase the susceptibility of plants to *Pythium* or *Rhizoctonia* spp. Badly affected plants early in the season may not show symptoms later on as the dead cells in the root cortex are sloughed off when growth resumes in warmer weather.

Favoured by

- Cool wet conditions – soil temperatures below 20°C are most favourable, but infection will still progress at temperatures up to 25°C.
- Medium to heavy clay soils.
- Back-to-back cotton or following susceptible crops including most legumes.

Host range

All cotton varieties are susceptible, as are most legumes, including faba bean, soybean, cowpea, field pea, chickpea, mungbean, lablab and lucerne. Datura weeds (thornapple, castor oil) are also hosts. Non-hosts include cereals, sunflower, brassicas such as canola and broccoli, and onions.

Black root rot on seedlings. (Duy Le, NSW DPI)

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. Sow early only if conditions are warm enough (minimum soil temperature of 16°C at 8am and rising over consecutive days). Temperature measurements should be taken in all fields.
- Make replanting decisions based on stand losses, not the size of the seedlings. Watch for early onset of water stress and irrigate accordingly, but avoid waterlogging.
- Anticipate delayed growth and later maturity and manage the crop accordingly (black root rot 'steals' time from your crop).
- Minimise tailwater.
- Practice good farm hygiene – Come Clean. Go Clean.
- Crop rotations have many benefits and increase microbial diversity in the soil, but will not reduce black root rot inoculum levels (apart from a rice rotation, where prolonged flooding can reduce inoculum levels).
- Rotate with biofumigation crops such as vetch or mustard between consecutive cotton crops or after a wheat fallow. Success depends upon the growth of the biofumigation crop and good incorporation (at least four weeks before planting cotton). Check that the biofumigant is not a host of other cotton diseases.
- Avoid legumes.
- Control weeds, cotton volunteers, and cotton ratoons.
- Flooding of fields for 30 days when maximum temperatures are above 30°C significantly reduces the population of *B. rouxiae.* Even better results will be seen if fields are flooded for 60 days.

Current research is investigating…

- **Novel products applied at planting.**
- **Soil mapping of inoculum levels.**
- **Disease characterisation and understanding virulence in different valleys.**

Black root rot significantly impacts seedling vigour. Healthy seedlings (left) compared with diseased seedling (right). (Duy Le, NSW DPI)

Boll rot, tight lock and seed rot

Boll rots are caused by a number of pathogens, including fungi and bacteria. Tight lock refers to a type of boll rot, where the lock remains hard and fails to fluff out. The term seed rot is used to describe a boll rot which begins in the seed.

Phytophthora boll rot

Infected bolls quickly turn brown and become blackened (sometimes with areas of white mould on the surface before opening prematurely). The locks, which remain compact and do not fluff out, can be easily dislodged and fall to the ground. Symptoms are most prevalent on the lower bolls. Phytophthora boll rot usually occurs when soil is splashed up onto low bolls that are beginning to crack open or when low bolls are subject to inundation by tail water backing up into rows.

Sclerotinia boll rot

Characteristically has black fungal structures (2-10 mm diameter) 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. The sclerotia germinate to produce apothecia (small cream coloured 'golf tees') which release clouds of microscopic spores that can infect the plant via 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.

CottonInfo video on Sclerotinia in cotton https://youtu.be/yt_542Kj3_0

Sclerotinia boll rot is more likely to be a problem in wet seasons as spores can be moved around the plant through rain-splash. (Linda Smith/Tony Cooke)

Advanced infestation of fusarium boll rot. (Linda Scheikowski, Qld DAF)

Fusarium affected boll (left) showing orange spore masses. (Duy Le, NSW DPI)

Fusarium boll rot

Not to be confused with Fusarium wilt, Fusarium boll rot causes similar boll rots to Phytophthora, with mould often appearing as a covering of orange or pink spore masses.

Diplodia boll rot

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

Several other fungi can cause secondary boll rots in cotton, taking advantage of injury or wounds in the boll wall, often caused by insect pests.

Anthracnose boll rot

Characterised by large spreading lesions on bolls, often with a pink spore mass in the centre. The pathogen is able to infect all parts of the cotton plant and at any stage of growth. Seedling stems may be girdled at or near the base of the stem. Anthracnose boll rot is uncommon in Australia, but is occasionally seen in Queensland cotton crops.

Bolls affected by Diplodia are covered in 'sooty' black spores. (Linda Smith, Qld DAF)

Tight locked boll. (Linda Smith, QLd DAF)

Healthy, fluffy locules (left) and fully affected, severe tight lock locules (right). (Linda Smith, Qld DAF)

Tight lock

Tight locked bolls are able to open normally but one or more locks remain compact and fail to fluff out due to fungal or bacterial infection. Flower thrips may also have a role in the development of tight lock. Due to the tight consistency of the seed cotton mass, harvesting equipment is either not able to extract the fibre from the locules or locks are knocked to the ground, giving the appearance of poor harvesting procedures.

Seed rots

Seed rot refers to boll rot that begins in the seed. Pathogens gain entry to the unopened boll when sucking insects (such as green vegetable bug, mirids or pale cotton stainers) feed on the developing seeds through the boll wall, as indicated by small black spots (1-2 mm diameter) on the surface of the boll. Seeds within the maturing green bolls are swollen and discoloured yellow or brown. When the affected bolls open, the locks with infected seed fail to fluff out and remain compact and discoloured. Seed rots do not necessarily affect the whole boll, rather they may be limited to one or two locks.

Favoured by

- Wet and humid conditions, especially from a thick rank canopy and high moisture from rains and dews.
- Rainfall on exposed soil that splashes soil up onto the plant. Low mature bolls and lodged plants are at higher risk of infection.

A cotton boll with seed rot. (Stephen Allen)

Bolls with seed rot caused by lint-stainer bugs. (Stephen Allen)

- High numbers of sucking pests soon after flowering (seed rots).
- Boll rots and tight locks can also develop when bolls that are opening are exposed to wet weather.

Host range

A broad range of fungal and bacterial species are associated with boll rots and their host ranges vary. For example, Phytophthora hosts include safflower, pineapple, tomato and citrus as well as a large number of ornamental plants derived from Australian native flora. Sclerotinia hosts include sunflower, safflower, soybeans and most pasture legumes.

IDM tactics

- Do not allow water to back-up into the field and inundate low bolls on plants near the tail drain.
- Avoid very low plant populations leading to exposed soil that can be splashed up onto low bolls at the end of the season.
- Avoid rank growth and a dense crop canopy if possible, especially in wet seasons.
- Assess incidence prior to or after defoliation by counting all of the bolls on ten plants from each of ten randomly selected sites across the field. Note that plants near the tail drain may bias the result.
- Thoroughly incorporate crop residues as soon as possible.
- Practice good farm hygiene and Come Clean. Go Clean.

Cotton bunchy top (CBT)

CBT is a viral disease spread by the cotton aphid, and can only survive in living plants.

Symptoms

Leaves usually have pale green angular patterns around the margins and darker green centres, and can be leathery and brittle compared to the leaves on healthy plants.

After the plant is infected, subsequent growth is characterised by small leaves, short internodes and small bolls.

When plants are affected at a very early stage (e.g. as seedlings) the whole plant has a compact, severely stunted appearance. Roots appear hairy and dark brown compared to the light yellow-brown colour of healthy roots, and small knots form on the secondary root branches.

Symptoms are difficult to distinguish in perennial volunteer cotton and late crops (post cut-out) where there has been insufficient new growth. It usually takes 3-8 weeks from infection until symptoms become obvious.

Patches of infected plants may occur around ratoon plants that were affected by CBT and survived from the previous season. These infected ratoon plants often harbour aphids which can then move to adjacent plants, spreading the disease.

Favoured by

- High aphid populations, in close proximity to ratoon cotton. Ratoons act as both a preferred host for the aphids and a reservoir for the disease, creating a source of infection in the new season.
- Climatic conditions suitable for aphid reproduction, feeding and spread.
- Wet or mild winters that enable more volunteer and ratoon cotton and aphids to survive between season and cropping cycles.

Cotton aphid has a broad host range, including many weeds. The presence of weed hosts allow cotton aphid populations to persist over winter, increasing the likelihood of aphids moving into cotton early in the season.

Host range

The most critical alternative host plant is ratoon or volunteer cotton that survives between seasons, retaining leaves through winter and supporting infected aphid populations from one season to the next. The importance of other host plants is not well understood but in some situations marshmallow weed (*Malva parviflora*) may be an important overwintering host for virus and aphids.

Pale green angular patterns around the margins and darker green centres is typical of cotton bunchy top. (Linda Smith, Qld DAF)

CBT infection leads to a distinctive leaf mottling. (Stephen Allen)

Thirteen natural field hosts of CBT have been identified including: cotton, *Abutilon theophrasti* (velvetleaf), *Anoda cristata* (spurred anoda), *Chamaesyce hirta* (asthma plant), *Gossypium sturtianum* (Sturt's desert rose), *Hibiscus sabdariffa* (rosella), *Hibiscus trionum* (bladder ketmia), *Lamium amplexicaule* (deadnettle), *Malva parviflora* (marshmallow weed), *Malvastrum coromandelianum* (prickly malvastrum), *Medicago polymorpha* (burr medic), *Sida rhombifolia* (Paddy's lucerne), and *Trianthema portulacastrum* (black pigweed). *Gossypium australe* and *Cicer arietinum* (chickpea) were also found to be hosts in field or pot experiments.

These are currently the only known hosts of CBT. However the virus may have a wider host range than originally thought and include further non-Malvaceae species.

IDM tactics

Step 1. Avoid the problem – elimination of hosts, particularly over winter, is the most effective means of minimising the risk of CBT. Break the green bridge and step 2 will not be required.

- CBT virus can only survive in living plants. A break in the presence of hosts between cotton seasons will reduce the risk of CBT surviving on-farm through winter. Cotton volunteers, regrowth and ratoons are important hosts of CBT. Good 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.

- Don't over-react to aphids. Excessive use of aphicides will select for resistance and restrict control options.
- Sample young cotton regularly for aphids and assess aphid spread within the field.
- 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.

CottonInfo videos:
Identifying cotton bunchy top disease https://youtu.be/xrp1420cjlk
Cotton bunchy top management https://youtu.be/3DOS61-wqqA

Fusarium wilt

Pathogen: *Fusarium oxysporum* f. sp. *vasinfectum* (Fov)

Symptoms

External symptoms include stunted growth and dull and wilted leaves followed by leaf yellowing or browning and eventual death from the top of the plant. Some affected plants may reshoot from the base of the stem. These symptoms most commonly become apparent in the seedling phase when plants are beginning to develop true leaves, or after flowering during boll fill. Symptoms can appear as individual plants or as a small patch, often near the tail drain or low-lying areas of the field.

Internal symptoms can be checked by cutting the stem. Infected plants will reveal continuous brown discolouration of the stem tissues from the main root up into the stem. The discolouration is similar to Verticillium wilt but usually appears as continuous browning rather than flecking.

Favoured by

- Use of susceptible varieties.
- Stresses in the crop – e.g. waterlogging, root damage through cultivation, cool and wet growing conditions.
- Poor farm hygiene on and between farms and districts.

Host range

The Fov pathogen is specific to cotton but can also live in the residues of most non-host crops. Bladder ketmia, sesbania pea, dwarf amaranth, bellvine and wild melon are alternative weed hosts that show no external symptoms. These weeds may act as an on-farm reservoir for the disease and need to be constantly managed.

IDM tactics

- If your farm is free from this disease, keep it that way! Ensure all staff and contractors practice good farm hygiene and Come Clean. Go Clean.
- Select varieties with a high F rank and use BION® Plant Activator.
- If possible, delay planting until soil temperatures are 16°C and rising.
- Manage the crop to avoid stresses such as waterlogging, over-fertilisation and root damage.
- Avoid mechanical inter-row cultivations if possible, as this can cause root damage that provides an entry point for the pathogen.

Fusarium wilt: Wilting and dying plants are often observed at the tail drain. (Linda Smith, Qld DAF)

- Regularly inspect fields for early detection and containment of isolated outbreaks. Send any suspect samples to Dr Linda Smith (Qld DAF).
- 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 at least a month (60-120 days if possible) prior to incorporation. Raking and burning the whole field is likely to spread any pathogen present.
- Fusarium can survive on non-host crop residues. Avoid green manure crops as this returns organic matter to the field which Fusarium can survive on as a saprophyte.
- Rotate with non-hosts for up to 3 years. Hosts such as legumes can potentially increase disease. A summer sorghum/maize-fallow-cotton rotation can increase cotton plant survival, reduce disease incidence and increase yield in the third year compared to continuous cotton.

CottonInfo videos:
Managing Fusarium wilt https://youtu.be/Cygy6XiRDcw
Post-harvest management of Fusarium wilt https://youtu.be/NGeQ4FTH7IM

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

Reniform nematode

Pathogen: *Rotylenchulus reniformis*

Reniform nematode is a plant-parasite that feeds on the plant root using retractable, hollow, spear-like mouthparts. Distributed worldwide within tropical and subtropical regions, reniform nematodes are one of the most damaging nematode pests. They are capable of attacking a wide range of crop plants, as well as many weed species.

Symptoms

Feeding causes damage resulting in stunting and generally poor plant growth. Reniform 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

- Warm climates (tropical and subtropical region), although it 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.

Host range

The very wide host range includes chickpeas, mungbeans, pigeon pea, sunflower and vetch. Certain crops are considered to be non-hosts, including corn, canola, faba beans, safflower, sorghum, soybean, wheat, barley, triticale and oats.

IDM tactics

- Come Clean. Go Clean. Good farm hygiene is the key to minimising the spread.
- Rotating with non-host crops such as wheat or sorghum 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 (Qld DAF).
- 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.

Stunted plants and uneven crop growth caused by reniform nematodes. (Linda Smith, Qld DAF)

Reniform nematode in cotton root. (Linda Scheikowski, Qld DAF)

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 111 for a form and checklist on sending plant samples for diagnosis).

CottonInfo video on reniform nematodes https://youtu.be/QgBn4vfkOzI

Reniform egg masses on cotton root. (Damien Erbacher)

Current research is investigating…

Soil samples are routinely collected early season across all regions from those cotton crops surveyed as part of annual disease surveys. Soil is assessed for the presence of reniform nematode, as well as other plant parasitic nematodes. To date, reniform nematode has only been detected in cotton crops grown in central Queensland.

Reoccurring wilt

Pathogen: Novel *Eutypella* species

Reoccurring wilt (first observed in the 2017/18 season) is caused by novel species of Eutypella. This is the first known detection of this fungus causing disease on cotton worldwide. Further information on its identification can be found at https://link.springer.com/article/10.1007/s13313-021-00843-8

Symptoms

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

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

Favoured by

The etiology is still being established. At this stage it is unclear what factors are contributing to the disease. Anecdotally, reoccurring wilt has been observed in plants suffering stress from water deficiency. The disease has also been observed in cotton grown in areas of fields where poor growth is typically observed.

Host range

It is too early to make assumptions on the host range of the pathogen that causes reoccurring wilt.

IDM tactics

There are no specific management tools yet determined for this disease. However, monitor fields for symptoms as described.

Contact your nearest REO or one of the pathologists if you suspect the disease on your farm.

Blackening of the stem. (Linda Smith, Qld DAF)

In cross-section the infected tissue may be V-shaped with reddish-grey discolouration. (Linda Smith, Qld DAF)

Come Clean, Go Clean. Implement and maintain good farm biosecurity practices between fields and farms to help prevent the spread of all pathogens.

Please send any suspicious plants to one of the cotton pathologists:

- Linda Smith (Qld DAF) – 0457 547 617.
- Duy Le (NSW DPI) – 0439 941 542 (do not send suspected Fusarium samples to Duy at ACRI).

Single dead plant amongst healthy plants. (Linda Smith, Qld DAF)

Variety trial…

A variety trial conducted by DAF Qld and CSD in the 2021-22 season in CQ determined there was no significant difference in susceptibility of four varieties to reoccurring wilt. The disease incidence at the end of the season for Sicot 714B3F, Sicot 746B3F, Sicot 748B3F and Sicot 606B3F was 0.94%, 0.85%, 1.6% and 1% respectively.

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Seedling diseases

Seedling diseases are caused by numerous pathogens either acting alone or in combination that commonly cause 'damping off' (death of seedlings) and reduced plant stands. The main pathogens infecting cotton seedlings are *Rhizoctonia solani, Pythium ultimum* and *Fusarium* spp. (not the Fusarium wilt pathogen).

Symptoms

- Pre-emergent seed rots.
- Post-emergent damping off (wilting, collapse and death of seedlings).
- Slow early season growth, small cotyledons and reddened hypocotyls.
- Lesions on roots.

Affected plants may be scattered across the field or concentrated in poorly drained areas. In some situations seedling disease may be particularly evident in rows where other factors such as fertiliser placement, herbicide application, planting depth etc have had an effect.

Favoured by

Anything that slows down germination and seedling growth, including cool and/or wet weather, poorly formed beds, compaction, waterlogging, incorrect planting depth, poor placement of fertiliser (under the plant line), excessive rates of herbicide at planting, movement of herbicide into the root zone (i.e. by rain) and infection by other pathogens.

Host range

Seedling disease pathogens have a wide host range and can survive on the residues of many crops and weeds. International research has determined that winter legume crops do not appear to increase the risk of cotton seedling diseases sufficiently to deter their use in reducing soil erosion and providing nitrogen to the following crop.

The pathogens can survive on plant residues, so incorporation early enough to allow breakdown is important.

IDM tactics

- Use a variety with good seedling vigour.
- Use effective seed treatment fungicides.
- Plant into well prepared, high, firm beds.
- Carefully position fertiliser in the bed (not under the plant line).
- Plant into moisture rather than planting dry and watering-up.
- Delay planting until temperature and moisture conditions are optimum.
- Be careful with the use of herbicides at planting.
- Incorporate rotation crop residues as soon as possible after harvest.

Rhizoctonia lesions on cotton seedlings. (Duy Le, NSW DPI)

***Rhizoctonia* seedling disease is favoured by cool, wet weather.** (Alison Seyb, formerly NSW DPI)

Verticillium wilt

Verticillium dahliae

Verticillium wilt is caused by the soil-borne fungal pathogen *Verticillium dahliae*. In Australian cotton there are currently four strains of *V. dahliae* (one was recently detected in Noogoora burr), however virulence varies greatly within all strains. All incidences of Verticillium wilt should be taken seriously regardless of the strain as yield losses can still be severe without defoliation occurring.

Symptoms

Symptoms of Verticillium wilt and Fusarium wilt are similar. Verticillium wilt has dark brown to black streaks through the centre of the stem when cut diagonally. When cut lengthways, stems show brown flecking of the inner tissues. As Verticillium wilt and Fusarium wilt can be difficult to tell apart, plant/s suspected of being infected with *F. oxysporum* f. sp. *vasinfectum* or *V. dahliae* need to be diagnosed by a pathologist. In some instances there are fields with both Verticillium and Fusarium wilt present, so send multiple stems in the sample.

V. dahliae can also cause a characteristic yellow mottle between the veins and around the leaf margins. Lower leaves are usually affected first. Dead tissue develops at the leaf edges and may replace the mottled areas.

Favoured by

- Cooler temperatures (cotton varieties that are resistant at 25-27°C are susceptible at 20-22°C).
- Extended wet and overcast weather.
- Waterlogging or over-irrigating (particularly in late-maturing crops).
- Nutritional imbalance such as potassium deficiency or excess nitrogen.

Typical leaf symptoms of Verticillium wilt. (Stephen Allen)

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

Characteristic symptoms of Verticillium wilt include wilted plants, leaf mottle and necrosis. As disease progresses, defoliation and the death of plants may occur. (Linda Smith, Qld DAF)

Extended crop growth late in the season, including through the use of excessive nitrogen, increases the risk of this disease.

Host range

V. dahliae has a large host range and causes vascular wilt on more than 250 plant species including volunteer cotton, ratoon cotton, soybeans, canola, safflower, sunflower, mungbean, chickpea and faba bean. Weeds that host the disease include Noogoora and Bathurst burr, saffron thistle, thornapple, caustic weed, bladder ketmia, burr medic, black bindweed, pigweed, devils claw, turnip weed, mintweed and blackberry nightshade. There is some host specificity between strains. International literature and pot trials with Australian strains also suggest that wheat, barley, oats, vetch and maize may be hosts.

IDM tactics

- Select varieties with a high V rank.
- Manage for earliness, including optimising nutrition and water inputs.
- Avoid over-watering, waterlogging and late season irrigations that extend maturity.
- Minimise tailwater to reduce risk of spread.
- Avoid inter-row cultivation with knives if possible. This causes root damage and provides an entry point for the pathogen.
- Ensure that crop destruction and incorporation occurs soon after picking to reduce the build-up of inoculum.
- Rotate with non-host crops (i.e. sorghum or maize).
- Avoid frequent fallows to maintain microbial diversity and populations of beneficial bacteria and fungi.
- Avoid/control alternative hosts, including volunteer and ratoon cotton.
- Send any suspicious plant samples to your state pathologist for correct identification of pathogen.
- If your farm is free of *V. dahliae*, try to keep your farm that way. Ensure all farm staff and contractors practice good farm hygiene and Come Clean. Go Clean.

CottonInfo video on Verticillium wilt https://youtu.be/hgiatA52nNw

Other diseases

Other diseases that can affect cotton include bacterial blight, bacterial stunt, post-harvest rot, sudden wilt, tobacco streak virus (TSV) and tropical rust. These diseases are much less common than the others mentioned in this chapter, largely thanks to cotton breeding programs and biosecurity measures.

Not all unusual plant symptoms are a sign of disease. Some herbicides, insects, soil constraints and environmental factors can also contribute to abnormal plant growth.

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

CottonInfo video on collecting stem and leaf samples for disease testing
https://youtu.be/4mCk2883I00

Bacterial blight.

SENDING A SAMPLE FOR DIAGNOSIS BY A PATHOLOGIST – ATTACH A COMPLETED FORM TO EACH SAMPLE

Collected/Submitted by: (e.g. Cotton Regional Extension Officer)	Address/Email/Fax/Telephone:
Property name and field number:	Date collected:
Grower/Agronomist	Grower's address or area/locality:

Mark (X) as appropriate

SYMPTOMS	DISTRIBUTION	INCIDENCE/SEVERITY	CROP GROWTH STAGE
☐ Poor emergence or seedling depth	☐ One field only	☐ All plants	☐ Irrigated
☐ Leaves: spots or dead areas	☐ In several fields	☐ Scattered single plants	☐ Dryland
☐ Leaves: discoloured	☐ In all fields	☐ Scattered patches of plants	☐ Seedling stage
☐ Leaves: mottled	☐ One variety only	☐ In a large patch (>5 m)	☐ Setting squares
☐ Leaves or shoots: distorted or curled	☐ Several varieties affected	☐ In a small patch (1-5 m)	☐ Early flowering
☐ Plants stunted	☐ Some rows more affected	☐ In a small patch (<1 m)	☐ Peak flowering
☐ Plants wilting	☐ On lighter soil types	☐ Plants dead	☐ First bolls open
☐ Premature plant death	☐ On heavier soil types	☐ Plants defoliating	☐ Defoliated
☐ Bolls: spots or dead areas	☐ In poorly drained area(s)	☐ One to a few plants only	☐ Ready to pick
☐ Roots: discoloured, bent, pruned, etc.	☐ Other: (please specify)		

OTHER INFORMATION

- Cultivar..
- Paddock History..
- Nearby crops..
- Rainfall in last 10 days..
- Average temperature range over the last 10 years..
- Date of last irrigation..
- Date of last cultivation..

Please contact your nearest CottonInfo REO to determine the appropriate pathologist and address for submitting sample

IF FUSARIUM WILT IS SUSPECTED,DO NOT SEND SAMPLES TO ACRI

When sending samples:

- Send multiple samples (e.g. more than 1 leaf, stem or plant).
- If possible include a healthy plant as well as the diseased plant material.
- It is better to despatch samples early in the week rather than just before the weekend.
- Never wrap samples in plastic. Dry or slightly dampened newspaper is better.
- When collecting seedlings – dig them up rather than pull them out. Include some soil.
- Several sections of stem (10-15 cm long) are usually adequate for wilt diseases.
- Keep the sample cool and send as soon as possible.

TABLE 28: Fungicides registered for use in cotton

	Active ingredient	Trade name	MoA group	Targets	Comments
Seed treatments*	Azoxystrobin 75 g/L + Metalaxyl-M 75 g/L + Sedaxane 35 g/L + Fludioxonil 12.5 g/L	Vibrance (V) Vibrance Complete (V2)	4, 7, 11, 12	Damping-off caused by *Pythium* spp. and *Rhizoctonia solani*	Seed treatment available through CSD when ordering seed.
Seed treatments*	Acibenzolar-S-methyl 500 g/L	Bion Vibrance Complete (V2)	No group	Fusarium wilt, black root rot	Seed treatment available through CSD when ordering seed. Suppression only. Activates the plant's natural resistance mechanisms.
Seed treatments*	Metalaxyl-M 350 g/L	Various	4	Damping-off caused by Pythium and Phytophthora. Fusarium wilt disinfection on seed	Seed dressing. QLD & NSW only. Does not protect against damping off by Rhizoctonia, Fusarium or other fungi. 97% R-enantiomer. Much more effective in controlling diseases. Lower rates can be used.
At planting	Quintozene 750 g/kg	Terraclor	14	Damping-off caused by Rhizoctonia	QLD, NSW & WA only. Soil fungicide. Spray over seed and surrounding soil at planting.
At planting	Tolclofos-methyl 500 g/L	Tolex Rhizolex In Furrow	14	*Rhizoctonia solani, Rhizoctonia* spp.	QLD & NSW only. Mix with seed immediately before planting. Applied as an in-furrow spray or water injection at planting.
Foliar fungicides	*Clitoria ternatea* extract 400 g/L	Sero-X	No group	Verticillium wilt microsclerotia	Will reduce the amount of microsclerotia (inoculum) returning to the soil. QLD, NSW & WA only. Three applications are required: 1. When majority of plants are between first square and first flower. 2. When majority of plants are between mid to peak flowering. 3. With the first defoliation. Foliar application only. Will not reduce the severity of the disease in the season it is applied.
Foliar fungicides	Prothioconazole 150 g/L + Bixafen 75 g/L	Aviator Xpro	3, 7	Sclerotinia stem rot	PERMIT 87169. Expires 30 September 2022. NSW, QLD & WA only. WHP: 5 weeks. Boomspray application only. Maximum 2 applications per season.
Foliar fungicides	Tebuconazole 430 g/kg	Various	3	Alternaria leaf spot	PERMIT 82660. Expires 30 November 2024. Southern cotton growing valleys: Bourke, Gwydir, Lachlan, Macquarie, Murrumbidgee, Murray and Namoi Valleys and north Queensland (tropical) region primarily around the Mareeba region on the Atherton tablelands only. WHP: 6 weeks. Maximum of 2 applications per season, 14 days apart.
Foliar fungicides	Mancozeb 750 g/kg	Various	M3	Alternaria leaf spot **(pima cotton varieties only)**	PERMIT 91475 for upland cotton varieties. Expires 31 August 2023. Protectant foliar spray post-flowering. Maximum of 4 sprays per season, 7-10 days apart.
Seed export	Carboxin 200 g/L + Thiram 200 g/L	Vitavax 200FF	7, M3	Seedborne disease control	Cotton seed destined for export to countries that specify such treatment only – not registered for seed used in Australia.

*Penflufen 154 g/L + trifloxystrobin 154 g/L (EverGol Xtend), also registered as a seed treatment, has been superseded by Vibrance.
Industry pathology team leaders:
Qld DAF pathologist, Linda Smith 0457 547 617
NSW DPI pathologists, Duy Le 0439 941 542, Karen Kirkby 0428 944 500
www.cottoninfo.com.au/publications/cotton-symptoms-guide

Regional disease update 2021-22

Commercial cotton crops across New South Wales and Queensland were inspected early and late in the 2021-22 season. This represents the 20th and 39th consecutive seasons of cotton disease surveys in Queensland and New South Wales and respectively.

The incidence (% of plants surveyed that had disease) and severity (extent of symptoms) of diseases present were assessed and field history, ground preparation, cotton variety, planting date and seed rate recorded for each field. The endemic diseases monitored include seedling diseases (caused by Rhizoctonia solani, Pythium spp. and Fusarium spp.), black root rot (BRR), Fusarium wilt, Verticillium wilt, Alternaria leaf spot, tobacco streak virus (TSV), cotton bunchy top (CBT) and boll rots, plus anything unusual.

Cotton industry biosecurity plan – Crop surveillance for priority pests

Particular attention was given to surveying fields for the presence/absence of exotic diseases including cotton leaf curl disease, blue disease, Phymatotrichopsis (Texas) root rot, the hypervirulent strains of the bacterial blight pathogen and exotic strains of the Verticillium wilt and Fusarium wilt pathogens. None of these diseases and/or pathogens were observed.

Acknowledgement: The regional surveys were undertaken by Linda Smith, Linda Scheikowski & Dinesh Kafle (Qld DAF), Duy Le, Chi Nguyen, Alison Young and Beth Shakeshaft (NSW DPI), and CottonInfo Regional Extension Officers. Thank you also to regional consultants who assisted with collection of disease incidence data. This work is being undertaken as part of the CRDC funded project DAQ2002 Characteristics of disease suppressive cotton farming systems and soils understood.

Queensland

A total of 48 fields across 32 farms were surveyed early season from October to December in 2021. Late season surveys were conducted from February to May 2022, with a total of 50 fields across 33 farms inspected. Rain and timing impacted the ability to complete surveys of all fields late season (where possible, alternative fields were surveyed). The key disease issues in the 2021-22 season for Queensland cotton varied for each region:

- **Central Queensland:** High reniform nematode pressure at planting impacted seedling development. The incidence of reoccurring wilt was less than compared to previous season. One field with a high incidence of plant death due to charcoal rot is of concern as *Macrophomina* sp. is not usually a significant pathogen of cotton.
- **Darling Downs:** Fusarium wilt was a key disease, with impacts felt both early and late season. Leaf spots associated with several pathogens were detected at a high incidence but generally at low severity during time of surveys, however the disease is occurring throughout the canopy and on younger leaves, leading to grower concern regarding the potential impact of leaf spot diseases.
- **St George:** Increasing occurrence of reoccurring wilt. Fusarium wilt (detected in 75% of farms surveyed) was the most prevalent and concerning disease late season. For the first time, a farm with known Fusarium wilt also recorded Verticillium wilt and reoccurring wilt, posing a significant management challenge.

Plant residues

The amount of cotton trash present at planting was estimated using a standardised photographic guide to provide information on the potential carryover of pathogen inoculum (Table 29a). Pathogens that cause Verticillium wilt, Fusarium wilt, black root rot, boll rots, seedling disease and Alternaria leaf spot can all survive in association with undecomposed trash from previous cotton crops. It is important that cotton residues are incorporated with sufficient time to allow for microbial breakdown.

Central Queensland

Emerald

Twelve fields across 8 farms were surveyed early season. A low incidence of Rhizoctonia and Pythium seedling diseases were detected, and tobacco streak virus (TSV) was present in five fields (incidence <1%). TSV is transmitted by thrips and causes only mild local lesions in cotton with no impact on yield. A low incidence of *Sclerotium rolfsii* (a necrotrophic, soilborne fungal plant pathogen that causes root and stem rot) was detected in one field. *S. rolfsii* is easily identifiable by the presence of abundant white mycelium on infected plants. Reniform nematode were recovered from 3/12 soil samples and observed in 2/12 root samples. Alternaria leaf spot was prevalent, with severity up to 2.75% of leaf surface with spotting.

Tobacco streak virus. (Linda Scheikowski, Qld DAF)

Ten fields across 6 farms were surveyed late season. A farm new to surveys had a 4.5% incidence of Fusarium wilt. All fields had some form of boll rot, generally at a low incidence. Mealybugs were observed in one field, highlighting the importance of removing volunteer cotton plants. An additional field with high plant deaths was also examined, and the disease identified as charcoal rot caused by *Macrophomina phaseolina.* Usually only seen in occasional plants, this disease can be severe under conditions of drought stress and high temperature. The soil-borne fungus invades

Charcoal rot: Wilting and dying plants with leaves attached, ashy-grey discolouration in stem, sclerotia observed in stem tissue. (Linda Smith, Qld DAF & Dinesh Kafle, Qld DAF) roots or lower stems, quickly colonises internal tissues, and the plant wilts and dies. Look for small, black sclerotia embedded in affected tissue.

Theodore

Eighteen fields across 9 farms were surveyed early season. The cool wet conditions were conducive to black root rot (BRR) and Fusarium wilt (up to 53% and 5% respectively). Sixteen fields had reniform infection. Mungbean is a host of reniform nematode, and volunteer mungbean plants may have provided an active population of reniform in the planting zone when cotton seedlings were emerging and establishing. Where reniform was detected, up to100% of cotton seedlings collected had reniform in their roots. One quarter of volunteer mungbean samples examined had reniform present in their roots. A trace of TSV was observed in one field.

Reniform feeding on cotton root. (Dinesh Kafle, Qld DAF)

Ten fields across 7 farms were surveyed late season. The highest incidence of Fusarium wilt detected was 37%. All fields surveyed had some form of boll rot, but incidence was generally low.

Reoccurring wilt (*Eutypella* species) in some fields has rapidly increased in incidence, causing concern for industry. However, a field with a high incidence of plant death in the 2019-20 season was planted back to cotton in 2021. Disease incidence was significantly less, and there were very few bare patches from early plant death compared to the 2019-20 season.

Darling Downs

Thirteen fields across 12 farms were surveyed early season; the main concern was the high incidence of Fusarium wilt, detected in 11 fields with an average incidence of 13.8% (the highest incidence last season was 12.3% in infected fields, with an average 1.6% across all fields). BRR incidence averaged 17.8% with a severity of 4.2% blackened tap root. This was a reduction compared to last season (average incidence and severity of 24 and 16% respectively), however it may reflect survey timing as seedling age greatly influences the ability to detect BRR presence, particularly if infection is mild.

Fusarium wilt was the most prevalent and concerning disease late season, detected in 10 fields surveyed. The average incidence was 17.7% (range of 1.5–92%). To better understand the impact of the pathogen on the cotton plant, the severity of vascular browning visible in a cross section of the main plant stem was rated using a vascular discolouration index (see diagram below). The average severity was 2.6 (with a range of 1–3.7). One field known to have Fusarium wilt also had Verticillium wilt detected for the first time, with an incidence of 1%. While Verticillium wilt incidence was low this season, the areas where this disease was previously prevalent were not able to be surveyed due to prolonged wet conditions. Boll rot, seed rot and tight lock were observed in most fields surveyed, but reoccurring wilt was not detected. Leaf spot disease had high incidence with low severity at the time of surveys, however it was occurring throughout the canopy and on younger leaves, and there was grower concern of the potential impact. Leaf spot pathogens detected included *Alternaria* sp., *Cercospora* sp. and *Stemphylium* sp.

High incidence of Fusarium wilt infection in some fields early season. (Linda Scheikowski, Qld DAF)

St George/Dirranbandi

Five fields across 3 farms were surveyed early season. Numerous rain events prevented more farms/fields being surveyed. Fusarium wilt was detected in two fields (incidence of 1% and 26.5%). A low incidence of Rhizoctonia and no BRR was detected, although the delayed timing meant plants would have been growing out of the disease if present.

Seventeen fields across 8 farms were surveyed late season. Fusarium wilt was the most prevalent and concerning disease, detected in 75% of farms and 53% of fields surveyed, with an average incidence of 17.7%. The severity rating of Fusarium wilt infection averaged 1.9 with a range of 1 to 3.3 (see Table 29b for explanation of severity rating). Verticillium wilt was detected in two fields for the first time. Both fields have a history of Fusarium wilt. In one field, both Verticillium and Fusarium was isolated from the same stem in 3% of stem samples. Reoccurring wilt was detected in four fields. Although at a low incidence, the increasing occurrence of reoccurring wilt is of concern. Boll rot, seed rot and tight lock were observed in most fields surveyed. Leaf spot disease associated with several pathogens was detected with spores of *Alternaria* sp., *Stemphylium* sp., *Corynespora* sp. and *Cercospora* sp. fungi recovered from necrotic lesions.

Cross section of cotton stems revealing vascular browning due to Fusarium wilt infection (Linda Smith, Qld DAF). **To better understand the impact of Fusarium wilt in the field, the browning was rated for severity using a scale of 0 to 5:**

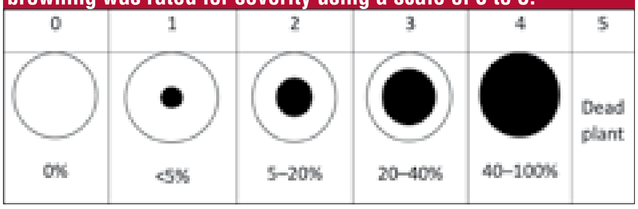


TABLE 29a: Overall average disease incidence (% of plants infected) detected during early season surveys in Queensland, with incidence range for fields where disease was present. Carry over of cotton trash is also provided.

2021/22	Seedlings/m	Fusarium	Pythium	Rhizoctonia	Black root rot*	Alternaria	Cotton trash (g/m^2)
CQ (Emerald)	10.34 (6.9–13.4)	0	0.06 (0.7, 1 field)	1.5 (0.3–5.3)	0	0	10.8 (0–69)
CQ (Theodore)	10.1 (5.7–13.3)	0.53 (0.5–5)	0	2.7 (0.5–9)	Incidence 8.3 (0.1–53) Severity 2.63 (0.2–22.9)	0	138 (2–333)
Darling Downs	10.75 (9.4–13.3)	13.8 (0.5–44.5)	0	1.8 (0.5–3.5)	Incidence 17.8 (0.5–41) Severity 4.2 (0.3–8.3)	Trace	56 (0–170.5)
St George/ Dirranbandi	17.5 (8.9–14.4)	5.6 (1.0–26.5)	0	1.3 (0.5–3.5)	0	0	44.3 (0–175)

*BRR also includes severity (%) from no blackening of the tap root to 100% of tap root blackened.

TABLE 29b: Overall average disease incidence (% of plants infected) detected during late season disease surveys in Queensland, with incidence range for fields where disease was present.

2020/21	Fusarium*	Verticillium	Boll Rot	Seed Rot	Tight Lock	Alternaria and other leaf spots**	Reoccurring wilt
CQ (Emerald)	0.45 (4.5%, 1 field) Severity not assessed	0	1.8 (0.4–4.1)	2.5 (0.9–5.4)	2.5 0.7-5.9)	Incidence 86 (30-100) Severity 1 (0.1–2.8)	0
CQ (Theodore)	4 (3–37% Severity not assessed	0	1.5 (0.65–3.85)	0.9 (0.3–1.75)	0.7 (0.7-4.4)	Incidence 100 Severity 2.2 (0.1–5.1)	0.8 (1 field, 8%)
Darling Downs	17.7 (1.5–92 Severity 2.6 (1.0–3.7)	0.08 (1 field, 1%)	4.2 (0.45–15.3)	3.1 (0.35–2.85)	3.7 (1.1-8.8)	Incidence 100 Severity 1.2 (0.1–3.45)	0
St George/ Dirranbandi	Incidence 15.6 (0.5–97) Severity 1.9 (1.0–3.3)	0.2 (0.5–3.0)	2.4 (0.4–7.9)	1.34 (0.4–4.35)	3.86 (0.4-11.4)	Incidence 100 Severity 1 (0.5–1.5)	0.4 (0.5–3.0)

*Fusarium wilt also includes severity rating based on % of stem vascular browning (VB) in cross section of stem (where 0=no VB, 1 = <5%, 2 = VB between 5–20% of stem, 3 = 20–40%, 4 = >40% VB and 5 = dead plant).
**Alternaria and other leaf spots also includes severity as % of leaf surface with leaf spotting.

New South Wales

A total of 80 fields from 60 NSW farms were surveyed during the last week of October and early December 2021. Fusarium wilt bounced back quite significantly in many fields in the Gwydir and caused some degree of seedling mortality, which has not been recorded in the past five years. Other common seedling diseases such as black root rot, Rhizoctonia rot and Alternaria leaf spot were detected across all cotton growing regions in NSW. Black root rot and Rhizoctonia rot incidence was high, but the severity varied among valleys. Alternaria leaf spot remained prevalent, but the damage was of minor concern in most of the surveyed fields, except for some back-to-back fields where the scored disease severity was up to 15% on cotyledons.

During the late season disease survey, a total of 86 fields across 63 farms were visited across NSW between mid-March to mid-April 2022. Mild and wet weather created conducive conditions for late season diseases such as Fusarium and Verticillium wilts, and boll rot development. Boll rot is a sporadic and complex disease, however this was the third consecutive season that the disease occurred at such a high level of prevalence across most surveyed fields. Alternaria leaf spot was prevalent across NSW but the severity was relatively mild. Reoccurring wilt was detected in many new fields/farms in Border Rivers, Gwydir, Namoi and Bourke regions.

Border Rivers

Fourteen fields were surveyed early season. Black root rot incidence averaged 61.7%, with a severity from 0.2 to 21.2%. Rhizoctonia rot incidence averaged 80.5%, with a severity from 0.8 to 22.2%. Alternaria leaf spot was prevalent in all surveyed fields, with incidence averaging 76.7% and a severity from 0.1 to 13.5%. Fusarium wilt on seedlings was detected in seven fields with an average incidence of 0.7%.

Fourteen fields across 7 farms were revisited during our late season survey. Fusarium wilt was detected in 11 fields with an average incidence of 12.5%, and Verticillium wilt was detected in 12 fields with an average incidence of 13%. Reoccurring wilt was detected in three fields with the incidence remaining below 1%. Alternaria leaf spot was relatively mild, with a severity between 0.3 and 25.5%. Boll rot and tight lock were detected in all surveyed fields with a mean incidence of 3.6% and 2.4%, respectively.

Gwydir

Sixteen fields were surveyed early season. Black root rot incidence varied between 6 to 83%, with a disease severity from 0.7 to 25.5%. Rhizoctonia rot incidence varied from 23 to 100%, with a disease severity from 0.9 to 25%. Alternaria leaf spot was prevalent in all surveyed fields, but incidence varied widely (1 to 97%). Only minor pin head lesions were

Bolls from the same branch were affected by two different pathogens being Fusarium (not Fusarium wilt pathogen) on the left and Sclerotinia on the right. (Duy Le, NSW DPI)

Fusarium wilt causing seedling mortality in the Gwydir valley. (Duy Le, NSW DPI)

observed in most fields and the severity was below 0.5%. Fusarium wilt on seedlings was detected in eight fields, with disease incidence reaching 32% in one sampling transect, higher than the past five season's surveys for this region.

The Gwydir was again a hot spot for Fusarium wilt late in the season, with the disease detected in 16 out of 19 surveyed fields. High disease incidence (over 82%) was recorded in four fields, however significant yield loss was likely to occur in only two of those fields. Mean incidence across the valley was 33.8%. Verticillium was also detected in 16 fields (mostly below 10%), and 15 fields had both wilt diseases present. Reoccurring wilt disease was detected again this season but in a new field. Although the average incidence was 6.5%, the disease was well-established and spread across the field. Alternaria leaf spot was relatively mild, with mean incidence across the valley of 4.3%. Boll rot and tight lock were detected in all surveyed fields, and seed rot was detected in several fields.

Walgett/Bourke

Six fields were surveyed early season. Black root rot incidence and severity were minor (0 to 1.5% and 0.2 to 0.5% respectively). Rhizoctonia rot incidence averaged 78%, with severity from 2.9 to 19%. Alternaria leaf spot incidence averaged 81.1%, with severity mostly below 5%, except for one back-to-back field where the disease severity scored up to 15.5%.

Fusarium wilt was detected in three of the five fields surveyed late season, with an incidence between 4-11%. Verticillium wilt was detected in two fields with at up to 25% incidence. Reoccurring wilt was detected in three surveyed fields for the first time in the region, with an average incidence of 0.6%. It was also detected in three other fields not formally included in our survey program. Detection in this region confirms that reoccurring wilt is more widespread in NSW than previously thought. Alternaria leaf spot was minor with a mean disease severity of 0.8%. Boll rot and tight lock were detected in almost all surveyed fields with a mean incidence of 5.1% and 1.7%, respectively.

Severe Alternaria infection on cotyledons was detected in a back-to-back field. (Duy Le, NSW DPI)

Namoi

Eighteen fields were surveyed early season. Black root rot was detected in 15 fields at an average incidence of 17.2% and a disease severity of up to 37.4%. Rhizoctonia rot incidence averaged 83.4%, with severity ranging from 0.5 to 30.5%. Alternaria leaf spot was prevalent in all surveyed fields, with an average incidence of 27.4% and severity mostly less than 1%.

Verticillium wilt remained a major disease in the valley later in the season (detected in 20 out of 21 surveyed fields), however disease incidence was mostly below 10% (only three fields had incidence over 25%), and it tended to occur later in the season, so yield may not be greatly affected. No Fusarium wilt was detected. Reoccurring wilt was detected again in the Namoi; three out of four fields were first time detections this season. The reoccuring wilt was widely distributed across two of the newly detected fields, with disease incidence up to 17% in one transect (mean 8.8%). This indicates that the disease is well established in these two fields. Alternaria leaf spot severity was up to 26% (mean 6.3%). Boll rot incidence remained mostly below 10%. Tight lock incidence was relatively low with the mean incidence of 2.1%. Seed rot was only detected in eight fields with a mean incidence of 0.4%.

Macquarie

Fourteen fields were surveyed early season. Black root rot incidence averaged 30.4%; severity was mostly around 10%, except for one severely affected field where severity reached 69.5%. Rhizoctonia rot incidence averaged 73%, with severity from 2.4 to 21%. Alternaria leaf spot was detected in all surveyed fields, with the incidence averaging 40.2%. While small lesions were observed in most fields, the severity was below 1%.

Verticillium was detected in five out of 13 fields late season. Most had an incidence below 10%, however one field's mean incidence of up to 78% was 12 times higher than the Valley's average of 6.3%. While Fusarium wilt was not detected in this survey, it was confirmed in samples from three properties that were collected and sent to ACRI. A single suspected reoccurring wilt sample is being investigated further. Alternaria leaf spot was prevalent with severity between 0.4 and 15.4%. Boll rot was detected

Severe Alternaria leaf spot infection was recorded in many Namoi fields this season. (Duy Le, NSW DPI)

A severe Verticillium affected field where almost all top leaves were desiccated (disease incidence of up to 86% was recorded). (Duy Le, NSW DPI)

in 12 of the 13 surveyed fields with the incidence up to 10.9%, but mean incidence across the valley remained below 2.5%. Tight lock was less common with a mean incidence of 1%.

Lachlan

Five fields were surveyed early season. Black root rot incidence averaged 73.4%, with severity from 05 to 87.5% (mean 48.2%). Trace infection of Rhizoctonia was detected with the incidence ranging from 0.3 to 10.7%. Alternaria leaf spot was detected in all surveyed fields with an average incidence of 30.3%; only minor pin head lesions were observed in most fields, with a severity of less than 0.5%.

Disease pressure was mild during the late season survey. Alternaria leaf spot was evident in the top half of the canopy in all five surveyed fields, with a disease severity of 0.1 to 8.5%. Relatively low incidences of boll rot, tight lock and seed rot were detected in the lower canopy in all surveyed fields. Verticillium was detected in three fields with an average incidence of 9.3%. However, one field had incidence up to 45%, indicating Verticillium wilt was well-established. Fusarium wilt and reocurring wilt were not detected.

Murrumbidgee

Seven fields were surveyed early season. Black root rot incidence averaged 35%, with a severity of 0.1 to 65.1%. Rhizoctonia rot incidence ranged from 6.5 to 36% but only trace infection was detected. Alternaria leaf spot was detected in all surveyed fields. Leaf spot incidence ranged from less than 1% to 48% (mean 12.8%) and severity was mostly less than 0.5%.

Similar to the Lachlan, the late season disease pressure in Murrumbidgee was mild. Alternaria leaf spot severity varied from 0.1 to 2.3%. Boll rot was detected in seven out of nine surveyed fields with incidence at less than one rotten boll every 10 plants. Tight lock was less common. Seed rot was also detected in five fields. Verticillium wilt was only recorded in one surveyed field, however the disease has previously been recorded more widely in this region. No Fusarium wilt or reoccurring wilt was recorded.

TABLE 30a: A summary of seedling diseases recorded during the early season disease survey in NSW.

Regions	Plant stand/m	Fusarium incidence (%)	BRR incidence (%)	BRR severity (%)	Rhizoctonia incidence (%)	Rhizoctonia severity (%)	Alternaria incidence (%)	Alternaria severity (%)
Border Rivers	11 (8.7-12.3)	0.7 (0-5)	61.7 (2-100)	7.7 (0.2-21.2)	80.5 (3-100)	8.7 (0.8-22.2)	76.7 (8-100)	2.5 (0.1-13.5)
Gwydir	11 (9.1-14.5)	2.9 (0-32)	45.3 (6-83)	8.5 (0.7-25.5)	86.9 (23-100)	10.4 (0.9-25)	27.3 (1-97)	0.3 (0.01-2.1)
Walgett/Bourke	9.4 (7.3-10.4)		0.8 (0-1.5)	0.3 (0.2-0.5)	77.9 (48-100)	9.1 (2.9-19)	81.1 (10-100)	2.5 (0.1-15.5)
Namoi	11.5 (6.8-14.2)	0	17.2 (0-100)	4 (0-37.4)	83.4 (8-100)	10.2 (0.5-30.5)	27.4 (1-100)	0.6 (0-6.1)
Macquarie	12.5 (10-17)	0	30.4 (0-100)	10.5 (0-83.9)	73 (15-100)	7.9 (2.4-21)	40.2 (3-99)	0.9 (0-4.6)
Lachlan	11 (7.8-13.6)	0	73.4 (1-99.3)	48.2 (0.5-87.5)	4.9 (0.3-10.7)	Trace	30.3 (1-60)	0.2 (0.01-0.8)
Murrumbidgee	10.4 (7.9-12.4)	0	35 (1-99)	19 (0.1-65.1)	18.2 (6.5-36)	Trace	12.8 (1-48)	Trace

TABLE 30b: A summary of disease incidence recorded during the late season disease survey in NSW.

Regions	Fusarium incidence (%)	Verticillium incidence (%)	Reoccurring incidence (%)	Alternaria severity (%)	Boll rot incidence (%)	Seed rot incidence (%)	Tight lock incidence (%)
Border Rivers	12.5 (0-80)	13 (0-89)	0.1 (0-2)	9.7 (0.3-25.5)	3.6 (0-9.6)	0	2.4 (0-7.4)
Gwydir	33.8 (0-99)	7.1 (0-60)	0.3 (0-10)	4.3 (0.01-10.2)	5.6 (1.8-21)	0.9 (0-10.1)	3.8 (0-15.2)
Walgett/Bourke	2.5 (0-11)	3.6 (0-25)	0.6 (0-2)	0.8 (0.03-3.5)	5.1 (0-10.7)	0	1.7 (0-4.3)
Namoi	0	10.2 (0-65)	1.1 (0-17)	6.3 (0.1-26)	5.3 (0-23.1)	0.4 (0-7.9)	2.1 (0-13.7)
Macquarie	0	6.3 (0-86)	0	6.4 (0.4-15.4)	2.5 (0-10.9)	0	1 (0-11.1)
Lachlan	0	9.3 (0-46)	0	1.8 (0.1-8.5)	Prevalent	Detected	Detected
Murrumbidgee	0	0.06 (0-1)	0	0.4 (0.1-2.3)	Prevalent	Detected	Detected

Biosecurity – we all have a responsibility

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

Biosecurity – a legal responsibility

All Australian states and territories have their own respective biosecurity legislation to minimise the risk of the entry and spread of pests, pathogens and weed seeds. Legislation in Queensland and NSW is based on the principle of a 'shared responsibility' where everyone has a responsibility to contribute to biosecurity. These regulations are designed to provide more capability, flexibility and innovation in the management of biosecurity risks. Everyone in the community has a responsibility to ensure they minimise the risk of spreading pathogens, pests and weeds ('biosecurity matter') which could impact the environment, the economy and the broader community.

It is your responsibility to ensure you meet the requirements of your state or territory. If you have any questions or concerns, contact your State or Territory Agriculture Department.

New South Wales Department of Primary Industries: 1800 680 244

Queensland Department of Agriculture and Fisheries: 13 25 23

Northern Territory Department of Industry, Tourism and Trade: (08) 8999 2118

Western Australia Department of Primary Industries and Regional Development: (08) 9334 1800

Anyone working on or visiting farms has a biosecurity responsibility

- **Come Clean. Go Clean.** Vehicles, farm equipment and people can carry weed seeds and diseases. Clean down between farms, including vehicles and footwear. Suggest using an on-farm vehicle where possible.
- **Spotted anything unusual?** Ensure any unusual plant symptoms or suspected exotic pests are reported to the Exotic Plant Pest Hotline (1800 084 881). Vigilance is vital for an early detection of an exotic plant pest threat.

Growers have a biosecurity responsibility

- **Check your crop frequently** looking out for unusual crop symptoms and if you find anything suspicious, report it immediately. Make sure that you and your employees are familiar with the most important cotton pests. Don't move the infected material.
- **Call the Exotic Plant Pest Hotline 1800 084 881,** a dedicated reporting line that will be answered by an officer from your state or territory's agriculture department. Early reporting improves the chance of effective control and eradication.
- **Communicate your biosecurity requirements using clear signage** to ensure only essential vehicles and equipment gain access to production areas.
- **Provide wash down facilities** for visitors to use with appropriate agricultural detergents and/or disinfectants to clean equipment and tools prior to entry and exit.
- **Develop a farm biosecurity management plan** to assess how pests, weeds and diseases could enter the farm and what practices are in place to manage or reduce these risks.
- **Declare visits to farms overseas on re-entry to Australia.** All clothes and footwear worn on-farm should be thoroughly washed before returning, or left behind.
- **Ensure all seed is pest free.** This includes cotton and other refuge and commercial crops. Keep records of all farm inputs just in case.
- **Maintain zero tolerance of cotton volunteer plants and other weeds** at all times throughout the year to prevent pests harbouring there.

Come Clean. Go Clean.

There are two different types of products used in wash down procedures: agricultural detergents and agricultural disinfectants.

Agricultural detergents (e.g. Bio-Cleanse™ or most industrial and domestic brands of soaps and detergents) provide optimal soil removal.

Agricultural disinfectants (e.g. Path-X™, Sporekill®, Steri-maX®, or products containing quaternary ammonium compounds) are effective against a range of pathogens found on agricultural farms.

To work properly, disinfectant products need to be applied to a surface that has all soil and trash removed. Effective decontamination (wash down) of items involves two steps:
(1) Cleaning with detergent, followed by
(2) Disinfection.

Product users must also satisfy themselves that the product they choose is appropriate for their situation, and ensure that all label requirements are read and followed.

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. Biosecurity planning is currently underway, with industry and government collaborating to review and develop the new Biosecurity Plan for the Cotton Industry.

For further information on cotton biosecurity stewardship contact Cotton Australia on 02 9669 5222 or go to https://cottonaustralia.com.au/biosecurity

For more information on the NSW's General Biosecurity Duty: www.dpi.nsw.gov.au/biosecurity/your-role-in-biosecurity

For more information on Qld's General Biosecurity Obligation: www.daf.qld.gov.au/business-priorities/biosecurity/policy-legislation-regulation/biosecurity-act-2014/general-biosecurity-obligation

To find out more about on-farm biosecurity measures to help prevent endemic and exotic pests entering and establishing on farm, go to Farm Biosecurity Program: www.farmbiosecurity.com.au

Department of Primary Industries

GRAINS FARM BIOSECURITY PROGRAM

Queensland Government

CottonInfo

Come Clean. Go Clean.

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

A GUIDE TO EFFECTIVE WASH DOWN OF VEHICLES AND MACHINERY

1 WASH DOWN

- Use compressed air or high pressure water to remove caked on trash and mud
- Get into crevices where mud or trash might be trapped
- Clean out the inside of the car, particularly foot pedals and mats regularly in contact with dirty footwear

WHERE

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

2 CLEAN

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

*unless otherwise directed by product label

Image: NSW DPI

REMEMBER

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

3 DECON

- After removing physical dirt, consider using an agricultural decontaminant to kill any remaining pests or pathogens
- Refer to the APVMA for registered decontaminants and follow label instructions
- An additional rinse step may be necessary following disinfection

NOTE

Make sure vehicles and equipment are clean and free of mud and trash before applying a decontaminant

Image: cleananddry.net.au

4 RINSE

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

CHECK

Equipment that has not been cleaned on farm should be thoroughly inspected to ensure cleanliness

Images courtesy of Sharna Holman, QDAF, unless otherwise stated

Together we can stop the spread of pests, weeds and diseases.

BE A GOOD MATE STOP IT AT THE GATE

JN14825_APR18

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 growers or farm managers to:

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

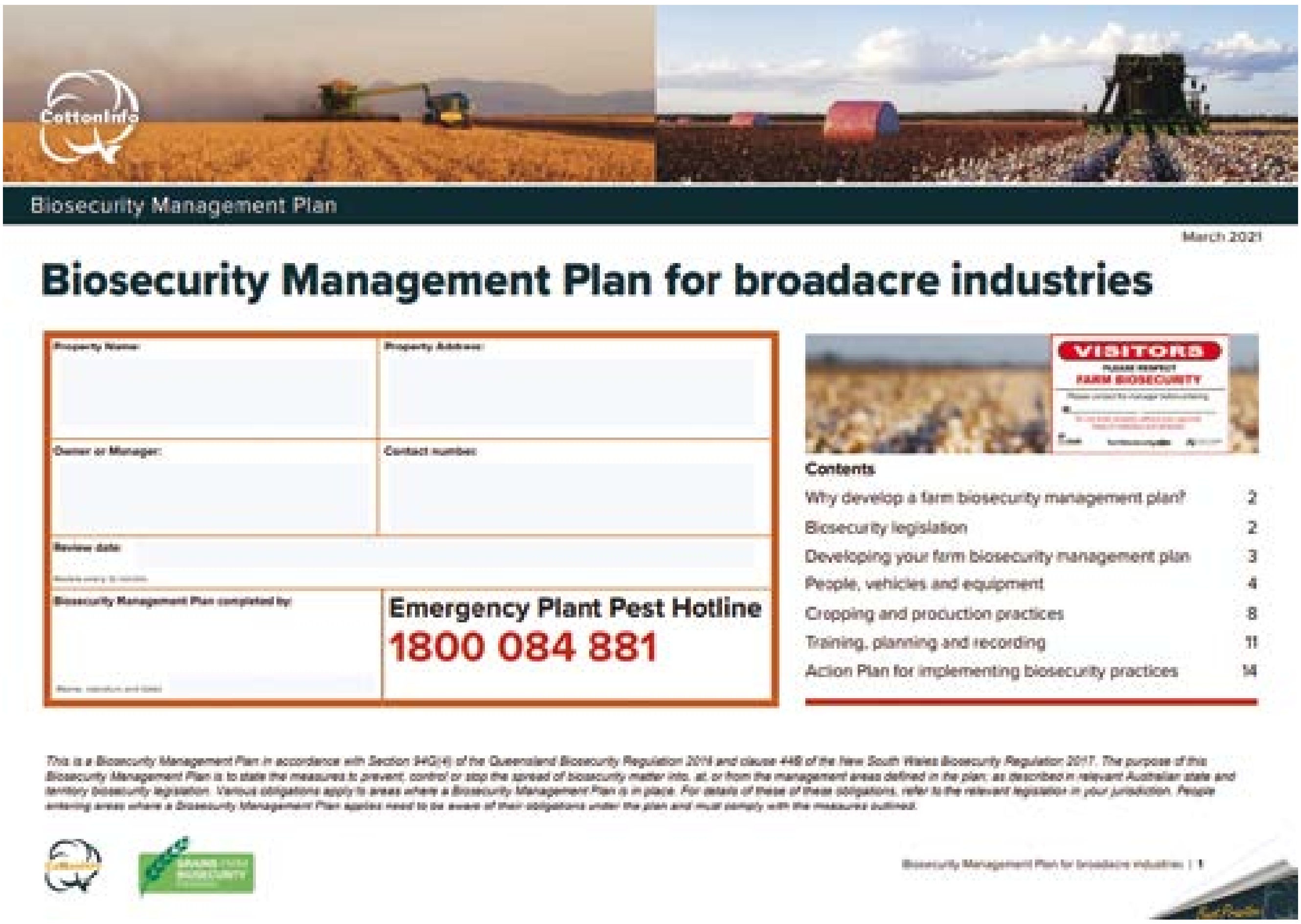
The suggested practices in a farm biosecurity management plan cover a range of farming scenarios and can be adapted to suit your particular circumstances. It is unlikely that all biosecurity risks or practices will apply to your farm, and in some cases alternative practices may be better suited to your farm and business. The important thing is that you are aware of your biosecurity risks and are taking reasonable steps to minimise those risks. If you build your plan around daily, monthly and yearly farming routines, biosecurity practices will become a habit rather than an additional task.

Completing a farm biosecurity management plan provides a point of discussion and clear instructions of your biosecurity expectations for farm visitors such as agronomists, researchers, utility workers and hunters. Farm biosecurity management plans are available on the CottonInfo website (www.cottoninfo.com.au). If you require assistance with developing a farm biosecurity plan, please contact the CottonInfo Technical Lead for Biosecurity.

Biosecurity Top Tips:

There can be several ways to mitigate a biosecurity risk; the practices you implement should reflect what suits you and your farming business. Check out the Biosecurity Top Tip videos on the CottonInfo YouTube channel to see short videos of growers, consultants and researchers sharing how they are implementing biosecurity in their day-to-day routines.

Visit www.youtube.com/CottonInfoAust


CottonInfo

Biosecurity Management Plan

March 2021

Biosecurity Management Plan for broadacre industries

Property Name:	Property Address:
Owner or Manager:	Contact number:
Review date:	
Biosecurity Management Plan completed by:	Emergency Plant Pest Hotline 1800 084 881

Contents

This is a Biosecurity Management Plan in accordance with Section 94Q(4) of the Queensland Biosecurity Regulation 2016 and clause 44B of the New South Wales Biosecurity Regulation 2017. The purpose of this Biosecurity Management Plan is to state the measures to prevent, control or stop the spread of biosecurity matter into, at, or from the management areas defined in the plan, as described in relevant Australian state and territory biosecurity legislation. Various obligations apply to areas where a Biosecurity Management Plan is in place. For details of these of these obligations, refer to the relevant legislation in your jurisdiction. People entering areas where a Biosecurity Management Plan applies need to be aware of their obligations under the plan and must comply with the measures outlined.

Biosecurity Management Plan for broadacre industries | 1

Ground Up Protection for the Australian Cotton Industry

1300 781 649   www.echem.com.au

High priority exotic pests and diseases

A risk assessment carried out during the development of the Biosecurity Plan for the Cotton Industry identified exotic pests that could significantly impact cotton production if they arrived and established in Australia. It is important that people working on-farm are aware of these pests as well as what to do if they see any unusual plant symptoms or pests to improve the chance of an effective control and eradication response.

Exotic pests

These pests have not yet been detected in Australia. Report suspected incursions to the Exotic Plant Pest Hotline on 1800 084 881.

Cotton boll weevil

Anthomonus grandis

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

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

Brown marmorated stink bug (BMSB)

Halyomorpha halys

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

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

Brown marmorated stink bug. (Steven Valley, Oregon Department of Agriculture, Bugwood.org)

Cotton stainer

Dysdercus spp.

Related to the already endemic pale cotton stainers (see page 41), these colourful red bugs are often found in groups. While feeding on cotton bolls they can transfer microorganisms that increase lint staining.

Adults and nymphs of the cotton stainer, *Dysdercus suturellus*. (Lyle J. Buss, University of Florida. https://entnemdept.ufl.edu/creatures/field/bugs/cotton_stainer.htm)

False codling moth

Thaumatotibia leucotreta

False codling moth is a pest of economic importance to many crops in its native habitat including avocado, citrus, corn, cotton, macadamia, peach and plum. Adult false codling moths are small, brownish-gray moths up to 20 mm, with a triangular mark on the outer part of the wing with a crescent shaped mark above it.

False codling moth larvae (left) and female moth (right). (Marja van der Straten, NVWA Plant Protection Service, Bugwood.org (left) and idtools.org (right))

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 plant bugs would be very disruptive to the current Australian IPM system.

Tarnished plant bug. (Scott Bauer, USDA Agricultural Research Service, Bugwood.org)

Cotton leaf curl disease (CLCuD)

CLCuD, sometimes referred to as Gemini virus, can cause yield losses of up to 35% in cotton. It is spread by whiteflies. There are at least seven different begomoviruses and several different DNA satellite molecules associated with CLCuD. A cotton plant needs to be infected with at least one begomovirus and one satellite to develop CLCuD.

Symptoms of CLCuD 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 only a few millimetres in diameter to almost the size of a normal leaf. These larger structures are often cup-shaped.

Leaf curl disease. (Cherie Gambley, Qld DAF)

Texas root rot

Phymatotrichopsis omnivore

Texas root rot is an extremely damaging fungal disease with a wide host range. It causes sudden death, usually during the warmer months. In cotton, infection can result in 100% crop loss. If this disease became established in Australia, control would be extremely difficult as management using rotations and fungicides is usually only partially effective.

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.

Texas root rot. (Chris Anderson, NSW DPI)

Blue disease

Cotton leafroll dwarf virus

Blue disease is a virus specific to cotton that can reduce yield potential by up to 20%. It is spread by a vector, the cotton aphid. It has been associated with plants infected with cotton leafroll dwarf virus (CLRDV) and has similarities with cotton bunchy top, anthocyanosis and cotton leaf roll. It is not known if the same pathogen causes all these diseases or if there are multiple pathogens causing similar symptoms. CLRDV has not been detected in Australian cotton affected by cotton bunchy top disease.

Affected leaves tend to be smaller, thicker, more leathery and brittle and are intense green to bluish with yellow veins. 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 a shortened branch internodes) and produce many branches, giving a bunchy zig-zag stem habit. Symptoms and stunting are more obvious in plants infected at an early age. Infected plants also produce smaller bolls and boll shedding may occur. Single infected plants can be difficult to spot if overgrown by nearby healthy plants.

Blue disease. (Murray Sharman, Qld DAF)

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

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 contact the relevant researcher if you've experienced an insecticide spray failure without a reasonable explanation, or are seeing new or unusual disease symptoms to organise the appropriate sampling and testing.

Bt-resistant cotton bollworm

Helicoverpa armigera (carrying Bt resistance alleles)

Bt cotton has dramatically reduced the need to control *Helicoverpa*. Exotic strains of *H. armigera* that carry resistance alleles (e.g. dominant resistance to Cry1Ac) would have a significant impact on Australia's cotton industry if they were to establish here. With the movement of *H. armigera* into South America, there is also some concern that *Helicoverpa zea* (American cotton bollworm) may hybridise with *H. armigera*.

Fall armyworm

Spodoptera frugiperda (exotic strains)

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

Cotton aphid

Aphis gossypii (exotic strains)

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

Bacterial blight

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

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

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

Bacterial blight.

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.

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

1800 084 881

Applying pesticides

Agrochemicals are chemical products that are used in agriculture. Usually, the term refers to pesticides (insecticides, herbicides, fungicides, nematicides etc), synthetic fertilisers, and chemical growth agents. Information relating to crop nutrition and fertilisers can be found in the *Australian Cotton Production Manual*.

Pesticides are an important component of pest management, 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.

Planning ahead

The development of a comprehensive Pesticide Application Management Plan (PAMP) prior to the season is an important part of the Best Management Practice (myBMP) program for cotton. Include:

- Farm layout
- Record keeping
- Weather monitoring
- Identification of sensitive areas and potential hazards
- Communications procedures and complaint handling.

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

Legal responsibilities

Be aware of federal and state regulations for chemical application. Staff responsible for handling and applying pesticides must be qualified according to relevant state and federal requirements.

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

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

- **Spray quality** is aligned with either the American society of Agricultural and Biological Engineers (ASABE) or British Crop Production Council (BCPC) classification systems. Select nozzles from charts that refer to one of these standards 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 specified range is usually above 3 km/h and less than 15-20 km/h.
- N**o-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 another crop). Always check the product label(s) for no-spray zone requirements 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.

Users are not absolved from compliance with the label directions/permit conditions or compliance with other legal requirements by reason of any statement made or not made in this publication. See also the Pesticides and regulations section of this publication.

Best practice…

Achieving the best outcome from spray application requires the careful consideration of many factors. Application technique needs to be matched to the target, tank mix and weather conditions. Best practice refers not only to maximising effectiveness of a spray event within your crop, but also minimising the potential for adverse outcomes such as spray drift. You need to be able to demonstrate what you have done, including how you have assessed safety risks and mitigated non-target consequences.

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.

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. For example, see spraywisedecisions.com.au or syngenta.com.au

Good communication

Prior to product selection and spray application, check the proximity of susceptible crops and sensitive areas.

BeeConnected can help identify nearby location of hives and facilitate communication between spray applicators and beekeepers (http://beeconnected.org.au). It is also good practice to notify neighbours and staff of your spray intentions, regardless of label requirements.

Cotton is extremely sensitive to phenoxy herbicide drift. SataCrop is a free online mapping tool that maps all crops, not just cotton, allowing growers and applicators of all products to be better informed of the location of potentially sensitive crops before spraying (https://satacrop.com.au/).

Optimising your 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 nozzle selection;
- Appropriate spray release height;
- Avoiding excessive travel speed (ground rigs);
- Appropriate pressure at the nozzle;
- Consideration of most suitable timing for mobile targets (insects);
- Suitable water volumes and quality; and,
- Regular calibration and rig maintenance.

See chapter 18 of the *Australian Cotton Production Manual* for more details on spray application.

Australian Government
Australian Pesticides and Veterinary Medicines Authority

UNDERSTANDING
PESTICIDE CHEMICAL LABELS

A WARNINGS AND PRODUCT DESCRIPTION

1 CAUTION

KEEP OUT OF REACH OF CHILDREN. READ SAFETY DIRECTIONS BEFORE OPENING OR USING.

2 JO BLOGGS 500

3 SELECTIVE HERBICIDE

4 ACTIVE CONSTITUENT: 500g/L 2,4-DB presents as dimethylamine salt

5 GROUP I HERBICIDE

6 For selective control of certain broadleaf weeds in various crops as per the directions for use table.

7 Jo Bloggs Pty Ltd, 80 Ryde St Tindale NSW 2000 EMERGENCY CONTACT NO. 1800 etc. Contents 20 L

B DIRECTIONS FOR USE

8 DIRECTIONS FOR USE

RESTRAINTS: DO NOT apply to crops or weeds stressed by drought or cold, frosty conditions.

SPRAY-DRIFT RESTRAINTS: DO NOT apply unless the wind speed is between 3 and 20 kilometres per hour at the application site ....etc.

	CROP	WEEDS	STATE	APPLICATION RATE	WHP	CRITICAL COMMENTS
9	Barley, Oats	Clovers, mallow	SA, Vic, NSW	1L in 40L water	7 days	DO NOT use on buffalo grass

10 NOT TO BE USED FOR ANY PURPOSE OR IN ANY MANNER CONTRARY TO THIS LABEL UNLESS AUTHORISED UNDER APPROPRIATE LEGISLATION.

11 WITHHOLDING PERIOD: DO NOT GRAZE OR CUT FOR STOCK FOOD FOR 7 DAYS AFTER APPLICATION.

C GENERAL INSTRUCTIONS

GENERAL INSTRUCTIONS

12 RESISTANCE WARNING: Jo Bloggs 500 is a member of the phenoxy group of herbicides. Its mode of action is to etc.

13 COMPATIBILITY: this product is compatible with most water-based insecticides.

14 MIXING: half fill spray tank with water, Slowly add chemical and then fill tank with water.

D PRECAUTIONS

PRECAUTIONS

15 RE-ENTRY PERIOD: DO NOT enter treated area for 3 days, unless wearing appropriate PPE.

16 PLANT-BACK PERIOD: DO NOT plant sensitive crops (eg tomatoes) in treated soil for at least 12 days.

17 PROTECTION OF CROPS, NATIVE & NON-TARGET PLANTS : DO NOT apply under weather conditions or from spraying equipment that may cause spray to drift onto nearby susceptible plants/crops, cropping lands or pastures.

18 PROTECTION OF LIVESTOCK: Dangerous to bees. DO NOT spray any plants in flower while bees are foraging.

19 PROTECTION OF WILDLIFE, FISH, CRUSTACEANS & ENVIRONMENT : DO NOT allow chemical or used containers to contaminate streams or waterways.

E STORAGE AND DISPOSAL

20 STORAGE & DISPOSAL: Store in the closed original container in a cool, well-ventilated area. DO NOT store for prolonged periods in direct sunlight. This container can be recycled if it is clean, dry and free of visible residues and has the DrumMaster logo visible. Triple or pressure rinse contanier for disposal. Dispose of rinsate by adding it to the spray tank.

21 SAFETY DIRECTIONS: Will irritate eyes. When opening the container and preparing the spray, wear face shield or goggles. Wash hands after use.

22 FIRST AID: If poisoning occurs, contact a doctor or Poisons Information Centre on 131 126.

23 APVMA APPROVAL NO. XXXX

24 Batch: A76932 DOM: 10062011

Refer to accompanying booklet 'Understanding Pesticide Chemical Labels' (available to download from apvma.gov.au/node/11041) for full details.

Effective decontamination

Thoroughly decontaminate application equipment after use, particularly when herbicides have been used. The *Australian Cotton Production Manual* includes a decontamination/cleaning product guide. Follow decontamination instructions on pesticide and cleaning product labels.

CottonInfo video on decontaminating a spray rig https://youtu.be/-zDQwolEcB0

Top tips for agronomists...

1. **Run through a pre-season spray plan with your growers (see module 5 of the GRDC spray application manual) and have a conversation if you suspect that spray practices can be improved.**
2. **Ensure the grower has realistic expectations of timeframes for pest control.**
3. **Check that your 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 not spraying under inversion conditions (including the need to halt the spray operation if conditions become unfavourable).**
5. **Ensure the grower is 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 coarser nozzle to reduce spray drift risk and higher water rates to improve efficacy of pest control where appropriate.**
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 commonly chosen as they 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. These units are responsive, cheaper and lighter (reducing potential field compaction), but have lower field capacity than larger spraying systems.

Spray contractors can be used if you do not have the equipment or expertise to apply pesticides yourself. Ensure your spray contractor has suitable training and accreditations and has the appropriate state license. For example, you can search to see if a ground or aerial contractor is licensed in NSW at https://apps.epa.nsw.gov.au/prrdlapp/plpr.aspx and in Qld at www.business.qld.gov.au/industries/farms-fishing-forestry/agriculture/land-management/chemical-controls/licence-search

Important considerations when setting up and calibrating a spray rig include:

- Choosing the best nozzle type for product (including adjuvants) and target;
- Ensuring appropriate nozzle spacing and boom height;
- Determining operation parameters such as speed and pressure;
- Adhering to all label restrictions for spray quality and drift risk; and,
- Calculating actual field application rate and required product and water volumes.

Banded sprays present an opportunity for strategic and economical use of products; 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 big 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 allows significantly less product to be used 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 for pesticide application in agriculture. Their advantage lies in being able to cover large areas quickly and in conditions that may not suit ground application (e.g. dense crop cover 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. RPA used for commercial operations such as spraying must be registered with CASA, and the pilot appropriately licenced.

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

Some key points that should be discussed are:

- **Target –** e.g. the pest's location within crop canopy or field, or if there are time constraints related to the pest's development.
- **Water rates –** lower water rates increase efficiency but may impact efficacy. It is critical that the correct coverage is achieved (as specified on the product label). Adhere to minimum water rates and increase if needed (e.g. to match weather parameters or to provide sufficient volume to carry all of the products in the tank).
- **Droplet size –** some product labels specify a certain number of droplets per square cm on the target. Aerial operators are well positioned to select the correct droplet size to achieve this. Small droplets may increase the risk of off-target movement.
- **Swath width –** A spray plane's swath width is wider than the wingspan, due to the vortex effect created by the wings as they move through the air. Each aircraft has recommended swath widths that they can use in various conditions. Many aerial operators do regular pattern testing as well to optimise the swath width that they use for each aircraft.

Review this data with your aerial operator to ensure that all parties are satisfied with the spray parameters being used.

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

Reducing drift

Spray application needs to maximise efficacy against the target pest, while minimising any off-target movement or effect. Movement of spray beyond the target area is undesirable as it represents wastage of product and exposure of sensitive non-target areas to potentially damaging materials.

The risk of spray drift can be influenced by weather conditions, spray rig set-up and operational parameters, and even the types of adjuvants used.

Consider temperature and humidity

Higher ambient air temperatures and lower relative humidity conditions increase evaporation rates, which will decrease droplet size and increase the risk of drift. It is preferable to spray when the Delta T (the difference between the wet bulb and dry bulb) is between 2-10°C (or up to 12°C where targets are not stressed and a coarse spray quality or larger is used). See GRDC's factsheet on weather monitoring equipment https://grdc.com.au/GRDC-FS-SprayEquipment

Avoid hazardous surface temperature inversions

DO NOT apply if there are hazardous surface temperature inversion conditions present at the application site during the time of application. Surface temperature inversion conditions exist most evenings one to two hours before sunset and persist until one to two hours after sunrise (see the 24 hour spray risk diagram on page 130).

GRDC and CRDC are working in partnership with Goanna Ag to develop a spray drift hazardous weather warning system that will provide real-time weather data and alerts to growers and spray operators about the presence of hazardous temperature inversions. For more information refer to www.goannaag.com.au/spray-inversion-network

Bayer's XtendFlex cotton Spray App helps spray planning by providing weather forecasts including inversion risk probability. www.crop.bayer.com.au/tools/weather-inversion

For more information refer to chapter 18 of the *Australian Cotton Production Manual* or GRDC's factsheet on surface temperature inversions https://grdc.com.au/GRDC-FS-SprayInversions

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. For more information, see the *Australian Cotton Production Manual* or download the GRDC factsheet on tank mixes https://grdc.com.au/resources-and-publications/all-publications/factsheets/2019/mixing-requirements-for-spraying-operations

Use vegetative plantings as spray drift barriers

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

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

The most effective traps for airborne droplets are trees and shrubs with long thin or needle-like leaves or hairy leaf surfaces. Choose hardy and drought tolerant species with thick cuticles to help them survive small doses of pesticide. For more information, see the CottonInfo fact sheet on vegetative barriers: https://cottoninfo.com.au/publications/nrmpesticide-input-efficiency-using-vegetative-barriers-minimise-spray-drift-cotton

Do not use remnant native vegetation or environmental corridors as a vegetative barrier. Identify habitat vegetation as 'sensitive' and protect it from spray drift, along with riparian areas and waterways.

Useful resources:

Chapter 18 in the *Australian Cotton Production Manual*

***my*BMP's Pesticide application module www.myBMP.com.au**

CottonInfo's Pesticide input efficiency page www.cottoninfo.com.au/pesticide-input-efficiency

Cotton Grower's Spray Application Handbook, 2nd edition, available from www.cottoninfo.com.au/publications/spraypak

GRDC's spray drift hub https://grdc.com.au/resources-and-publications/resources/spray-drift includes links to its spray drift manual and other relevant factsheets and posters. See also GRDC's practical tips to reduce spray drift www.grdc.com.au/GRDC-FS-SprayPracticalTips

Nufarm's Spraywise decisions www.spraywisedecisions.com.au

Mary O'Brien Rural Spray Drift resources www.maryobrienrural.com.au/resources

A number of spray-related apps are also available, including weather forecasting, nozzle selection, calibration and/or tank mixing.

For more information on best practice for aerial and ground spray application go to www.myBMP.com.au. (Jack Hawkins, Cotton Australia)

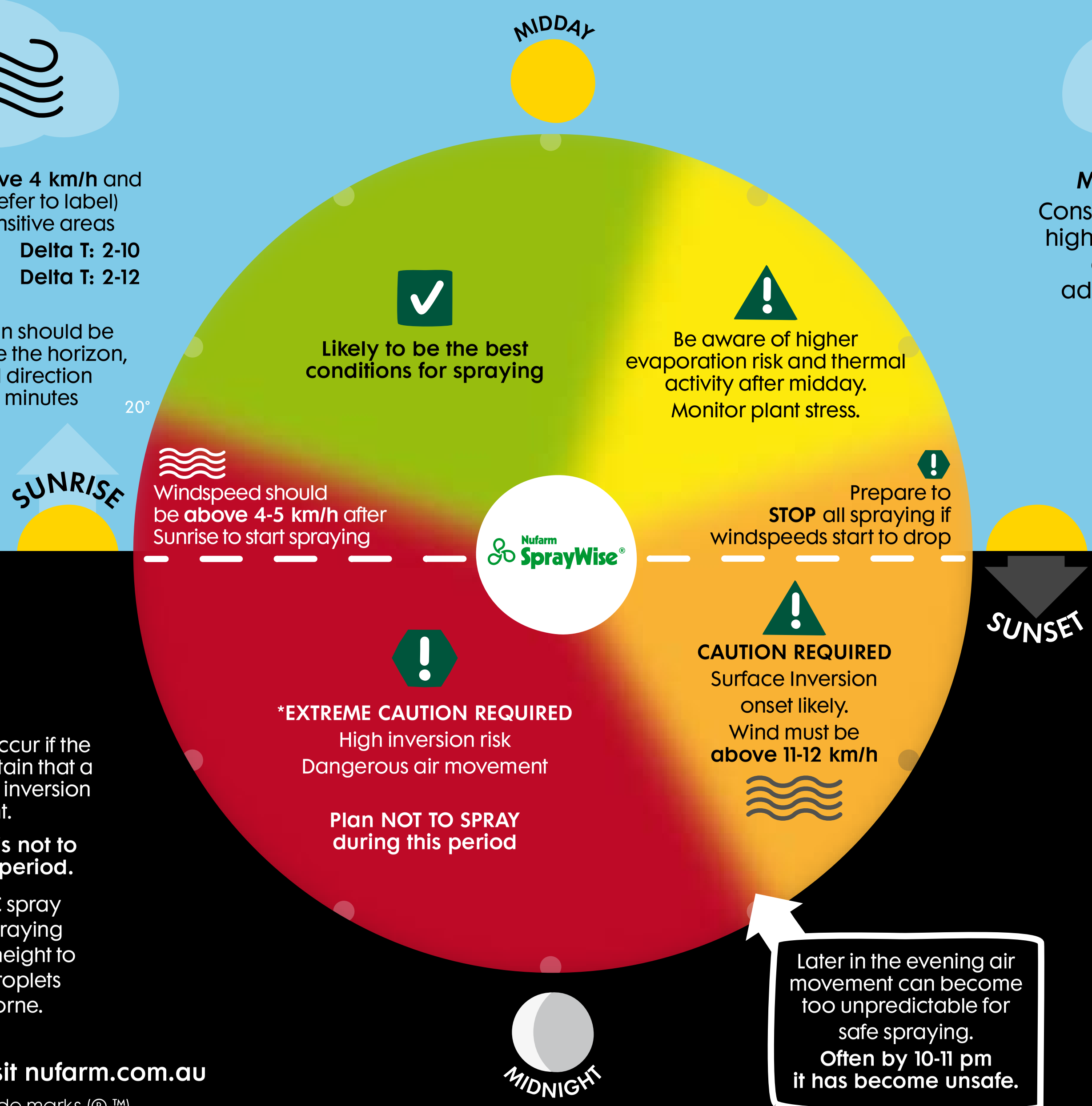
24 Hour risk profile for Summer spraying

Always follow label instructions

Windspeeds must be **above 4 km/h** and **less than 15-20 km/h** (refer to label) blowing away from sensitive areas

Medium spray quality: Delta T: 2-10
Coarse spray quality: Delta T: 2-12

To start spraying, the sun should be about 20 degrees above the horizon, and wind speed and direction consistent for 30-40 minutes



Monitor conditions closely
Consider using larger spray quality, higher water rates and managing evaporation with suitable adjuvants (ie. Collide, Activator)

Often spraying into the early evening is possible in summer when air movement has continued to mix the air and prevent a surface temperature inversion forming.

Pay very close attention to changes in wind speed and wind direction through out the evening.

Later in the evening air movement can become too unpredictable for safe spraying.
Often by 10-11 pm it has become unsafe.

Spraying can only occur if the operator can be certain that a surface temperature inversion is not present.

The safest option is not to spray during this period.

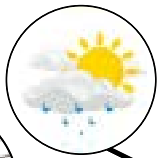
Only use XC or UC spray quality, reduce spraying speed and boom height to minimise risk of droplets remaining airborne.

For more information visit nufarm.com.au

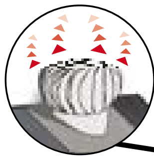
Nufarm
Grow a better tomorrow

ChemCert Storage Guide for Hazardous Chemicals

Chemical Shed 10 Point Guide

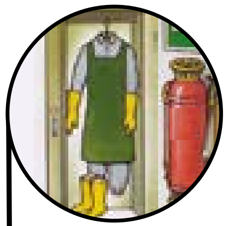


Fire & Weather Resistant Structure, chemicals protected from extreme heat and UV exposure

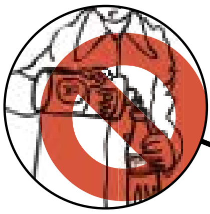


Ventilated (cross flow & roof exhaust vent), seek advice over the use of shipping containers

Well lit with strong metal shelving to prevent people stacking drums on top of each other

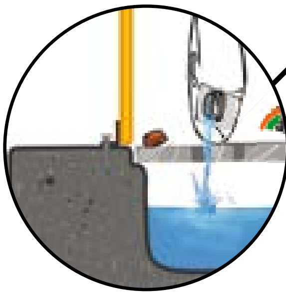


Fire extinguisher, first aid kit and PPE should be kept nearby and maintain a safety shower and eyewash station capable of 15 minute eyewash in the event of a pesticide splash into the eyes



Original Containers with intact legible label, never decant into food/beverage container

Lockable with a child proof latch and ***appropriate signage***



Bunded non slip concrete floor to contain 25% of total volume or 100% of the largest package

Spill kit should be kept inside the storage area suitable for the chemicals housed

Emergency plan with emergency contact numbers and SDS nearby, Poisons Information centre number and diagram of assembly area should be mounted near entrance.

Segregated & correctly stored, separate flammables from non-flammables by at least 3 metres and pesticides from animal food and feedstuffs/seed/fertilisers, out of direct sunlight and away from materials that burn readily like oils, hay, straw, old tyres, saw dust and tall dry grass. Solids should be stored above liquids.

Hazardous Chemical Storage

Federal - Make sure all Agvet chemicals stored carry an APVMA approval number

EPA - Waste management – spills, chemical and container disposal – Chemclear and drumMuster

WHS - Keep a register of all hazardous chemicals and their current (less than 5years old) safety data sheets (sds)

Larger quantities - placarding, manifests and notification

GHS Hazard class	GHS Hazard category	ADG Class/ Packing Group	Placard quantity	Placard to display	Manifest Quantity
Acute toxicity	1	6.1 PG 1	50 kg/L	 TOXIC	500 kg or L
"	2	6.1 PG 11	250 Kg/L		2,500 Kg or L
"	3	6.1 PG 111	1,000 kg/L		10,000 Kg or L

As a general rule GHS flammable liquids, Skin corrosion and Oxidising liquids and solids require the same placard and manifest quantities as above but display their own respective placards.

Agsafe www.agsafe.org.au

An industry safety initiative from ChemCert
www.ChemCert.com.au

ChemCert AUSTRALIA

Pesticides and regulation

APVMA product registration

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

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

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

Using the APVMA website

The APVMA Public Chemicals Registration Information System (PubCRIS) database can be searched to find agvet chemical products, active constituents and labels approved and registered for use in Australia at: https://portal.apvma.gov.au/pubcris

Products approved for minor use or under temporary emergency use permits can be searched at https://portal.apvma.gov.au/permits

The APVMA may undertake a formal review (or reconsideration) to scientifically reassess the risks and determine whether changes are needed to ensure the 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 https://apvma.gov.au/chemicals-and-products/chemical-review/listing

Legal responsibilities

All agricultural chemical applications MUST accord with the approved label instructions or permit conditions for that particular registered agricultural chemical, crop, pest and region.

Each state and territory administer their own control-of-use legislation, to enforce the safe and responsible use of agricultural chemicals. Jurisdictions may differ in the various requirements for agricultural chemical use, licensing, training and record-keeping. It is therefore important for all chemical users to gain an understanding of their obligations, as set out in legislation applicable to their state or territory.

Label instructions

All control-of-use legislation focuses on using only registered agricultural chemicals and complying with label instructions. The risks associated with chemical use have been assessed by the APVMA at registration and such risks are primarily managed through controls which appear on labels. For this reason, it is critical that the directions for use, constraints and all other label instructions are read and understood. Periodically reviewing the labels of all chemicals used is important, keeping in mind that labels are sometimes revised and amended.

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 https://apvma.gov.au/node/935#Label_layoutremains

There are some limited exceptions to the requisite adherence to all label instructions, most notably when an APVMA permit approves a minor, emergency or research use of an agricultural chemical (which may deviate from the use pattern described on the label). Chemical uses supported by permits are also assessed by the APVMA prior to approval. Following all permit instructions and conditions is therefore essential, from both a risk management and a compliance perspective.

The risks managed by regulatory controls on chemical labels and permits include those to human health (occupational exposure on-farm as well as to consumers further down the commodity supply chain), trade and the environment. Such mitigation aligns with best practice chemical application. For example, achieving an appropriate spray quality and maintaining an awareness of the suitability of weather conditions throughout spraying operations (as required by spray drift restraints on certain labels) will manage spray drift risk to non-target crops and the environment. Such practices will also maximise deposition on the target, the cost-efficiency of application and crop protection efficacy.

Chemical use risk management provides a degree of protection to the cotton industry. Management of residue risk contributes to the maintenance of international market access. The minimisation of environmental impacts is important, not only to facilitate biodiversity and ecosystem health in local catchments, but also to support the cotton industry's broader efforts to reduce their environmental footprint. A secondary benefit of regulatory risk management is demonstration of one aspect of social license to farm, increasingly demanded by supply chain stakeholders.

Licensing, training and record-keeping

The commercial application of agricultural chemicals, with aerial or ground distribution equipment, will often require licensing of both the applicator and the contractor business (check with the agricultural chemical licensing agency in your state or territory). The use of remotely piloted aircraft (drones) for chemical distribution is generally regarded as aerial distribution, with respect to licensing requirements and compliance with label instructions.

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

Over recent years there has been considerable progress in national agvet chemical policy, which seeks to harmonise major aspects of control-of-use legislation, across states and territories. National agreement has been reached, concerning certain minimum training and record-keeping requirements, however the extent to which implementation of such reforms has progressed in any particular jurisdiction should be established in that state or territory.

Training requirements can also pertain to the use of certain hazardous chemicals. For the majority of cotton growers, the relevant chemicals will be those which contain Schedule 7 poisons, such as paraquat, MSMA and methomyl. 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). Any training believed to be equivalent will generally be considered. For example, competency units superseded by, but deemed equivalent to, the currently prescribed units.

Record-keeping obligations may include when a record should be made and a period of time for which records should be kept. The particulars required in each jurisdiction will vary slightly but are largely aligned with best practice spray record-keeping, i.e. that which is relevant in meeting cotton production objectives, as well as managing risk and providing evidence that label conditions have been met. Some of the parameters that need to be recorded include the time, date, location and crop as well as those which identify the agricultural chemical used, the rate of application, equipment and settings, and contact details of the applicator and the contractor business (if relevant). Meteorological conditions, such as wind speed and direction, should be monitored and documented throughout spraying operations, noting that the labels of certain agricultural chemicals also stipulate record-keeping particulars under their spray drift restraints.

An example record keeping sheet (developed by NSW DPI) has been provided on the following page. Some commercial farm management software and apps include the ability to record spray details.

Further information on relevant State regulations and training requirements:

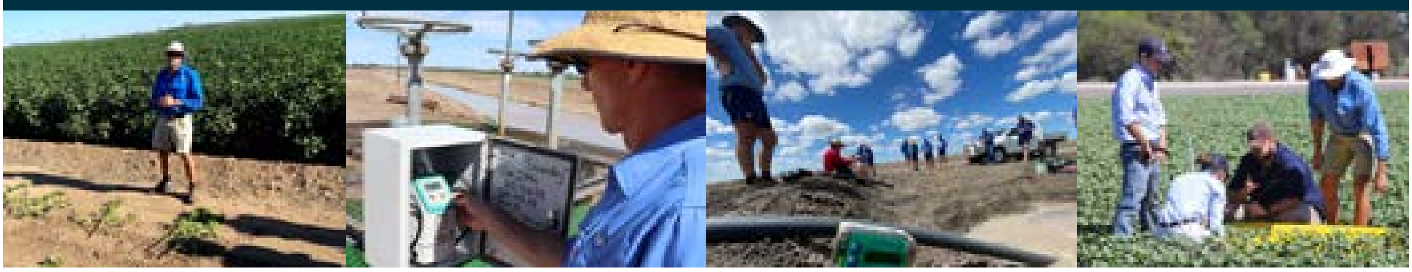
NSW: www.dpi.nsw.gov.au/agriculture/chemicals and www.epa.nsw.gov.au/your-environment/pesticides

QLD: www.business.qld.gov.au/industries/farms-fishing-forestry/agriculture/land-management/chemical-controls

WA: www.agric.wa.gov.au/pests-weeds-diseases/control-methods/chemicals and ww2.health.wa.gov.au/Articles/N_R/Pest-industry-licensing-and-registration

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

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



Pesticide Application Record Sheet

NSW GOVERNMENT | Industry & Investment

Location, Applicator, Date of Application

Property/Holding: (residential address)					Date:
Applicator's Full Name:			Owner (if not applicator):		
Address:			Address:		
		Phone:			Phone:
Mobile:	Fax:	Email:	Mobile:	Fax:	Email:
Sensitive Areas (including distances, buffers): N W Treated Area E S			Comments (including risk control measures for sensitive areas):		

Host/Pest

Paddock Number/Name:	Paddock Area:	Order of Paddocks Sprayed:

Crop/Situation:	Type of Animals:
Crop/Pasture Variety:	Age/Growth Stage:
Growth Stage:	Mob/Paddock/Shed:
Pest/Disease/Weed:	Animals — Number Treated:
	Pest Density/Incidence: Heavy ❑ Medium ❑ Light ❑

Application Data

Full Label Product Name:			Rate/Dose:	Water Rate L/ha:
Permit No.:	Expiry Date:		Additives/Wetters:	
Total L or kg:	WHP:	ESI*:	Date Suitable for Sale:	
Equipment Type:		Nozzle Type:	Nozzle Angle:	Pressure:
Date Last Calibrated:	Water Quality (pH or description):			

Weather

Showers ❑ Overcast ❑ Light Cloud ❑ Clear Sky ❑

Rainfall (24 hours before and after)
Before: mm During: mm After: mm

Time (show time in this column)	Temperature °C	Relative Humidity (%)	Wind Speed	Direction	Variability (e.g. gusting)
Start					
Finish					

Comments:

* When using herbicides in mixtures with fungicides and insecticides, an ESI may apply to the non-herbicide component of the mixture.

Using pesticides safely

Post-spray periods

Pesticide and other agrochemical labels will usually specify a minimum amount of time after application before:

- The treated field can be safely re-entered by unprotected persons (re-entry period); and,
- The crop can be harvested, or grazed/cut for domestic stock fodder (withholding period).

Always check the label of each product in the tank mix for these periods before use. Note they are subject to change and may be different according to concentration or formulation, even if the products have the same active ingredient.

Non-compliance with current label restrictions may result in prosecution under relevant state or territory legislation.

Re-entry period

Re-entry periods and any specific personal protective equipment (PPE) to be worn provide a guide to the risk associated with dermal (skin) contact with spray deposits. Consider re-entry periods (see Table 31) when developing workplace health and safety procedures and protocols. More information on WH&S is available in the *Australian Cotton Production Manual*.

All workers must be advised of the appropriate time to wait before re-entering a sprayed field. It is particularly important to observe the re-entry period when contact between foliage and skin is likely. 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 (a notable exception is profentofos, which has a re-entry period of 34 days); if no re-entry period is listed, wait until after the spray has dried before entering the field.

If the field needs to be entered prior to the stated re-entry period or before the spray is dry, limit the duration of entry and wear the PPE specified on the label. Even after the re-entry period has been observed, some protective clothing may be advisable. If not specified, appropriate PPE should be determined using a risk assessment.

Withholding period

A withholding period (WHP) is the minimum period from when a pesticide is applied to when the treated area is allowed to be grazed, cut for fodder or harvested (see Table 31). The WHP aims to prevent the presence of inappropriate levels of chemical residues in the harvested crop or in stock that graze the stubble or are fed by-products of the treated crop.

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 & storage

A critical part of responsible use of pesticides is their safe storage, transport and handling, as well as appropriate disposal of product that is no longer wanted or able to be used. Storing, handling and applying pesticides correctly greatly reduces any potential negative impacts to you, your staff, your business, your neighbours and the environment.

Many registered pesticides are classified as hazardous chemicals, or pose some degree of health risk to those who use them or are exposed to them. Workplace health and safety regulations exist to protect workers from both short and long term health effects of exposure to hazardous chemicals. *my*BMP provides guidance and resources to meet legal requirements for handling, storage and application of agrochemicals. It also includes templates to help document farm-specific procedures to minimise harm and respond in the event of an injury, fire, or spill. These procedures must be communicated to all staff.

Ensure anyone handling or applying pesticides has the appropriate training/accreditations, and maintain a collection of easily accessible copies of Safety Data Sheets (SDS) for all products used.

Safe disposal

Disposing of empty containers

Empty chemical containers present a risk to people and the environment. Clean empty containers according to the steps below and store securely until they can be recycled.

- Triple rinse or pressure rinse your containers immediately after use (residues are more difficult to remove when dry). Pour the rinse water back into the spray tank.
- Thoroughly clean the container thread and outside surfaces with a hose into the spray tank. Rinse all caps separately in a bucket of clean water, and pour the rinsate from the caps into the spray tank.
- Inspect the container, particularly the thread and screw neck to ensure all chemical residues have been removed.
- Use a steel rod or crowbar to puncture metal containers. Pass it through the neck/pouring opening and out the base of the container.
- Allow the containers to drain completely and air dry.
- Store capless cleaned containers in a sheltered place to keep them clean and dry until they can be delivered to a *drumMUSTER* collection centre.

Take empty containers marked 'returnable' back to the supplier. Many 'non-returnable' metal and plastic containers used for farm chemicals can be recycled via Agsafe's national drumMUSTER program (look for the logo on the container). Containers presented at a drumMUSTER receival site will be inspected to ensure that there is no visible product residue (including powder, flake, coloured/dark or clear fluid) on the inside or outside of the container. Some stains (including dirt, dust or mould) are acceptable.

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

Disposing of unwanted chemicals

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

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

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

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

Further information:

Agsafe Limited 02 6206 6888 www.agsafe.org.au

***drumMUSTER* program 1800 008 707 www.drummuster.org.au or contact your local representative (www.drummuster.org.au/our-people/your-local-regional-consultant)**

ChemClear program 1800 008 182 www.chemclear.org.au

TABLE 31: Re-entry and withholding periods of commonly used pesticides (excluding herbicides and seed treatments).

	Active	MoA group	Re-entry	Withholding (days)*	
				Harvest	Stock
Insecticides and miticides	Abamectin	6A	dry	20	20
	Acetamiprid	4A	dry	10	NG
	Afidopyropen	9D	dry	7	—
	Alpha-cypermethrin	3A	24 hrs	14	—
	Amitraz	19	dry	21	—
	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
	Chlorantraniliprole/ Thiamethoxam	28/4A	dry	28	NG
	Chlorfenapyr	13	12 hrs	28	NG
	Chlorpyrifos	1B	dry	28	28
	Chlorpyrifos/ bifenthrin	1B/3A	dry	28	NG
	Chlorpyrifos-methyl	1B	24 hrs	28	NG
	Clitoria ternatea extract	—	dry	0	—
	Clothianidin	4A	—	5	NG
	Cyantraniliprole	28	dry	14	NG
	Cypermethrin	3A	12 hrs	14	—
	Deltamethrin	3A	dry	7	NG
	Diafenthiuron	12A	24 hrs	14	NG
	Dimethoate	1B	dry	14	NG
	Dinotefuran	4A	dry	14	NG
	Emamectin benzoate	6A	12 hrs	28	NG
	Esfenvalerate	3A	dry	7	—
	Etoxazole	10B	dry	21	NG
	Fipronil	2B	dry	28	NG
	Gamma-cyhalothrin	3A	dry	21	—
	Helicoverpa NPV	—	dry	0	0
	Imidacloprid	4A	12 hrs	91	NG
	Indoxacarb	22	dry	28	NG
	Lambda-cyhalothrin	3A	dry	21	—
	Magnet®	—	24 hrs	See insecticide mix	
	Methidathion	1B	48 hrs	3	—
	Methomyl	1A	24 hrs	0	NG
	Paraffinic oil	—	—	1	—
	Pirimicarb	1A	dry	21	21
	Phorate	1B	48 hrs	70	70
	Profenofos	1B	34 days	28	—
	Propargite	12C	dry	28	NG
	Pymetrozine	9B	dry	28	NG
	Pyriproxyfen	7C	24 hrs	28	NG
	Quintozene	14	dry	N/A	NG
	Spinetoram	5	dry	28	NG
	Spirotetramat	23	dry	21	NG
	Sulfoxaflor	4C	dry	14	NG
	Thiamethoxam	4A	dry	28	NG
	Thiodicarb	1A	24 hrs	21	21

	Active	MoA group	Re-entry	Withholding (days)*	
				Harvest	Stock
Fungicides	*Clitoria ternatea* extract	—	dry	0	—
	Mancozeb (including PERMIT)	M3	dry	14-42	NG
	Quintozene	14	dry	N/A	NG
	Prothiconazole/ Bixafen (PERMIT)	3/7	dry	35	NG
	Tebuconazole (PERMIT)	3	dry	42	NG
	Tolclofos-methyl	14	dry	N/A	N/A
Other (including aids & adjuvants)	Carfentrazone-ethyl	desiccant (G)	dry	1	NG
	Diquat	desiccant (L)	dry	N/A	1 day
	Ethephon	conditioner	4 hrs	14	NG
	Ethephon + AMADS	conditioner	—	1	NG
	Mepiquat	PGR	dry	28	NG
	Paraffinic oil & other non-ionic surfactants	adjuvant	—	1	—
	Paraquat + diquat	desiccant (L)	dry	7	1-7
	Petroleum oil	adjuvant	—	1	—
	Pyraflufen-ethyl	defoliant (G)	dry	7	7
	Sodium chlorate	desiccant	dry	0	NG
	Thidiazuron	defoliant	dry	N/A	NG
	Thidiazuron + diuron	defoliant (- + C)	—	N/A	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.
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.

Cotton growth regulators and harvest aids

The application of growth regulators and harvest aids to the crop utilises the same spray equipment as pesticides, and follows the same principles of product registration, safety and application efficiency (including minimising drift risk).

Plant growth regulators

Excessive vegetative growth can result in poor within-canopy light interception, reducing fruit retention 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), resulting in less expansion of developing plant cells. 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 parts of the plant (elongating stems, leaves and roots).

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

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

For more information refer to Chapter 17 of the *Australian Cotton Production Manual*. For cotton production in the tropics, NORpak Burdekin has detailed mepiquat chloride usage guidelines for wet season production.

Harvest aids

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

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

Both the process of crop senescence 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 defoliate (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 (such as caused by frost or herbicide) usually kills the leaf blade before the leaf drops, which can result in dead leaves remaining in the canopy.

Boll opening is a largely mechanical process of dehydration of the boll wall, causing the boll to split open and unfurl. Leaf removal exposes bolls to more direct sunlight, promoting increased temperatures for 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.

Desiccants dry all plant parts (including stems), potentially increasing the trash content of harvested lint. Avoid them unless conditions do not enable the effective use of defoliants (e.g. very cold weather). Desiccants are also a reliable method to reduce leaf regrowth. High rates of some defoliants can act as desiccants.

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 issues. If product rates are too high, the plant material may die before releasing enough ethylene to cause defoliation, resulting instead in leaf desiccation (leaf death).

Temperature plays a critical role (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. Aim to 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 on defoliation refer to Chapter 20 of the *Australian Cotton Production Manual.*

Registration of a chemical is not a recommendation for the use of a specific chemical in a particular situation. Satisfy yourself that the chemical you choose is the best one for the crop and situation. Carefully study the container label before use and note any specific instructions relating to the rate, timing, application and safety. Take every precaution to minimise the risk of causing or suffering spray drift damage

More information is available in a CottonInfo factsheet on defoliation www.cottoninfo.com.au/blog/defoliation-what-do-consultants-say

The Burdekin and Wet Tropics NORpak is available from CRDC's Inside Cotton archive www.insidecotton.com

APVMA's PubCRIS database can be searched for current registrations and permits. https://portal.apvma.gov.au/pubcris

CottonInfo videos:
What is pix? https://youtu.be/clFpyymWW6Q
Using harvest aids in cotton https://youtu.be/8st4yggcCNY

Pesticides and the environment

The cotton industry's guidelines for minimising risk to the environment are a component of the *my*BMP program.

Most insecticides are toxic to aquatic organisms, bees, birds and other fauna. Fungicides and herbicides are relatively safe to bees in terms of their active ingredients, but their carriers and surfactants may be toxic. The risk that a particular product poses to the environment (native terrestrial and aquatic plants and animals) are reflected in statements on the label under headings like 'Protecting wildlife, fish, crustaceans and the environment'.

Pesticide residues may accumulate in animals treated with any pesticides or fed any crop product, including crop residues, which have been sprayed with pesticides. Animals that test positive for chemical residues (i.e. with readings which exceed maximum residue limits) at slaughter will be rejected.

Pesticide residues may also contaminate other plant products for human use and consumption. Observe harvest withholding periods on the pesticide label and do not assume that in the absence of a withholding period or after the expiry of a withholding period that plant products will be free of residues.

Significant off-target environmental damage can be reported to the APVMA for investigation at https://apvma.gov.au/node/86336

Australian cotton industry sustainability reporting: Draft pesticide target

The Australian cotton industry has set a draft target to reduce the environmental impact of pesticides by five per cent, every five years. Environmental toxic load (ETL) is the indicator used to assess the average amount of toxic pressure on human health and the environment from pesticides applied on one hectare. The target is based on the ETL bees for insecticide hazard, and the ETL algae for herbicide hazard. To reduce your ETL, aim to both reduce total volume of pesticides used, as well as selecting pesticides with lower toxicity. For more information refer to www.crdc.com.au/growers/sustainability

Highly hazardous pesticide

Highly Hazardous Pesticides (HHPs) are pesticides that are acknowledged to present particularly high levels of acute or chronic hazards to health or environment according to internationally accepted classification systems. Reducing reliance on HHPs is a goal and industry is working with the Better Cotton Initiative (BCI) to develop a strategy for phasing out use in Australian production systems.

Protecting the aquatic environment

Aquatic fauna and flora

Aquatic fauna and flora are often highly sensitive to agrochemicals, as are many other species that utilise aquatic areas as part of their habitat. When spraying, always consider the risk of contaminating nearby standing water.

- Prevent drift onto surface waters during application;
- Locate mixing/loading and decontamination facilities well away and use bunding and sumps to prevent movement of either concentrate or rinsate into surface waters;
- Install valves that prevent back-flow in equipment used to fill spray tanks from surface waters and in suction lines for chemigation systems that draw directly from surface waters;
- Avoid aerial application of spray on fields during irrigation;
- Build sufficient on-farm storage capacity (including provision for storm runoff) to contain pesticide-contaminated tail water from irrigation;
- Spray in an upstream direction (when spraying near water is necessary), to reduce the maximum concentration at any one point in the watercourse;
- Use only registered products to control aquatic weeds, e.g. Roundup Bioactive® rather than Roundup®; and,
- 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.

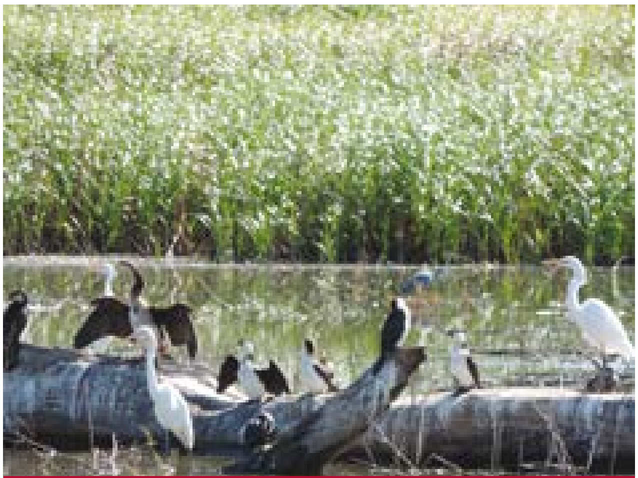
- Ensure complete incorporation beneath the soil, particularly at row ends where spillage may occur; and,
- Immediately clean up spillage, however small.

Bait materials for control of rodents (not registered in cotton, but relevant to rotation crops) or soil insect pests can also be hazardous to birds, 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; and,
- 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.

Whistling ducks. (Anne Palfreyman)



Protect aquatic environments from pesticides; many aquatic birds such as egrets contribute towards natural pest control. (Stacey Vogel, CottonInfo)

- 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; and,
- Actively discourage birds from feeding in crops that are to be sprayed.

Pesticides can also indirectly impact on bird populations through the loss of plants and animals on which they feed and through loss of habitat.

- Protect sensitive areas such as remnant vegetation, riparian areas and waterways from spray drift;
- Where possible use target-specific as opposed to broad-spectrum pesticides (that are more likely to impact on non-target organisms and plants in the environment) and adopt an Integrated Pest Management (IPM) approach to controlling pests;
- Spray late in the day when birds have finished feeding; and,
- Use only low toxicity chemicals when large concentrations of birds are nesting nearby.

Other fauna

Sodium fluoroacetate (1080) baiting has been an essential tool for protecting and recovering threatened species, especially mammals threatened by foxes. There are non-target risks associated with almost every poison, including 1080. However based on years of scientific research the APVMA concluded that although individual poisoning of non-target animals can occur this does not adversely affect the overall population of non-target wildlife. For more information on the impacts of 1080 baits on wildlife visit the PestSmart website https://pestsmart.org.au/domestic-animal-safety/the-facts-of-1080-baiting/

- Tie or bury baits where applicable to limit removal by non-target species;
- 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,
- Regularly check and replace baits to reduce excess baiting and to be more effective.

Top arrow – vegetative barrier.
Bottom arrow – remnant vegetation.

Soil health

Pesticides can have undesirable side-effects on soil biota. The impacts are highly variable, influenced by the ingredients and application rate of the product(s), the application method, soil conditions (including temperature, moisture, and organic matter), the speed of chemical degradation, and the extent of leaching from the site. Generally, herbicides are less toxic than insecticides, with fungicides most likely to cause harm to soil biota.

A relatively easy way to check your soil's biological health is the 'Soil your Undies' challenge. Watch the CottonInfo video series explaining how at www.youtube.com/CottonInfoAust

A Soil Sustainability Framework, including management aspects to promote soil health, is currently under development.

Remnant native vegetation

Remnant native vegetation, i.e. any native patches of trees, shrubs or grasses that still remain in the landscape, can be damaged by herbicide and defoliant poisoning either via leaching through the soil or absorption through the leaves.

- Prevent drift by implementing best practices for spray application;
- Install natural or artificial barriers to intercept spray drift;
- Adhere to product label no-spray zone instructions;
- Select target-specific herbicides;
- Select non-soil active herbicides when remnant vegetation is nearby; and,
- Use an Integrated Weed Management (IWM) approach when managing environmental weeds.

The best way to manage any long term adverse environmental risk is to follow the protection statements on labels, minimise spray drift, and to dispose of chemical containers and waste in accordance with label directions and codes of practice.

Cotton Landcare Innovations project

Under the National Landcare Program's Smart Farming Partnerships initiative, CRDC secured a $1.3 million grant to bring Cotton Landcare Tech-Innovations 2021 onto Australian cotton farms to enhance natural resources and biodiversity.

The project consists of four key activities: biodiversity, innovation, technology, and collaboration, and builds on international best practice to implement and develop cutting-edge technologies, such as drone mapping and aerial seeding, acoustic monitoring and big data, to help Australian cotton better report on and improve on-farm biodiversity.

For more information, visit www.crdc.com.au/cotton-landcare-tech-innovations

Protecting pollinators

Although cotton is commonly regarded as being largely self-fertile and self-pollinating, bees provide an important service to agriculture generally. Native stingless bees are resistant to diseases and parasites common in honeybees (including varroa mite) and therefore provide an 'insurance policy' for pollination. 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 cotton IRMS highlights insecticides with a label warning about bee safety. The relative toxicity of cotton insecticides to honeybees is listed in Table 4 on pages 14-15.

The residual toxicity (the amount of time the product remains toxic to bees after the time of application), should also be considered. Many insecticides are safe to bees once the spray deposits have dried on the crop. The label provides information about what action must be taken to avoid impacting bees (note label recommendations may vary between different formulations containing the same active ingredient). Refer to the APVMA PubCRIS database to search for information about individual insecticides (https://portal.apvma.gov.au/pubcris).
ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS.

Bee ecology

Honeybee field activity is temperature and food-related. The bees become more active above 12-13°C with most foraging activity occurring between 19-30°C. With water gatherers, the main flight activity occurs when temperatures are above the mid-thirties. Honeybees usually forage within 2-4 km of their hive, although they will fly long distances (7-10 km) in search of good food.

Native bee species often have much shorter flight ranges; as little as 500 m for some of the smaller species.

Bees collect nectar from extra-floral nectaries (e.g. under leaves) as well as from cotton flowers so they may be foraging in cotton crops before, during and after flowering. They may also visit weeds in flower in and around fields. Damage can also occur to bees if pesticides drift over hives, water surfaces or neighbouring vegetation being foraged by bees.

Coolibah trees (*Eucalyptus microtheca*), black box (*E. largiflorens*) and river red gums (*E. camaldulensis*) are a primary source of nectar and pollen for honeybees. These trees grow on the black soil plains along many of the river courses in cotton growing areas, and flower in response to good spring rains. In northern NSW trees begin to flower mid to late December, finishing about the end of January. Flowering times may vary by a few weeks in the southern and central areas of Queensland. When heavy flowering is expected, beekeepers may move large numbers of hives into these regions.

Cotton can be a high-risk environment for bees. (Susan Maas, CRDC)

Protect bees when using fipronil

While bees are susceptible to many insecticides used on cotton, fipronil risk to managed hives has been highlighted due to the extended residue risk. The industry IRMS recommends *fipronil should not be applied to flowering crops.* Refer to label for statement about bees.

Example of fipronil label statement:

"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 to move hives to a safe location with an untreated source of nectar, if there is any potential for managed bees to be affected by the spray or spray drift. 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."

Reducing the risk

- Follow the registered label directions.
- Register on BeeConnected (see details below).
- If beehives are in the vicinity of crops, notify apiarists at least 48 hours before spraying, to allow time for removal of the hives.
- Inform contract pesticide applicators of apiary locations.
- Pay particular attention to wind speed and direction, air temperature and time of day before applying pesticides.
- Use buffer zones to reduce the impact of spray drift or overspray on non-target crops and native vegetation.
- Avoid contamination of surface waters where bees may drink.
- Use an IPM framework to minimise the need for pesticides.
- Favour pesticides that have lower toxicity to bees and other beneficial insects (see Table 4).
- 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 good will, 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.

BeeConnected app

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 go to: http://beeconnected.org.au

Other information sources

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. More information is available at www.croplife.org.au/resources/programs/seed-treatment-stewardship-strategy

BeeAware

BeeAware is a hub of information for beekeepers and growers about honeybee biosecurity and pollination of agricultural and horticultural crops. The site contains information about the pollination of crops and how beekeepers and growers can work together to provide and receive best practice pollination services.

BeeAware was funded by the Australian honeybee industry, pollinator-reliant plant industries, Plant Health Australia, governments and R&D agencies (https://beeaware.org.au/).

Native bees

More detailed Information on native beekeeping is available from the Australian Native Bee Association website www.anba.org.au or in the Australian Native Bee Book. https://nativebeebook.com.au/

Australian cotton industry sustainability reporting: Bees

It is important that the industry continues to practice IPM, and where possible avoid use of products that are highly toxic to bees such as fipronil, neonicotinoids (e.g. clothianidin), abamectin, chlorpyrifos and bifenthrin. The industry's voluntary IRMS includes a specific recommendation to avoid applying fipronil to flowering crops.

CottonInfo video on bees in cotton: https://youtu.be/LBRUaqZaVoQ

For further information or to notify the owner of beehives not logged in BeeConnected, note the registration number or brand and contact your state agricultural department or apiarist/beekeeping association:

New South Wales
NSW DPI Biosecurity Helpline 1800 680 244
NSW Apiarists' Association
www.nswaa.com.au – E: info@nswaa.com.au
Apiaries on public land in NSW are displayed on the BPASS map (https://bpass.dpi.nsw.gov.au/s/view-sites-public)

Queensland
Biosecurity Queensland 13 25 23
Queensland Beekeepers' Association
www.qbabees.org.au – E: statesecretary@qbabees.org.au

Western Australia
DPIRD Apiary and biosecurity officers
E: PBHoney@dpird.wa.gov.au
Bee Industry Council of Western Australia
www.bicwa.com.au – E: info@bicwa.com.au

Northern Territory
Plant Biosecurity Branch (08) 8999 2118

Victoria
Agriculture Victoria 136 186
E: honeybee.biosecurity@agriculture.vic.gov.au
Victorian Apiarists' Association
www.vicbeekeepers.com.au – E: vaa@vicbeekeepers.com.au
Licensed apiary sites in Victoria can be identified in the Department of Land Water and Planning – Mapshare system (https://mapshare.vic.gov.au/MapShareVic)


COTTON AUSTRALIA
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Celebrating 50 years of serving our industry to become successful and effective.
Thank you to all growers who have contributed to Cotton Australia over its history.
It is for you that we do what we do.
Follow our journey today

Glossary & acronyms

ACPM. *Australian Cotton Production Manual* (available from CottonInfo).

Action threshold. See threshold.

Adjuvant. A substance (e.g. wetting agent, sticker, thickener, buffering agent) added to a spray mixture to enhance performance or overcome an inhibiting factor.

AMF (formerly VAM). Arbuscular mycorrhizal fungi symbiotically colonise plant roots, transferring extra nutrients, especially phosphorus, from the soil in exchange for photosynthates from the plant.

Aphid colony. Four or more aphids within 2 cm^2 on a leaf or terminal.

APVMA. Agricultural Pesticides and Veterinary Medicines Authority.

Area wide management (AWM). Growers working together in a region to manage pest populations.

At-planting insecticide. Insecticides applied as a granule or spray in the seed furrow with the seed during planting.

BCI. Better Cotton Initiative.

Beat sheet. Large sheet of yellow or white canvas, placed in the furrow and extended over the adjacent row. Plants are beaten against the sheet with a stick, dislodging insects which are quickly counted.

Beneficials. Biological agents that are beneficial to the crop, including natural enemies and pollinators.

Beneficial to pest ratio. Ratio used to incorporate predatory insect activity into pest management decisions.

Biological insecticides. Insecticides based on or derived from living organisms (e.g. NPV or Bt).

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. Toxin derived from *Bacillus thuringiensis* that is toxic to many caterpillar species.

Buffer zone. An area where pesticide application does not occur between the application site and an identified sensitive area which is downwind from the application site. 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.

Come Clean. Go Clean. Industry slogan promoting thorough cleaning to prevent transfer of pests between fields and farms.

Conditioner. Product used to hasten boll opening.

Consecutive checks. Successive insect checks taken from the same field or management unit.

Conventional cotton. Cotton varieties that are not genetically modified (in this guide the term is usually used to indicate absence of genes that produce Bt-derived insecticidal proteins).

Cotton bunchy top (CBT). Cotton virus vectored by aphids.

Crop compensation. Plant's capacity to 'catch-up' after insect damage without affecting yield or maturity.

Cut-out. Assimilate (photosynthesis products) demand exceeds supply and no more harvestable fruit is set.

Damage threshold. Level of damage leading to economic loss of yield or delay in maturity. Usually used in conjunction with pest thresholds to account for both pest numbers and plant growth. See also 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.

Defoliation. Leaf removal in preparation for harvest by artificially enhancing the natural process of senescence and abscission.

Desiccant. Harvest aid chemical that damages the leaf membrane, causing moisture loss and dessication.

Diapause. Period of physiologically controlled dormancy in insects (e.g. at the pupal stage in the soil for *Helicoverpa armigera*).

Double knock. Sequential application of two pesticides with different modes of action in a short timeframe.

DST. Decision support tool used with consecutive silverleaf whitefly sampling to consider management options based on population pathways.

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.

***Eretmocerus*.** 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.

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.

GVB. Green vegetable bug.

Herbicide Resistance Management Strategy (HRMS). Voluntary industry strategy designed to delay herbicide resistance.

Honeydew. Sticky sugar-rich waste excreted by sap-sucking insects that can interfere with photosynthesis, promote sooty mould, affect lint quality and cause problems with fibre processing.

In-furrow insecticide. See at-planting insecticide.

Insect growth regulator (IGR). Compound that influences insect growth and development.

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.

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.

Mode of action (MoA). Pesticide classification scheme based on target site that aims to prevent the development of cross-resistance to related pesticide compounds.

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).

No-spray zone. Mandatory unsprayed distance between sprayed and downwind sensitive areas. See also buffer zone.

NPV (nucleopolyhedrovirus). An entomopathogenic virus. Commercial formulations targeting *Helicoverpa* are available in Australia.

Nursery. Crop or natural habitat that attracts and sustains pests or beneficials through multiple generations.

Nymph. Immature insect stage that looks like the adult but without wings (e.g. bugs, thrips, mites). Nymphs go through a series of moults and do not pass a pupal stage.

Organophosphates (OPs). Broad-spectrum insecticides classified into MoA Group 1B.

OTT. 'Over the top' of the crop application of herbicides.

PAMP. Pesticide application management plan.

Parasitoid. Insect that lays its eggs on or in another arthropod; the larva develops within the host, killing it on emergence.

Pathogen. Microorganism that causes disease (e.g. Fusarium wilt is the disease caused by a soil-inhabiting fungus *Fusarium oxysporum* f.sp. *vasinfectum* (Fov)).

Peak flowering. Period where the plant has the highest numbers of flowers opening per day.

Pest flaring. Increase in a pest population (usually in species with very fast life cycles) following a pesticide application targeted at another species.

Pest resurgence. Increase in a targeted pest population following a pesticide application. Usually due to a reduction in beneficial populations.

Pest threshold. Pest population at which a control measure is needed to prevent eventual economic loss to the crop. See also threshold and damage threshold.

Pix. See mepiquat chloride.

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 knockdown herbicide. Herbicide used to rapidly control weeds after they emerge.

PPE. Personal protective equipment.

Pre-plant knockdown herbicide. Herbicide used to rapidly control weeds prior to planting.

Presence/absence. Noting presence/absence of a numerous pest rather than counting absolute numbers.

Prophylactic sprays. Insecticides applied in anticipation of a potential pest problem (rather than in response to a threshold). These 'insurance' sprays are usually not recommended due to increased costs, selection for insecticide resistance, and the risk of secondary pest outbreaks.

PSO (petroleum spray oil). Petroleum-derived oil used to control insect pests. Can also be used to deter egg lay of some pests.

PubCRIS (Public Chemicals Registration Information System). APVMA's searchable database of agrochemcials registered for use in Australia including products with off-label permits (https://portal.apvma.gov.au/pubcris).

Pupa. Stage where larva undergoes transformation into an adult (e.g. from caterpillar to moth).

Pupae busting. Tillage to reduce the survival of overwintering pupae.

Rank growth. Excessive vegetative growth; usually managed using mepiquat chloride.

Ratoon cotton. Regrowth from the previous season's rootstock.

Re-entry period. Mandatory period between chemical application and re-entry to the treated area.

Refuge. Area left untreated with an insecticide or technology that generates unexposed susceptible individuals to act as a dilution factor when mating with resistant adults.

Resistance. When individual pests 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 developing. Complicance to the Bollgard 3 RMP is required under the Bt cotton Technology User Agreement.

Retention. See fruit retention.

Rotation crops. Other crop types grown before or after the cotton crop.

Scouting. Checking crops (for insects, damage, weeds, growth etc). Often refers to the gathering of data only; interpretation and management recommendations are provided by crop agronomists/consultants.

Secondary pests. Pests that do not usually become a problem unless their natural enemies (predators or parasitoids) are reduced in number by insecticides. See also pest flaring.

Seed treatment. Insecticide/fungicide coating on cotton seeds that offers protection during germination and establishment.

Selection pressure. Pesticide sprays remove susceptible individuals. More selection events from a particular chemical group leads to greater 'pressure' or chance of selecting a resistant population.

Shedding. Abortion/loss of reproductive structures (squares, flowers or bolls) caused by environmental factors or pest damage.

Siphunculi. Pair of wax-secreting tubular organs on the abdomen of aphids (also called cornicles).

SLW. Silverleaf whitefly.

'Soft' approach. Managing insect and mite pests using options that have minimal impact on beneficial populations.

Square. Cotton flower bud.

Stacked genes. Two or more genes that express similar activity (e.g. in Bollgard 3 there are three genes Cry1Ac, Cry2Ab and Vip3a), or different activities in the same variety (e.g. Bollgard + Roundup Ready®).

Sucking pests. Bugs with piercing mouthparts (e.g. mirids, aphids, whitefly).

Sweep net. Large cloth net with long handle used to sample insects in the upper canopy.

Synthetic insecticides. Non-biological insecticides (artificial versions of natural insecticides or synthetic molecules with insecticidal/miticidal activity).

Systemic pesticide. Pesticide that is taken up through plant tissue (as opposed to remaining on the surface) and transported through the plant's vascular system.

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. See also pest threshold and damage threshold.

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.

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.

Withholding period. Minimum period allowed between application of an agrochemical and crop harvest (or use for stockfeed).

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