



Cotton Pest Management Guide 2019–20



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

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Cover photos courtesy Melanie Jenson and Johnelle Rogan.



Foreword

Susan Maas and Ruth Redfern, CRDC and CottonInfo

Welcome to the 2019–20 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 2019–20, CRDC will invest \$20.2 million into RD&E projects on behalf of growers and the Government, in collaboration with around 100 research partners.

CottonInfo is an initiative of CRDC, along with industry partners 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 practice program, *myBMP*, supported by Cotton Australia and CRDC, which sets the industry's best practice performance criteria and provides a framework by which growers can participate in, and be accredited in, best practice.

We hope you find this year's Cotton Pest Management Guide a valuable and informative reference.

This year, we have again partnered with our fellow key industry organisation, Crop Consultants Australia (CCA), on the development of this Guide. This partnership sees the continuation of the Technical Review Panel to review the Guide, provide technical expertise, and to ensure it remains as useful as possible for both growers and consultants.

As a result, you will continue to see some changes in this year's Guide, including more information about spray application, 2,4-D application regulations, and updated product registrations relevant to the cotton industry.

This Guide, along with its sister publication, the Australian Cotton Production Manual, are two of the key ways that CRDC and CottonInfo get the latest in cotton industry RD&E out to the industry each year.

The Australian Cotton Production Manual contains additional information on spray application and integrated pest, weed and disease management and is available to download from the CottonInfo and CRDC websites (www.cottoninfo.com.au/publications or www.crdc.com.au/publications).

Remember, the CottonInfo team of regional extension officers, technical leads and *myBMP* 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 *myBMP* website (www.mybmp.com.au). And you can find information about all of CRDC's investments online at the CRDC website (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. Our particular thanks to CCA Executive Officer Fiona Anderson, CCA project lead Vivienne McCollum, and the CCA Technical Review Panel members Bill Back, Elle Storrer, Sam Simons and Peter White for their input and guidance.

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Impact of insecticides and miticides on beneficials and bees

Susan Maas, CRDC

Successful pest management aims to keep pest populations to levels that do not cause economic damage, to maintain profitability year after year and to preserve a healthy environment.

Integrated Pest Management (IPM) is a concept developed in response to problems with managing pests, insecticide resistance and environmental contamination. The basic concept of IPM is to use knowledge of pest biology, behaviour and ecology to implement a range of tactics throughout the year in an integrated way that suppresses and reduces their populations. This systems approach considers tactics to suppress or avoid pests across the farm and surrounding areas, and tactics to manage pest and beneficial insect populations in the crop, including the responsible use of insecticides. Table 1 outlines seasonal activity for an IPM program.

Because all pests have other animals that eat them, such as predators or parasites (known as beneficials or natural enemies), building and conserving populations of beneficials is at the heart of IPM. To conserve natural enemies, a pest management decision needs to be well informed, supported by good sampling, valid control thresholds and knowledge of the beneficials present and their activity.

For more information on IPM refer to page 49.

Choose insecticides wisely to conserve beneficials

IPM strategies aim to balance the contribution of beneficials with the need to protect the crop from significant loss. Where insecticide control is warranted (based on industry recommended monitoring and threshold pages 12-48), selection should be based on:

- How effective they are on the pest (to ensure adequate control).
- Their risk (selectivity) to the beneficial population and to bees (to conserve beneficials) (refer Tables 2 and 3 page 8-11).
- Allowable usage with regard to the Insecticide Resistance Management Strategy (IRMS) (to manage resistance) pages 61-64).

Consideration should also be given to rate, application technique and other products (e.g. adjuvants that help plant up take or efficacy against pest or other actives that can either improve or hinder efficacy) used in tank mix so as to maximise effectiveness against pest while minimising impact on beneficials.

Some insecticides are very selective and have very little impact on beneficial insects (often referred to as 'soft') while others are highly disruptive to beneficial populations ('broadpectrum' or 'hard'). The relative selectivity of all insecticides available for use in cotton can be found in Table 2 (Impact of insecticides at planting or as seed treatments on key beneficial groups in cotton) page 8 and Table 3 (Impact of insecticides and

miticides on predators, parasitoids and bees in cotton) pages 10-11. The selectivity of the insecticide helps to assess the risk that if, following its use, populations of other pests may 'flare' (increase rapidly). The table has largely been developed based on industry funded research.

In addition to detailing general selectivity, the tables list product's selectivity relative to the types of beneficials you have and want to conserve. For example if making a pest control decision when mealybugs are present, it would be useful to look for insecticides that have less effect on parasitic wasps and key predators such as ladybird beetles and lacewing.

It is important to note that for many products, Table 3 considers rate as well as product. Lower registered rates of a product may provide sufficient efficacy against some target pests, while minimising impact on beneficials. It is also very important to note that the data supporting this table on product disruptiveness is based on results after a single application, and multiple applications of a product with a low rank can still have a cumulative disruptive impact.

In selecting an insecticide, it is also important to adhere to the IRMS, to reduce the risk of resistance. Of course, always follow label directions. ■■■

DISCLAIMER

This document has been prepared by the authors for CRDC in good faith on the basis of available information. While the information contained in the document has been formulated with all due care, the users of the document must obtain their own advice and conduct their own investigations and assessments of any proposals they are considering, in the light of their own individual circumstances.

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IMPORTANT – Use an integrated approach to pest management. For more information on Integrated Pest Management Guidelines for Australian cotton refer to page 47.

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 PAMP, 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 local CottonInfo Regional Extension Officer (REO) (see inside back cover for contact details) to join 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.	Begin planning for rotation crops.	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 bee keepers in the region. Avoid spray drift. Consider native vegetation as part of pest management. Maximise its value by improving its health, linking patches of vegetation, controlling weeds and keeping it diverse for a range of species (including birds and bats).			
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.
Consider options to escape, avoid or reduce pests	When planning cotton, consider proximity to sensitive areas, pest hosts and beneficial habitats. Manage areas of vegetation to encourage beneficials. If planning to release <i>Trichogramma</i> , plan to sow other crops (e.g. sorghum) that will host <i>Helicoverpa</i> .	Practice Come Clean. Go Clean. all year round Assess risk of soil pests before planting to decide on control options. Use a suitable variety for your region. Provide optimum planting conditions to promote healthy seedlings. Consider summer trap crop. Consider insecticide choice or releasing beneficials to build beneficial numbers.		
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 throughout the season. Track pest trends. Use pest and damage thresholds and the beneficial to pest ratio.	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.
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.	Provide optimum planting conditions to promote healthy seedlings that can outgrow damage. Monitor leaf and tip damage and development of first squaring node.	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 Consider the beneficial to pest ratio taking parasitism into account.		
Choose insecticides wisely	Use thresholds and careful spray selection for all crops.	Consider insecticide selectivity and impact on beneficials and bees. Avoid early season use of broad-spectrum (e.g. OPs) sprays. Consider edge or patch spraying for aphids and mites. Avoid prophylactic sprays.	When choosing insecticides think about impact on beneficials and bees.	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 in the entire landscape.	Adhere to refuge requirements. Consider choice of at-planting insecticides/seed dressings and implications for later sprays.	Ensure that Bt Cotton refuges are attractive/effective.	Follow pupae busting guidelines for Bt cotton.
Use pest thresholds and follow your Insecticide Resistance Management Strategy for every spray				

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TABLE 2: Impact of insecticides at planting or as seed treatments on key beneficial groups in cotton

Insecticides	Rate (g ai/ha)	Main target pest(s) ⁵					Persistence ⁶	Overall ⁷	Beneficial group				
		WW	Mite	Mir.	Aph.	Th.			Predatory beetles ¹	Predatory bugs ²	Spiders	Wasps and ants	Thrips
At Planting													
Phorate	600	✓	✓	✓	✓	✓	medium-long	Very low ^{3,4}	No data	No data	No data	No data	Very high
Carbosulfan	750-1000	✓		✓		✓	medium-long	Very low ^{3,4}	No data	No data	No data	No data	Very high
Chlorpyrifos	250-750	✓					medium	Very low ⁴	No data	No data	No data	No data	No data
Seed Treatments													
Thiodicarb	500 g ai/100 kg seed					✓	short	Very low ³	Very low	Very low	Very low	Very low	High
Thiodicarb + Fipronil	259 + 12 g ai/100 kg seed	✓				✓	short-medium	Very low ^{3,4}	No data	No data	No data	No data	High
Imidacloprid	525 g ai/100 kg seed	✓			✓	✓	medium	Very low ³	Very low	Very low	Very low	Very low	Very high
Imidacloprid	700 g ai/100 kg seed	✓			✓	✓	medium	Very low ^{3,4}	Very low	Very low	Very low	Very low	Very high
Thiamethoxam	280 g ai/100 kg seed	✓			✓	✓	medium	Very low ^{3,4}	No data	No data	No data	No data	Very high

1. Predatory beetles – including ladybird beetles, red and blue beetles.

2. Predatory bugs – big-eyed bugs, minute pirate bugs, brown smudge bugs, glossy shield bug, predatory shield bug, damsel bug, assassin bug, apple dimpling bug.

3. Except for effects on thrips which are predators of mites. Note that aldicarb and phorate will also control mites.

4. Based on observations with other soil or seed applied insecticides.

5. WW = wireworm; Mir. = mirids; Aph. = aphids; Th. = thrips.

6. Persistence: Short, 2-3 weeks; medium, 3-4 weeks; long, 4-6 weeks.

7. Impact rating (% reduction in beneficials following application): Very low, less than 10%; low, 10-20%; moderate, 20-40%; high, 40-60%; very high, more than 60%



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- **No significant yield difference**
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TABLE 3: Impact of insecticides and miticides on predators, parasitoids and bees in cotton

Toxicity to bees ¹⁴		VL	VL	VL	VL	VL	L	VL	VL	H	H	H	VL	VL	VL	VL	—	H ¹⁵	VH	M	VL	H ¹⁵	VH ¹⁵	VH	VL	VH	VL	VH	H	H	H	H	L																										
Pest resurgence ¹²	Helicoverpa																			+ve																																							
	Aphid									+ve		+ve	+ve									+ve			+ve																																		
	Mite																+ve	+ve	+ve				+ve	+ve								+ve																											
Beneficials	Thrips ²²	VL	VL	L	VL	VL	VL	VL	VL	L	VL	VL	VL	L	H	VL	VL	H	VH	L	VL	VL	H	H	M	H	VL																																
	Hymenoptera	Ants	VL	VL	VL	H	VL	VL	VH	VL	H	H	H	L	—	VH	M	H	H	VH	H	M	VH	VL	H	M	VL	H	H	M	M	M																											
		Trichogramma	VL	VL	M	VL	VL	VL	L	VL	VL	VL	VL	L	—	H	—	H	H	H	VL	L	VL	VL	M	M	H	VL	H	H	VH	M	M																										
		Eretmocerus ¹⁹	VL	VL	M	—	—	L	—	—	—	—	—	—	M	H	—	H	—	—	H	L	—	—	—	—	L	M	M	—	H	M	—																										
	Total (wasps)	VL	VL	VL	VL	VL	VL	L	L	VL	L	L	L	—	L	L	M	M	M	L	L	L	VL	M	M	M	M	M	M	M	M	M	M																										
	Spiders	VL	VL	VL	L	VL	VL	VL	M	VL	VL	VL	VL	L	VL	L	L	VL	VL	L	L	L	M	VL	M	M	M	VL	L	M	M	M	M																										
	Lacewing adults	VL	VL	VL	VL	VL	VL	L	VL	VL	M	M	M	VH	—	VL	L	VL	VL	VL	M	M	VH	H	M	VH	VL	H	VL	VL	L	VL	VL																										
	Predatory bugs	Apple Dimpling	VL	VL	VL	VL	VL	—	L	VL	H	H	H	VL	L	H	L	L	VL	VL	H	H	VH	L	VH	M	M	H	VH	M	H	H	L	L																									
		Other Predatory bugs	VL	VL	VL	VL	VL	—	—	VL	L	L	L	L	—	—	—	L	VL	VL	L	VL	L	H	M	VL	H	VL	M	M	M	M	VL																										
		Big-eyed Bugs	VL	VL	M	VL	VL	L	—	VL	VL	—	—	—	VL	VL	VL	L	H	VL	VL	M	L	M	L	VL	VH	L	M	VH	M	M	H	VL																									
		Damsel bugs	VL	VL	L	VL	L	—	VL	VL	L	L	L	VL	—	VL	—	L	L	VL	VL	M	L	M	VL	VL	H	VL	L	VL	VL	L	H																										
	Total ²	VL	VL	L	VL	L	VL	VL	VL	VL	VL	VL	VL	L	VL	M	M	M	VL	VL	L	L	M	M	L	H	H	L	M	M	M	H	M																										
	Predatory beetles	Other ladybird beetles	VL	VL	VL	VL	L	M	L	L	M	M	M	L	—	M	M	VL	H	M	M	M	VH	L	M	H	VL	H	M	VL	VL	M	M																										
		Minute 2-spotted ladybird beetle	VL	VL	VL	L	VL	M	M	—	H	H	H	M	—	H	—	L	H	M	VL	M	VH	VL	L	H	VL	M	M	M	H	M	H																										
		Red & Blue beetle	VL	VL	VL	L	VL	—	VL	VL	L	L	L	M	—	L	L	M	M	M	H	M	L	M	L	L	VL	L	M	M	M	VL	H																										
		Total ¹	VL	VL	VL	L	M	VL	VL	L	L	L	L	L	L	L	L	VL	M	M	M	M	H ¹³	M	L	M	VL	M	M	L	M	L	M	M																									
Overall Ranking ¹⁰		very low	very low	very low	very low	very low	very low	low	low	low	low	low	low	low	low	low	low	low	low	low	low	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate	moderate																										
Target pest(s)		Persistence ⁸	very short	very short	short	short	medium-long	long	medium-long	short	medium	medium	medium	long	long	long	short	medium	long	medium	short	medium	long	medium	medium	medium	medium	medium	medium	medium	medium	medium	medium																										
		Silverleaf whitefly					✓	✓											✓	✓		✓	✓	✓	✓		✓																																
		Thrips																	✓																																								
		Aphids			✓	✓									✓						✓	✓	✓ ²⁰	✓	✓	✓	✓	✓																															
		Mirids						✓	✓	✓	✓	✓								✓		✓	✓	✓	✓	✓	✓	✓	✓																														
		Mites							✓					✓						✓		✓		✓						✓																													
		Helicoverpa	✓	✓		✓	✓	✓	✓				✓		✓	✓	✓	✓	✓			✓	✓	✓					✓ ⁶	✓																													
Rate (g ai/ha)				250	2%	400	50	800	38.5	60	60	60	52.5	960	10	2500	96	48	350	150	127.5	60	48	96	70	72	18	5.4	8.4	1500																													
Insecticides (in increasing rank order of impact on beneficials)		Bt ¹¹		Nucleopolyhedrovirus NPV		Pyrimicarb		PSO (Canopy) ¹⁶		Methoxyfenozide		Pyriproxyfen		Sero-X (SX151019)		Etoxazole		Indoxacarb (low)		Indoxacarb (low+salt)		Indoxacarb (low+Canopy)		Chlorantraniliprole		Dicofol ³		Afidopyropen		Amorphous silica ¹⁷		Spinosad		Spinetoram		Diafenthiuron		Pymetrozine		Indoxacarb		Cytraniliprole		Sulfoxaflor (low)		Spirotetramat		Flonicamid (high)		Sulfoxaflor (mid)		Dinotefuran (low)		Abamectin		Enamectin		Propargite	

1. Total predatory beetles – advantage beetles, red and blue beetles, other predatory beetles

1. Total predatory beetles – ladybird beetles, red and blue beetles, other predatory beetles
2. Total predatory bugs – big-eyed bugs, minute pirate bugs, brown smutbugs, glossy shield bugs, predatory shield bugs, damsel bug, assassin bug, apple dimpling bug

3. Information: 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.

4. Pyrethroids: alpha-cypermethrin, cypermethrin, beta-cyfluthrin, cyfluthrin, bifenthrin, fenvalerate, esfenvalerate, deltamethrin, lambda-cyhalothrin.

5. Organophosphates: omethoate, monocrotophos, profenofos, chlorpyrifos, chlorpyrifos-methyl, azinophos ethyl, methidathion, parathion-methyl, thiometon

6. *Helicoverpa punctigera* only.

7. Bifenthrin is registered for mite and silverleaf whitefly control; alpha-cypermethrin, beta-cyfluthrin, bifenthrin, deltamethrin and lambda-cyhalothrin are registered for control of mirids.

8. Persistence of pest control: Short, less than 3 days; medium: 3-7 days; long, greater than 10 days.

9. Suppression of mites and aphids only.

10. Impact rating (% reduction in beneficials following application, based on scores for the major beneficial groups): V.L (very low), less than 10%; L (low), 10-20%; M (moderate), 20-40%; H (high), 40-60%; V.H (very high), > 60%. A '-' indicates no data available for specific local species.

11. *Bacillus thuringiensis*

12. Pest resurgence is +ve if repeated applications of a particular product are likely to increase the risk of pest outbreaks or resurgence. Simultaneous sequential applications of products with a high pest resurgence rating will increase the risk of outbreaks or resurgence of the particular pest species.

13. Very high impact on minute two-spotted ladybird beetle and other ladybird beetles for wet spray, moderate impact for dried spray.

14. Data Source: British Crop Protection Council. 2003. The Pesticide Manual (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 scale: very low = LD50 (48h) > 100 ug/bee, low = LD50 (48h) < 100 ug/bee, moderate = LD50 (48h) < 10 ug/bee, high = LD50 (48h) < 1 ug/bee, very high = LD50 (48h) < 0.1 ug/bee. Refer to the Protecting Bees section in the Appendix for more information.

this booklet.

15. Wet residue of these products is toxic to bees, however, applying the products in the early evening when bees are not foraging will allow spray to dry, reducing risk to bees the following day.

16. PSO = Petroleum Spray Oil. May reduce survival of ladybird beetle larvae – rating of moderate for this group.

17. May be detrimental to eggs and early stages of many insects, generally low toxicity to adults and later stages.

18. Will not control organophosphate resistant pests (e.g. mites, some cotton aphid (*Aphis gossypii*) populations

19. Rankings for *Eretmocerus* based on data from Jamie Hopkinson in semi-laboratory replicated experiments (QD)

20. Suppression only

21. Transform is registered for control of greenhouse whitefly at the 96 g ai/ha rate.

22. Effects on thrips are for populations found on leaves. This is relevant to seedling crops, where thrips damage leaves, and to mid-late season when thrips adults and larvae help control mites by feeding on them as well as on leaf tissue. Note that flowers are a protected site, so live adult thrips may be found in flowers even after crops have been treated with products that would control them on leaves.

23. Skope is a mixture of acetamiprid and enamectin benzoate. At the low rate (175 ml/ha) this is 38.2 g a.i./ha acetamiprid and 5.7 g a.i./ha enamectin benzoate. At the high rate (350 ml/ha) this is 76.3 g a.i./ha acetamiprid and 11.4 g a.i./ha enamectin benzoate. Skope may also be used as a seed treatment. It has been found that mites do not feed on treated seedlings.

24. Voliam Flexi is a mixture of thiamethoxam and chlorantraniliprole. At the 250 g/ha rate this is 40 g a.i./ha thiamethoxam and 40 g a.i./ha chlorantraniliprole. It is a mixture of two spotted mites are present.

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Management of key insect and mite pests

Paul Grundy, DAF and CottonInfo

Acknowledgements: Sally Ceeney (Cottoninfo); Susan Maas (CRDC); Sharon Downes, Simone Heimoana, Tanya Smith, Lewis Wilson, Mary Whitehouse, Sandra Williams (CSIRO); Lisa Bird, Grant Herron, Kate Langfield, Robert Mensah (NSW DPI); Jamie Hopkinson, Richard Sequeira (Qld DAF); Sharna Holman (Qld DAF and Cottoninfo)

This chapter is presented as a guide to assist growers in planning their Integrated Pest Management (IPM) programs. This section provides specific management information for each of the key insect and mite pests of Australian cotton. For each pest, information is provided under the sub-headings of:

- Damage symptoms
- Sampling
- Thresholds
- Key beneficial insects
- Selecting an insecticide/miticide
- Resistance status
- Overwintering habits
- Alternative hosts

Damage symptoms indicate that a pest could be influencing crop development and possibly yield potential. In some instances, damage symptoms will be observed without the pest. This may mean that the pest is there but cannot be observed or that the pest has caused the damage but has since left the crop. In other instances, the pest will be observed but there will be no symptoms of damage to the crop. Knowledge of the pests and beneficials present and crop damage should be used in combination to make pest management decisions.

Sampling is the process of collecting the day-to-day information on pest and beneficial abundance and crop damage that is used to make pest management decisions.

Thresholds provide a rational basis for making decisions and are a means of keeping decisions consistent. Knowing the key beneficial predators and parasitoids for each pest is important for developing confidence in IPM approaches to pest management.

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

All pests have survival strategies that allow them to live and breed in cotton farming systems. Understanding how pests can survive, including knowing their resistance status and risks, overwintering habit and alternative hosts can help with good decision making for the long term.

Information in this section links to a number of tables in the Guide.

Registration of a pesticide is not a recommendation for the use of a specific pesticide in a particular situation. Growers must satisfy themselves that the pesticide they choose is the best one for the crop and pest. Growers and users must also carefully study the container label before using any pesticide, so that specific instructions relating to the rate, timing, application and safety are noted. Confirm registration is current prior to use.

Growers must also ensure that their insecticide program fits in with the Insecticide Resistance Management Strategy (see pages 54-64). Insecticides can be a costly part of cotton production. Ensure that industry thresholds are followed to prevent unnecessary spraying.

Important – avoid spray drift

For legal requirements and best practice information on reducing spray drift, refer to the Spray Application chapter page 129. Carefully follow all label directions.



INSECT PEST	MANAGEMENT
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Green Vegetable Bugs	Page 19
Helicoverpa (Cotton Bollworm)	Page 21
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Aphids

Cotton aphid – *Aphis gossypii*

Green peach aphid – *Myzus persicae*

Cowpea aphid – *Aphis craccivora*

Cotton aphid is the most common aphid pest in cotton. Green peach aphid and cowpea aphid are occasional pests of young cotton but both species decline as temperatures increase (generally early December). In recent years with hot conditions, cotton aphids have been more abundant later in the season as temperatures cool.

Damage symptoms

Nymphs and wingless adults of cotton aphid feed on the undersides of leaves, in the terminals, on young stems and on developing fruit. Damage to leaves may cause stunting 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. Cotton aphids have also been shown to transmit the disease Cotton Bunchy Top (CBT). CBT is described on page 118. Once bolls begin to open, the sugary 'honeydew' excreted by aphids can contaminate the lint. Green peach aphid causes similar but more severe damage to plant growth than similar densities of cotton aphid.

Sampling

Sampling should focus on non-winged adults together with their nymphs. Winged adults may be transitory, while the presence of non-winged adults together with their nymphs indicates a population has settled in the crop. As the different aphid species differ in their potential to damage cotton or spread CBT it is important to identify the species present.

Sample for Species and Population

Species: Verify which aphid species is present before implementing any management strategies. Aphid species can be distinguished by close examination with a hand lens. Green peach are pale green, are more oval than cotton aphid, and have tubercles (on the head between the antenna), 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 very short. 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



Aphids and mummies. (Lewis Wilson, CSIRO)

widely from yellow, green, brown to dull black. If you are unable to make a determination, or suspect both could be present, contact Simone Heimoana or Tanya Smith, CSIRO Agriculture and Food at Narrabri, to arrange for a sample to be sent for identification. Contact details are provided at the end of this section.

For more information on aphids and species identification see the following cottoninfo video: <https://www.youtube.com/watch?v=Vi07GhSoQtg>

Population: 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.

Frequency

Check the **population** at least weekly. Begin aphid sampling at seedling emergence and continue until defoliation. The species composition may change during the season. Particularly when aphid infestation occurs early in the season, the species should be verified on more than one occasion during the season.

Methods

Seedling to first open boll: Use a 0-5 scoring system based on the number of aphids/leaf. The protocols for scoring aphids are presented in full on page 21.

If hot spots 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. Aphids, mites and whitefly can be sampled using the same leaf if necessary. Sample at least 20 leaves per location. Only score a plant as infested if there are 4 or more non-winged aphids within 2 cm². Aphids are most abundant on the edges of fields so ensure perimeter sampling occurs. Assess plants for the presence of honeydew.

Thresholds and Cotton Bunchy Top

Cotton aphid

From the seedling stage through until first open boll, thresholds are based on the potential for feeding damage of the aphid population to reduce yield. These thresholds are dynamic, allowing the grower/consultant to 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. As penalties for honeydew contamination are severe, thresholds aim to limit honeydew contamination to trace amounts.

Additional information for how to sample aphids and calculate the threshold can be found in the following cottoninfo video: <https://www.youtube.com/watch?v=L9N64u1yi8E>

There is also a risk that yield loss can occur through crop infection with CBT. These thresholds do not take into account the risk of yield loss due to CBT. Recent research has shown that risks of CBT spreading through crops and affecting yield are low unless significant populations of ratoon cotton or alternative weed hosts are neighbouring or within the field. If there are many hosts of CBT near the field and a large influx of aphids occurs from these hosts into the cotton crop, control of aphids in the cotton may be required to prevent spread of CBT.

In these situations the development and spread of aphids should be monitored intensively (at least twice weekly), and any hotspots checked for the presence of plants showing CBT symptoms. Mark aphid hotspot areas and return to them to check aphid survival. If it is low, then no action may



be needed; but if populations are healthy, increasing and spreading, control may be required to prevent transmission of CBT within the crop. If control is needed, 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 in these hosts. Refer to page 112 for hosts of CBT.

SEEDLING TO FIRST OPEN BOLL	FIRST OPEN BOLL TO HARVEST
Calculate the Cumulative Season Aphid Score (page 17)	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 on seedlings is lower: 25% 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 occur on seedling cotton crops, sometimes in quite high numbers. 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 beneficial insects

Predators – ladybird beetle adults and larvae, red and blue beetles, damsel bugs, big-eyed bugs, lacewing larvae, hoverfly and silverfly larvae

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

Selecting an insecticide

The insecticide products registered for the control of cotton aphid and green peach aphid in cotton in Australia are presented in Table 4 on page 16. If aphid control is required early season, use a selective option to help conserve beneficial populations, in accordance with the IRMS. 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 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 remains critical to follow the recommendations of the industry's IRMS and rotate insecticide chemistries taking into account the insecticide group of any seed treatment (currently all commercially treated seed includes a neonicotinoid, refer to Table 2) or at-planting insecticide.

There is cross resistance in cotton aphid between pirimicarb and dimethoate, and in the early 2000s this resistance rendered these compounds ineffective. Fortunately in recent years resistance to these compounds has declined dramatically and they again will provide effective control of aphids. However, 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. Neonicotinoid resistance places strong pressure on pirimicarb and dimethoate/omethoate and attention should be paid to the effective management of these valuable products.

When choosing an aphicide, consider previous insecticide choices for mirids as well as for aphids and rotate chemical groups. It should be noted that if a phorate side dressing is used instead of a neonicotinoid seed dressing then do not use pirimicarb or dimethoate/omethoate as first foliar spray as there is cross resistance between them all. Dimethoate/omethoate use will re-select 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 the growth rate of aphids dramatically. In cotton growing areas aphids persist through winter on whatever suitable host plants are available, including cotton volunteers and ratoons.

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 may also carryover the CBT disease. 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 the 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, volunteer cotton and in summer on these hosts as well as hogweed, cathead, volunteer cotton, beggars ticks, datura, 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.

**TABLE 4: Control of cotton aphid (*Aphis gossypii*) and Green peach aphid (*Myzus persicae*)**

Active ingredient	Insecticide group	<i>A. gossypii</i> 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	Group 1A	Occasional – low & 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.
Diafenthiuron	Group 12A	Cross-resistance between all the neonicotinoids	Low	Apply before damage occurs. Only use lower rate when spraying by ground rig. Maximum 2 applications per season.
Pymetrozine	Group 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.
Afidopyropen	Group 9D	Unknown	Low	Will disrupt insect behaviour and feeding. Provides a slow knockdown. Maximum 4 applications per season.
Cyantraniliprole	Group 28	Unknown	Moderate	Suppression only. Maximum 2 applications per season.
Chlorantraniliprole/ Thiamethoxam	Group 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.
Sulfoxaflor	Group 4C	Unknown	Moderate	Use higher rate under heavy aphid infestations and/or when water volume is reduced such as aerial application. Maximum 4 applications per season.
Spirotetramat	Group 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.
Fonicamid	Group 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	Group 6/4A	Cross-resistance between all the neonicotinoids	Moderate	Use the high rate under sustained heavy aphid pressure. Maximum 2 applications per season (note Max 3 applications in total of Group 6 insecticides). Use organosilicone adjuvant as per label.
Phorate	Group 1B	Occasional – low. Phorate is cross resistant to pirimicarb and dimethoate.	Moderate	For short residual control at time of planting. Irrigate as soon as possible after treatment. For extended period of control. Only use the highest rate on heavy soils when conditions favour good emergence, use higher rates (NSW and WA only). Maximum 1 application per season.
Acetamiprid	Group 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	Group 19	Unknown	Moderate	Suppression when used for controlling Helicoverpa (Helicoverpa rates). Maximum 4 applications per season.
Clothianidin	Group 4A	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	Group 4A	Cross-resistance between all the neonicotinoids	Moderate	Add Pulse penetrant at 0.2% v/v (2 m L/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	Group 1B	Occasional – low. 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 stockfeed for 14 days after application. Maximum 2 applications per season.
Chlorpyrifos	Group 1B	Occasional – low	High	Use higher rates on heavy infestations. Maximum 3 applications per season.

#For all control options always refer to the label for instructions and to minimise impact on bees.

*For more details about impact on beneficial insects, refer to table 3 in this guide.



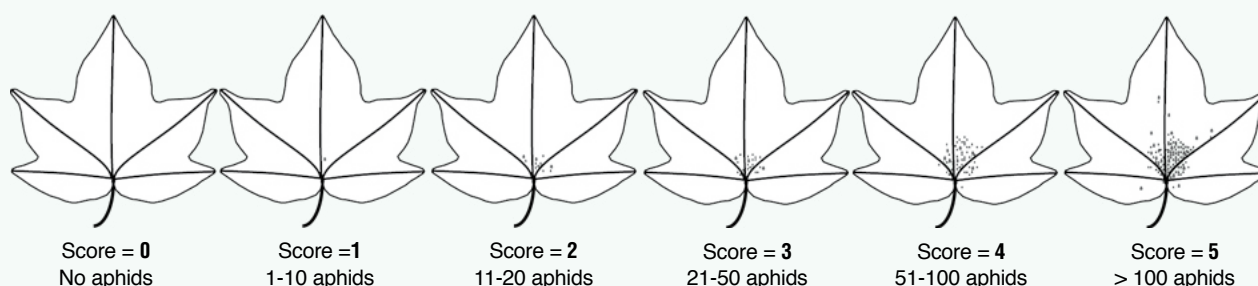
SAMPLING PROTOCOLS FOR COTTON APHID FOR USE UNTIL FIRST OPEN BOLL

STEP 1: Collect leaves.

Fields should be sampled in several locations as aphids tend to be patchy in distribution. At each location collect at least 20 leaves, taking only one leaf per plant. Choose mainstem leaves from 3, 4 or 5 nodes below the terminal. The same leaves can also be used for mite and whitefly scoring. It is important to sample for aphids regularly, even if it is suspected that none are present. The estimate of yield loss will be most accurate when sampling detects the time aphids first arrive in the crop.

STEP 2: Score leaves.

Allocate each leaf a score of 0, 1, 2, 3, 4 or 5 based on the number of aphids on the leaf. After counting aphids a few times, you will quickly gain confidence in estimating abundance. As a guide, the diagrams below represent the minimum population for each score. Discount pale brown bloated aphids as these are parasitised. Sum the scores and divide by the number of leaves to calculate the Average Aphid Score.



STEP 3: Manual calculation of the cumulative season aphid score.

Use the Look Up Table below to firstly convert the Average Aphid Score calculated in Step 2 to a Sample Aphid Score. This step accounts for the length of time the observed aphids have been present in the crop. 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.

Find the value in the table where 'this check' and the 'last check' intersect. Multiply this value by the number of days that have lapsed between checks. This value is the Sample Aphid Score.

As the season progresses, add this check's Sample Aphid Score to the previous value to give the Cumulative Season Aphid Score.

When aphids are sprayed, or, if during the season the Average Aphid Scores return to '0' in 2 consecutive checks, reset the Cumulative Season Aphid Score to '0'. Disappearance of aphids can occur for reasons such as predation by beneficials, changes in the weather and insecticide application.

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 4: Manual calculation of the yield loss estimate.

Use the table to estimate the yield loss that aphids have already caused, and note that this does not take into account risks of yield loss from Cotton Bunchy Top disease. The 'Time Remaining' in the season needs to be determined the first time aphids are found in the crop. The data set is based on 165 days from planting to 60% open bolls. If for example aphids are first found 9 weeks after planting, the Time remaining would be ~100 days. As the Season Aphid Score accumulates with each consecutive check, continue to read down the '100' days remaining column to estimate yield loss. When aphids are sprayed, or, if aphids disappear from the crop then reappear at a later time, reassess the time remaining based on the number of days left in the season at the time of their reappearance.

Crop sensitivity to yield loss declines as the crop gets older. The estimate takes into account factors that affect the rate of aphid population development, such as beneficials, weather and variety. Yield reductions >4% are highlighted, however the value of the crop and cost of control should be used to determine how much yield loss can be tolerated before intervention is required.

Cumulative Season Aphid Score	Time Remaining (days until 60% open bolls at 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



Green Vegetable Bug (GVBs)

Nezara viridula

Damage symptoms

Nymphs and adults cause dull to black shiny spots on the boll walls, warty growth inside the carpels and brown staining of lint in developing bolls. In severe cases, it is hard to peel the carpel off the damaged lint which may result in tightlock and yield loss. Damage symptoms cannot be distinguished from those caused by mirids. GVB damage varies with boll age, small bolls suffering more damage than old bolls. Bolls aged up to 7 days old are usually shed. Bolls eight to 24 days old are not shed but can suffer significant damage resulting in incomplete development of one or more sectors (locks) of the bolls, stained lint and reduced yield. Bolls aged 25 days or older will not suffer any damage.

Sampling

Sample adults and nymphs and monitor fruit retention. 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. A cluster (more than 10) of first and second instars causes as much damage as one adult. Third instars cause half the damage of adults, but fourth and fifth instars inflict the same amount of damage as adults.

Instar	Length (mm)	Description
1	1	Orange on hatching with 2-3 dark spots. They quickly darken to brown/black with 2-3 small lighter brown spots.
2	2	Black with 2-4 white shoulder spots and 4 or more orange to yellow abdomen spots. Two orange to yellow spots may develop on the edges behind the head.
3	4	Black/brown with 2 orange spots on each side of the thorax, 6 yellow/green spots in the centre of the abdomen and white spots around the perimeter of the abdomen.
4	7	Green/dark green with developing wing buds. Two orange spots on each side of the thorax, yellow/green spots in the centre of the abdomen and white and orange spots around the perimeter of the abdomen.
5	10	Light green body with obvious wing buds. Edge of the abdomen and thorax is orange/red, centre of the abdomen with 6 white spots on either side of 2 or 3 large red spots.
Adult	15	All green with wings



GVB will use turnip weed as a host in spring. (Lewis Wilson, CSIRO)

Frequency

Sample bugs and 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.

Methods

GVBs are most visible early to mid morning. Visual sampling and beat sheets are equally effective checking methods from the start of squaring until flowering. From flowering onwards, when the crop is most susceptible to damage, beat sheeting is twice as efficient at detecting GVBs. Although beat sheet sampling is efficient it may tend to give a lower population than the actual number in the field. It has been found that the first and second instars tend to hide in the bracts and may be difficult to dislodge.

Thresholds

Sampling Method	Flowering to First open boll	First open boll to Harvest
Visual	0.5 adults/m	0.5 adults/m
Beat Sheet	1.0 adult/m	1.0 adult/m
Damage to small bolls (14 days old)	20%	20%

Convert nymph numbers to adult equivalents and include in the counts. Fourth or fifth instars are each equivalent to 1.0 adult, each third instar counts as 0.5 adult and clusters of 10+ first/second instars count as 1.0 adult.

Comparing damage between stinkbugs using GVB adult equivalents

There are five more stinkbugs occasionally occurring in cotton that cause damage similar to that of GVB. However, their damage potential is less than that of GVB so their counts need to be adjusted to GVB adult equivalents according to the table below:

Other Stink Bugs	Proportion of damage compared to GVB	Threshold (based on GVB adult equivalents)
Green stinkbug (GSB)	1/2	2
Red banded shield bug (RBSB)	1/3	3
Pale cotton stainer bug (CSB)	1/3	3
Brown stinkbug (BSB)	1/4	4
Harlequin bug (HRLQB)	1/4	4

Key beneficial insects

Parasites – *Trissolcus* is a wasp which parasitises GVB eggs by inserting their 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. They lay eggs on the outside of bugs. The eggs hatch and *Trichopoda* larvae bore into the GVB, which dramatically reduces the bug's feeding, egg lay and ultimately kills them.

Selecting an insecticide

The insecticide products registered for the control of GVBs in cotton in Australia are presented in Table 20. Mid-season use of dimethoate for GVB control should be carefully considered as this compound also selects for organophosphate/carbamate resistance in aphids, particularly if using an OP/carbamate early season in furrow treatments for thrip control etc.



GVB with 4 Trichopoda parasite eggs. (Hugh Brier Qld DAF)

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. They 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 and will feed on whatever hosts are available.

Alternative hosts

In Qld 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 and variegated thistle. Early mungbean crops are also a favoured host in spring. The second generation breeds in late summer and early autumn. Pulse crops – particularly soybeans and mungbeans – are key hosts for this generation. Recent data has shown that blackberry nightshade (*Solanum nigrum*) is a good second generation weed host. 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 Qld.

Further Information:

CSIRO, Narrabri – Tanya Smith: (02) 6799 1543

ALERT EXOTIC BUG THREAT



Brown Marmorated Stink Bug.
(Kristie Graham, USDA ARS, Bugwood.org)

Brown Marmorated Stink Bug (BMSB)

BMSB is an exotic pest that could cause damage to crops including cotton. It is well known to stow away in cargo coming out of the northern hemisphere between September and April each year and there have been a number of post border detections that are currently being managed.

Be alert when receiving goods from overseas

This 'hitchhiker' has been associated with a variety of cargo including shipping containers and machinery, as well as household items (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. Look for black and white banding on the antennae and black and white banding on the sides of the abdomen.

TABLE 5: Control of green vegetable bug (*Nezara viridula*)

Active ingredient	Insecticide group	Overall impact on beneficials*	Comments#
Fipronil	Group 2B	Moderate	Apply when pests appear. Use higher rate when higher infestations are present. Avoid repeated use of this insecticide group.
Emamectin benzoate/Acetamiprid	Group 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.
Clothianidin	Group 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.
Dimethoate	Group 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 stockfeed for 14 days after application. Maximum 2 applications per season.
Dinotefuran	Group 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.

#For all control options ALWAYS refer to the label for instructions and to minimise impact on bees.

*For more details about impact on beneficial insects, refer to Table 3 in this guide.



Helicoverpa (Cotton Bollworm)

Helicoverpa armigera

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. Based on research conducted in Bollgard II, in any year an average of 15% of Bt cotton area may carry *Helicoverpa* larvae at or above the recommended threshold levels for a short period during peak to late flower. In Bt cotton, chewing damage is mostly confined to fruit and may lead to yield loss.

Sampling

Sample the egg and larval growth stages of the pest. The growth stages of the cotton bollworm are defined as:

White egg	WE	pearly white
Brown egg	BE	off-white to brown
Very small larvae	VS	0 mm–3 mm
Small larvae	S	3 mm–7 mm
Medium larvae	M	7 mm–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. Sample the whole plant.

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

Sample key beneficials. This information will allow thresholds based on the beneficial to pest ratio to be applied. Collect eggs to check for parasitism by *Trichogramma* spp. Only collect brown eggs as white eggs may have only recently been laid.

Frequency

Check at least 2 times/week in both conventional and Bt cotton crops.

Begin *Helicoverpa* sampling at seedling emergence. Cease sampling when the crop has 30–40% open bolls.

Methods

Through the entire season, *Helicoverpa* are most accurately sampled using visual methods. Check at least 30 plants or 3 separate metres of row for every 50 ha of crop.



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

Larger samples will give more accurate estimates. Fields are rarely uniform, lush areas often occur in head ditches and these are more attractive to insects. The crop variability within the field may determine the minimum number of sampling points required.

Thresholds

Using eggs as the basis of a threshold can be very misleading as not all eggs hatch. Successful egg hatch can be as high as 20% early season, 25% mid season and 40% late season. Early in the season eggs are particularly prone to desiccation and being washed or blown from the small plants. Parasitism and predation also reduce survival. *Trichogramma* parasitoids have the potential to reduce egg survival by over 90%. Larval thresholds are also affected by beneficial insects. Therefore it is important to assess beneficial insect numbers when making pest control decisions. Fruit retention can also be used to determine whether pests have caused, or are at risk of causing economic damage.

Helicoverpa in Conventional cotton

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

Helicoverpa in Bt cotton

Calculation of spray thresholds in Bt cotton should exclude larvae that are smaller than 3 mm. Be sure to objectively assess larval size. There are no egg thresholds in Bt cotton. Preliminary research has shown no effect on yield from high egg lays (over 100/m) on Bt cotton.

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

Where larvae between 3 mm 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:

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

At least 30 plants or 3 to 4 separate metres of row by visual sampling or 20 metres of row by suction sampling is needed in order to use the ratio. The total number of beneficials **must only** include the key beneficial insects (marked with an asterisk on the following page). **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 calculated 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. For how to monitor egg parasitism levels and use the beneficial to pest ratio refer to page 50.

Key beneficial insects

Predators of eggs – red and blue beetle*, damsel bug*, green lacewing larvae*, brown lacewing*, ants, nightstalking 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

*See ratio formula on page 21.

Selecting an insecticide

The insecticide products registered for the control of *Helicoverpa* in cotton are presented in Table 4 on page 16. The use of more selective insecticide options will help to conserve beneficial insects. Refer to Table 3 on pages 10–11.

Be aware of resistance status in *H. Armigera* and follow IRMS (pages 61–64).

Resistance profile

H. Armigera – conventional insecticides

With the introduction of transgenic cotton, *H. Armigera* is no longer front of mind as a major pest of concern for cotton. However maintaining effective control is critical for conventional cotton as well as other crops such as pulses. Importantly, large plantings of Bt cotton does 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 the industry-wide resistance surveillance program, implemented by NSW DPI and supported by CRDC and GRDC, shows levels of resistance to indoxacarb in *H. Armigera* is 8.7%. 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. Research suggests that diapause in indoxacarb resistant *H. Armigera* incurs a fitness penalty 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. 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*.



***H. Armigera* & *punctigera* moths.** (Hugh Brier Qld DAF)

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 (pages 61–64). As well as the cotton IRMS, it is important to adhere to the resistance management strategy (RMS) for the grains industry. www.ipmguidelinesforgains.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 products' Resistance Management Plan.

H. Armigera – Bt cotton

A gene is present in field populations of *H. Armigera* that has the potential to confer high-level resistance to Cry1Ac. Monitoring suggests that this gene occurs at a low frequency which is probably less than 5 in 10,000. It is not cross-resistant to Cry2Ab or Vip3A and in certain environments is largely recessive.

A gene that confers high level resistance to Cry2Ab is also present in field populations of *H. Armigera*. This gene does not confer cross-resistance to Cry1Ac or Vip3A. Currently around 2% of the *H. Armigera* population carried the Cry2Ab resistance gene. A gene that confers high level resistance to Vip3A is present in field populations of *H. Armigera*. This gene does not confer cross resistance to Cry1Ac or Cry2Ab. Currently around 3% of the *H. Armigera* population carries the Vip3A resistance gene. The continued efficacy of Bt cotton has become even more dependent on how the industry manages its refuges and implements the other elements of the resistance management plan (RMP). For further details, including information about recent changes in the frequency of Bt resistance genes in *H. Armigera*, refer to the Preamble to the Bollgard 3 RMP for cotton on page 65.

Overwintering habit

H. Armigera over-winters in cotton fields as diapausing pupae. These pupae are the major carriers of resistance from one season to the next. The initiation of diapause in the pupae is caused by falling temperatures and shortening day lengths. 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 is initiated in at least 50% of pupae by the first week in April. Diapause termination is based on rising soil temperatures beginning in mid to late September in most regions. Emergence from diapause usually occurs over a 6 to 8 week period in each valley.



Alternative hosts

Spring host crops 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.

Further Information:

CSIRO Narrabri

Sharon Downes: (02) 6799 1576 or 0427 480 967.

Mary Whitehouse: (02) 6799 1538 or 0428 424 205.

NSW DPI, Tamworth

Lisa Bird: (02) 6763 1128.

Helicoverpa (Native Budworm)

Helicoverpa punctigera

Damage symptoms

Larvae cause early to mid season damage to terminals, squares, flowers and bolls of conventional cotton (non-Bt varieties) in a similar manner to *H. armigera*.

Sampling

Refer to the section on sampling *Helicoverpa* on page 21. It is not possible to visually differentiate the eggs or early larval stages of the *H. Punctigera* from the *H. Armigera*, hence it is appropriate that these pests be sampled as one.

Thresholds

Refer to the section on thresholds for *Helicoverpa* on the previous pages. The thresholds for *Helicoverpa* are based on the assumption of potentially mixed populations of *H. Armigera* and *H. Punctigera*.

Key beneficial insects

Refer to the section on Key Beneficial Insects for the *Helicoverpa* on the previous page. These beneficials and parasitoids also attack the native budworm.

Selecting an insecticide

The insecticide products registered for the control of *H. Punctigera* in cotton in Australia are presented in Table 4 on page 16. The use of more selective insecticide options will help to conserve beneficial insects. Refer to Table 3 on pages 10-11.

Survival strategies

Resistance profile

Conventional cotton

Resistance to insecticides has only rarely been detected in *H. Punctigera*. In conventional cotton, the tendency for the *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

A gene is present in field populations of *H. Punctigera* that confers resistance to Cry1Ac. Around 1% of the *H. Punctigera* population carries a Cry1Ac resistance gene. It is not cross-resistant to Cry2Ab or Vip3A and in certain environments is largely recessive.

A gene that confers high level resistance to Cry2Ab is present in field populations of *H. Punctigera*. Around 1% of the *H. Punctigera* population carries a Cry2Ab resistance gene. It is not cross-resistant to Cry1Ac or Vip3A and is recessive.

A gene that confers high level resistance to Vip3A is present in field populations of *H. Punctigera*. This gene does not confer cross resistance to Cry1Ac or Cry2Ab. Around 1% of the *H. Punctigera* population carries the Vip3A resistance gene.

The continued efficacy of Bt cotton has become even more dependent on how the industry manages its refuges and implements the other elements of the resistance management plan (RMP).

For further details, including information about recent changes in the frequency of Bt resistance genes in *H. Punctigera* refer to the Preamble to the Bollgard 3 RMP for cotton on page 65.

Overwintering habits of *H. Punctigera*

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 over-wintered pupae were rarely found in the ground in the temperate cotton growing areas.

Spring migrations from the western inland have largely been thought to be the main source of this species in the eastern cropping regions, and importantly have historically never shown any trends towards insecticide resistance in the past.

However, in recent times *H. Punctigera* ecology appears to have been changing, with this species now persisting throughout the whole cotton-growing season and significant overwintering now taking place.

Migration flights also appear to have lessened, thus reducing that natural genetic dilution factor of the past and hence possibly becoming more of a threat to developing Bt resistance in the future. Research continues to investigate these issues.

Alternative hosts

H. Punctigera moths are able to utilize 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*, such spring crops as chickpea, canola, faba-beans and linseed can be heavily infested by this species. Summer crops hosts can include cotton, pigeon pea, sunflower and various legume crops (mungbean, soybean etc).

Further Information:

CSIRO Entomology, Narrabri

Sharon Downes: (02) 6799 1576 or 0427 480 967

Mary Whitehouse: (02) 6799 1538 or 0428 424 205

Qld DAF, Toowoomba

Melina Miles: (07) 4529 4169

NSW DPI, Tamworth

Lisa Bird: (02) 6763 1128.



TABLE 6: Control of *Helicoverpa*

Active ingredient	Insecticide group	Resistance (<i>H. Armigera</i>)	Overall impact on beneficials*	Comments#
<i>Bacillus thuringiensis</i>	No group	Non detected	Very low	Restrictions apply –refer to Bt cotton resistance management plan.
Helicoverpa NPV	No group	Non detected	Very low	Use alone or with compatible larvicide. Target application to coincide with egg hatching.
Paraffinic oil	No group	Non detected	Very low	Use a minimum of 80 L/ha of water. Apply only by ground rig before crop closure.
Magnet	Attractant	Non detected	Very low	Use with insecticides as per label instructions.
Indoxacarb	Group 22A	Widespread – moderate	Low	Compatible with Amitraz and Pix. 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.
Spinetoram	Group 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.
Chlorantraniliprole	Group 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.
Cyantraniliprole	Group 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	Group 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	Group 6	Occasional – low	Moderate	Use the higher rate alone or the lower rate with a suitable mixing partner. Some labels indicate control of <i>H. Punctigera</i> only. Maximum 2 applications per season.
Emamectin benzoate	Group 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	Group 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	Group 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	Group 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	Group 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	Group 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	Group 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. <i>H. Armigera</i> resistance to bifenthrin has increased. Field failures are likely. Maximum 1 application per season.
Cypermethrin	Group 3A	Widespread – high	Very High	See label for specific concentrations and higher rate situations. Maximum 1 application per season.
Deltamethrin	Group 3A	Widespread – high	Very High	Use low rate as ovicide and high rates for small to medium larvae. Maximum 1 application per season.
Esfenvalerate	Group 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 <i>H. Punctigera</i> >10 mm and/or <i>H. Armigera</i> <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 and to minimise impact on bees.

*For more details about impact on beneficial insects, refer to Table 3 in this guide.



Mealybug

Phenacoccus solenopsis

The solenopsis mealybug (*Phenacoccus solenopsis*) has been found in a range of locations in Qld, NSW, WA and Vic.

Damage symptoms

Nymphs and adults can affect plant growth at all stages of crop development. When infested during early development, plants exhibit distorted terminal growth, crinkled and bunchy leaves, and in severe cases plant death will occur. On older plants, mealybugs can cause shedding of leaves, squares and small bolls as well as fewer, smaller and deformed bolls, and premature crop senescence. Small bolls with severe infestation may crack open prematurely. Heavy infestations (>500 mealybug in top 8 nodes at cut-out) have been found to result in around 80% reduction in harvestable bolls. Honeydew excreted by the insects onto the leaves is high in melezitose sugar which is very sticky and can promote the development of black sooty mould.

Trials on mealybug damage to date have revealed that damage varies depending on crop stage at infestation, plant stress and population density. The earlier the establishment of mealybug, the greater the damage they cause. 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.

Sources and sampling

At low densities, mealybug can be present anywhere on the plant. Trials on mealybug distribution within the plant have revealed that they like to aggregate on the underside of leaves and inside bracts of squares or bolls within the top 10 leaf nodes. Hence, checking in the upper half of the crop canopy would be the most effective sampling strategy for mealybug.

A number of weed species and volunteer cotton can be sources of mealybug within the crop. Uncontrolled volunteer cotton growing in the off season (autumn and winter) can be a significant infestation source in the following season. Mealybug populations from volunteer cotton and weeds are easily dispersed onto nearby cotton. Checking volunteer and adjacent cotton will help to detect early infestations in the field. Based on observations from commercial crops, mealybugs often appear to be more prevalent in crops that are stressed from lack of moisture, water logging and/or nitrogen deficiency. Hence it is important to include stressed areas when checking e.g. tail drains. Investigate patches of stunted or dead plants. As solenopsis mealybug has a very wide host range, also monitor surrounding vegetation including gardens.

Some useful videos about cotton mealybug

<https://www.youtube.com/watch?v=vOTJ2XkAsug> and what to do if you find a hot spot in your crop https://www.youtube.com/watch?v=pR7U_1ng71E



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

Research done to date in Australia and other countries where the solenopsis mealybug is an endemic problem has shown that it is best controlled by beneficial insects. An IPM friendly cotton production system that minimises impacts on the community of beneficial insects is critical for the cost effective control of this pest

Upon first detection, mark infested plants/spots. Monitor regularly for mealybug and key beneficials – lacewings, ladybird beetles (e.g. Cryptolaemus, 3-banded), Aenasius parasitoid. Recent research has shown

What to do if you find them...

- **Correct identification.** Whilst it is likely that observed mealybug are Solenopsis mealybug, there are other similar looking species that occasionally occur in cotton, but they are rarely damaging.
- **Mark the plants they are on, as they can be difficult to relocate when in low numbers.** Re-checking marked plants will enable you to judge the efficacy of any natural enemies that are present.
- **Drones can be useful in identifying further hot spots.**
- **Look for the presence of natural enemies.** Evidence of predation and parasitism and whether or not the solenopsis colony is growing or dwindling in number will provide a picture of the effectiveness of natural enemies in your field.
- **Come Clean Go Clean.** Be mindful of spreading mealybug with passage of people and machinery.
- **Contact your local Cottoninfo REO (Regional Extension Officer) for assistance in assessing the situation and determining further course of action if necessary.**

TABLE 7: Control of Solenopsis Mealybug (*Phenacoccus solenopsis*)

Active ingredient	Insecticidegroup	Overall impacton beneficials*	Comments#
Buprofezin	Group 16	Low**	Limited use allowable under Permit (PER85053)Refer to permit for details.
Spirotetramat	Group 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 for of Spirotetramat presents a risk for SLW resistance management.
Sulfoxaflor	Group 4C	Moderate	Limited use allowable under Permit (PER85052). Refer to permit for details.

#For all control options ALWAYS refer to the label for instructions and to minimise impact on bees.

*For more details about impact on beneficial insects, refer to table 3 in this guide.

**Estimation. Buprofezin has only had one year of trials so impact on beneficials has not yet been finalised.

that releases of predatory insects (green lacewing, three-banded ladybird beetle) commercially available from Bugs-for-Bugs have good potential to assist with mealybug control in hot spots when the first defoliation is at least 3-4 weeks away.

Adhere strictly to good farm hygiene principles and ensure everyone entering the farm should practice Come Clean Go Clean – brush down clothing after entering a field with mealybugs and ensure farm equipment is cleaned down after entering fields with mealybugs.

Beneficial insects are highly effective in keeping mealybug populations in check and 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 will still rely on beneficials. Good coverage is critical for effective control of mealybug with chemical insecticides. Depending on plant size, higher water volumes will increase efficacy of any rate. Sequential application 10-14 days apart may be required to achieve a satisfactory level of mealybug control with some insecticides (see permit/label). Refer to the product label for directions. For management advice in specific situations or circumstances, contact the Cottoninfo team.

Mealybug management options for squaring and early flowering cotton

Mealybug infestation carries a significant risk of plant death in the seedling, squaring and early flowering stages when the cotton plant is highly susceptible and before the seasonal build-up of beneficial insects occurs. In such circumstances where there is a growing risk of mealybug infestation/damage, and beneficials are not adequately building up, chemical intervention may be required:

1. Recommended insecticidal options for specifically targeting mealybug include crop oils, sulfoxaflor (available for use under permit 85052), spirotetramat and buprofezin (available under permit 83180). Sequential applications of crop oils as a stand-alone tactic at 5% v/v can suppress mealybug and may be useful when infestations are detected early and population density is low. Two sequential applications 10-14 days apart may be necessary to get good efficacy with sulfoxaflor and spirotetramat. Refer to product labels for specific application guidelines. Addition of Pulse penetrant at 1% (v/v) may enhance efficacy of sulfoxaflor and spirotetramat on mealybug. Increasing water volume will improve coverage and increase efficacy on mealybug.
2. If mirids are at or nearing threshold in the crop with mealybug, aim to control mirids without flaring mealybug; sulfoxaflor is the product of choice for mirid control and has efficacy on mealybug.
3. If SLW 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 (stops population growth) and can suppress SLW.

Mealybug management options from late flowering to defoliation

4. Mealybug hot spots in mid-late season cotton may be indicative of failure to detect and manage infestations early, and/or disruption of beneficials. If mealybug hotspots are confined to a small section of the paddock, remove and destroy infested plants where possible. 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.
5. Aim to control mirids and/or SLW without flaring mealybug by following the recommendations in (2) and (3) above.
6. 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, leave picking of the crop or infested sections for last. If possible lift picker heads above mealybug host spots or infested sections.
- After harvest, destroy crop residue thoroughly and root cut to a depth of 10 cm or more to minimise the survival of plant material in the soil that can harbour mealybug
- Consider pupae busting if you are planning on growing cotton again in the same or neighbouring field within 1-2 years.

Key beneficial insects

Predators – Three banded ladybird beetles, white collared ladybird beetles, transverse ladybird beetles, cybocephalus beetles, red and blue beetles, lacewings, cryptolaemus, smudge bugs, earwigs and native cockroaches. Of these, lacewings and three banded ladybird beetles are the most common and effective.

Parasitic wasps – *Aenaisus bambawalei*, a parasitoid of solenopsis mealybug are reasonably wide spread and are effective in suppressing populations.

Key features that influence survival and pest status

All stages of mealybug can cause damage. They have a high reproductive rate. One female can produce hundreds of offspring; eggs hatch out within an hour. They take about two weeks to develop from egg to adult. They shelter in protected positions on the cotton plant; in squares, bracts and under surfaces of leaves. The waxy coating on mealybugs is water repellent, making insecticide contact difficult. They can be spread in the field by wind, surface water runoff, rain splash, birds, people and farm equipment. Mealybugs disperse most readily as first instar 'crawlers'. All stages of nymphs and adults can move between plants by crawling.



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



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

Overwintering mealybugs, usually at the small and large nymph stage, can be found in the root zone of weed hosts; loose soil and ant nests on the ground can also provide them shelter during winter. Once the weather begins to warm, breeding and dispersal begins.

Alternative hosts

The solenopsis mealybug has an extremely wide host range. In Pakistan, it has been recorded on 154 plant species, including field crops, vegetables, ornamentals, weeds, and trees. In Australia, solenopsis mealybug has been recorded from a range of common weed species on-farm such as 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.

Mirids

Green mirid – *Creontiades dilutus*

Brown mirid – *Creontiades pacificus*

Yellow mirid (Apple Dimpling Bug) – *Campylomma liebknechti* (Girault)

Both green and brown mirids are similar in appearance, however brown mirids are slightly larger and many have darker pigmentation. While the brown mirid can cause similar damage to green mirid at the boll stage, at the squaring stage they cause less damage than green mirids. Brown mirids are usually found in much lower numbers than the green mirids on cotton and they move into cotton crops later than green mirids. The yellow mirid or apple dimpling bug (ADB) is about 1/3 the size of a mirid, can damage small squares and is also known to be a predator of mites, silverleaf whitefly eggs and Helicoverpa eggs. Past research has shown that 4 apple dimpling bugs do damage equivalent to 1 adult mirid.

Damage symptoms

Adults and nymphs cause early season damage to terminals and mid-season damage to squares and small bolls. Types of damage include blackening and death of terminals of young plants, blackening of pinhead squares and large square loss.

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 damage 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 be also caused by high temperatures. The relationship between mirid numbers and square loss is not always the same due to the different responses from various size squares, as well as changes in mirid feeding, likely due to a number of factors including temperature and the presence of natural enemies. For this reason both retention and mirid numbers should be considered when making a control decision.

Bolls that are damaged during the first 10 days of development may be shed. Bolls damaged between 10-20 days old will be retained but may not develop normally and have one or more stunted, brown locks. Apart from reduced weight, damaged bolls may not open properly 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. Cutting bolls open with a sharp knife to inspect the underlying tissue is the most effective field technique for confirming whether or not 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 becomes less as fibre elongation ceases and the developing seed becomes located deeper within the boll relative to the boll wall.

Further information on mirid identification and damage symptoms can be found in this cottoninfo video https://www.youtube.com/watch?v=FdCtVONjh_Y

Sampling

Mirids are a very mobile pest and are easily disturbed so care must be taken during sampling, otherwise numbers may be underestimated (discussed below). It is important to distinguish between nymphs and adults. The presence of nymphs can indicate that a mirid population has become entrenched, whilst older 4th and 5th instars can cause as much damage as adults.

Once squaring commences, regularly assess fruit retention. It is also important to monitor for all types of plant damage that are symptoms of mirid feeding such as tip damage (early-season) and boll damage (mid-season) by checking damaged bolls.

Frequency

Sampling at least twice a week is important in order to identify sudden changes in abundance which may indicate rapid influxes of mirid adults. The greatest risk from mirids is through the period of peak fruit production, from first flower until 60% of bolls are 20 days old.

Methods and sample size

The distribution of mirids is usually not uniform (patches of higher density amongst areas of low density) so sample throughout the field to gain a more reliable estimate of overall density. There are three options for sampling: visual inspection of whole plants or using a beat sheet or sweep net. All methods 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 without disturbing the mirids. From 10 nodes onwards, only a beat sheet or sweep net should be used.



A damaged boll showing warty growths and discolouration caused by mirids. (M.Hickman, QDAF)



When beat sheeting, the beat sheet is placed against the base of a row of plants and draped across the furrow and up over the adjacent row. Each sample consists of the plants in a 1 m section of row of plants being vigorously pushed with a 1 m stick to create a shaking motion on to the area of beat sheet lying across the furrow. Quickly count the number of mirid adults and nymphs dislodged onto the beat sheet. Pay attention to not miss first and second instar nymphs which are very light green in colour and may be difficult to see against the yellow beat sheet. Mirids are more easily discerned from other small green insects by observing their fast motion and rather long antennae.

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 sweep net, a sample can consist of 20 sweeps along a single row of cotton using a standard (380 mm diameter) sweep net. Preliminary research has shown that 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 damage is affecting the crop. Note that other stresses (e.g. high temperatures (day or night) or cloudiness) can cause square and young boll shedding in the absence of mirids. If boll damage is suspected, a sample of bolls from multiple locations should be cut open and checked for internal damage.

More information on mirid sampling and thresholds can be found in this cotton info video <https://www.youtube.com/watch?v=iK63neuw7rU>

Thresholds

Central to the decision to spray is the economic threshold, which is the level at which the amount of damage by a given population of pests will exceed the costs associated with controlling that pest. Control costs include product and application costs as well as costs that may later arise as a result of the control operation. For example, the level of pest damage required to offset an inexpensive broad-spectrum insecticide might at first appear to be very low, therefore justifying a low threshold. However, part of the cost of that control option maybe that a more expensive product is more likely to be required later in the season to control a secondary pest such as Silver Leaf Whiteflies. Cheap broad spectrum products might on the surface justify low pest control trigger points, however it may be more cost effective to delay control until pest numbers are higher and would justify the cost of using a more expensive but selective product option which may generate additional savings down the track. Alternatively the use of a more expensive, but selective option might be justified at a particular pest threshold on the basis of potential future savings on consequent controls or secondary pest control. Consequently control costs are only estimates of the true cost of deciding to spray.

A recent review has reconsidered the historical basis for mirid thresholds in the context of modern day high yielding Bollgard 3 production systems. Whilst this has raised new research questions, existing mirid threshold data can be interpreted in a way that better reflects current economics and production practices.

The 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) 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.

Deciding when to spray

Under field conditions, the link between mirid density and damage is not straight forward. 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 crops ability to compensate for damage** – This varies with the season length and with the plant's development stage. For agronomically well managed crops with optimised agronomic inputs, the capacity for compensation to overcome fruit loss during squaring is very high, but reduces as the crop progresses through early flowering. Ultimately the capacity for compensation depends on the extent of damage and crop stage and 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 which could be unfavourable for some regions. Therefore for shorter season regions, additional caution maybe required when managing mirids e.g. using lower thresholds or higher levels of retention.
- **Other factors** that may influence the likelihood of mirids causing damage are the presence of beneficials (due to predation and disruption of mirid feeding behaviour), the presence of other pests (mirids may preferentially feed on eggs), temperature, which may affect the behaviour of the mirids, the behaviour of mirid predators (work on this is on-going), and of the ability of the plant to compensate for damage. There are 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 might be flared by ongoing control practices e.g. whitefly or mealybug.

THE FIRST STEP is to confirm that the damage in the crop is caused by mirids (or other sucking pests). Low temperatures can stop cotton plants developing squares, lack of water, high temperatures, or cloudiness may cause the plant to shed squares. High temperatures on fruit may cause infertility, resulting in beaked bolls. Bolls get a number of black dots on them during the season that are unrelated to mirid activity. If you find damage, but not mirids, it is unlikely that mirids caused the damage.

Table 8 provides a checklist to assist with making the decision to spray based on economic thresholds. The "calculated cost of control" incorporates the cost of the insecticide and application, but may also include other costs harder to calculate, such as triggering other pests and the need for subsequent sprays. Each farm will vary in this respect so consider your unique system.

Key beneficial insects

Damsel bugs, big-eyed bugs, predatory shield bugs, as well as lynx spiders, yellow night stalkers and jumping spiders feed on mirid adults, nymphs and eggs. 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

The insecticide products registered for the control of green mirid in cotton in Australia are presented in Table 9. The use of more selective insecticide options will help to conserve beneficial insects (see Table 3 on pages 10–11). Research by Qld DAF and CSIRO entomologists have shown that salt mixed with a low rate of insecticide provides similar efficacy against mirid and stinkbug to the full rate alone but with reduced negative effects on beneficials.

However, a factor to consider with the use of 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. Caution should be used when considering reduced rates where populations have built up over time to reach threshold levels, as a mixed population of adults and eggs is more likely to exist compared with treating sudden influxes.

Resistance profile

Mirids are not known to have developed resistance to insecticides in Australian cotton, however mirids are difficult to bioassay and so there is currently limited resistance monitoring for mirids. 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) are registered for the control of mirids, but could cause resistance to aphids

and SLW. Any decision to use an additional active ingredient (either in a co-formulation or a mix) should be based on threshold. Not only can additional active ingredients be unnecessarily disruptive, but can lead to resistance. For example use of abamectin (group 6) when treating mirids has caused high-level resistance in mites.

Overwintering habit

Mirids are known to survive on weeds and native plant hosts surrounding cotton fields. They are also known to breed on native hosts in inland (central) Australia in winter and can migrate to cotton growing areas in spring in a similar way to *H. punctigera* (see section on Native Budworm, page 23). 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:

Qld DAF, Emerald – Richard Sequeira: 0407 059 066.

CSIRO, Narrabri – Mary Whitehouse: 0428 424 205 or
Simone Heimoana: 0427 992 466.

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

TABLE 8: Mirid revised 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 threshold if:

- No plant compensation time (e.g. short, cold 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 (c. 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 9: Control of mirids (Green mirid *Creontiades dilutus* and Yellow mirid or Apple dimpling bug *Campylomma liebknechti*)

Active ingredient	Insecticide 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	Group 22A	Low	Under high populations suppression only may be observed. Maximum 3 applications per season.
Indoxacarb + salt	Group 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	Group 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	Group 4C	Moderate	Use lower rate when infestation is predominately nymphs. Maximum 4 applications per season.
Fipronil	Group 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.
Fonicamid	Group 29	Moderate	Thorough spray coverage is essential. Maximum 2 applications per season.
Emamectin benzoate	Group 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	Group 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	Group 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	Group 4A	Moderate	Apply when numbers reach threshold levels requiring treatment. Maximum 2 applications per season.
Imidacloprid	Group 4A	Moderate	Do not use as first foliar if neonicotinoid seed treatment used. Maximum 2 applications per season.
Dinotefuran	Group 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.
Phorate	Group 1B	High	Qld and WA only. Suppression only. Apply into seed furrow at planting or incorporate into the soil as side dressing deep enough to avoid disturbance by future cultivations. Maximum 1 application per season.
Dimethoate (high rate)	Group 1B	High	Do not use where resistant strains are present. Do not harvest for 14 days after application. Do not graze or cut for stockfood for 14 days after application. Maximum 2 applications per season.
Gamma-cyhalothrin	Group 3A	Very High	Apply at recommended threshold levels as indicated by field check. Maximum 1 application per season.
Lambda-cyhalothrin	Group 3A	Very High	Apply at recommended threshold levels as indicated by field checks. Maximum 1 application per season.
Alpha-cypermethrin	Group 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	Group 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	Group 3A	Very High	Suppression only. Maximum 1 application per season.

#For all control options ALWAYS refer to the label for instructions and to minimise impact on bees.

*For more details about impact on beneficial insects, refer to table 3 in this guide.



Pale cotton stainers

Dysdercus sidae

Damage symptoms

Pale cotton stainers are occasional pests of cotton in Australia. Economic damage is unusual because of their:

- Susceptibility to insecticides used for other pests, especially in conventional cotton;
- Inability to survive high temperatures (> 40°C); and,
- Need for free water to be present.

However in mild seasons Bt crops may be a favourable environment for cotton stainers and management may be required.

Pale cotton stainers are able to 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 seed viability all decline as a result of cotton stainer feeding. Loss of seed viability should be a consideration in pure seed crops.

Damage to bolls up to 20 days old may cause warty growths on the inner boll wall. Damage to older bolls, 20 days old onwards, usually shows no external symptoms and only small dark marks will be seen on the inside of the boll wall. Most damage is to seeds, reducing their growth and sometimes lint production. Tightlock can result around damaged seeds, preventing the lint from fluffing out as the boll opens, and damaged locks (boll segments) often appear yellow or stained.

Sampling

Sample for adults and nymphs of the pest as both stages can cause similar amounts of damage. Where adults and nymphs are observed feeding, monitor the percentage of damaged bolls.

Frequency

Sample at least weekly once bolls are present, and more often if pale cotton stainer numbers approach threshold.

Usually cotton is infested by adults flying into fields around the time of first open boll. Sometimes however, perhaps due to seasonal conditions,



Juvenile pale cotton stainers are often found in aggregations low in the canopy. They will feed on developing bolls.
(Lewis Wilson, CSIRO)



Adult pale cotton stainers are often seen in maturing cotton, often as mating pairs. They can damage maturing bolls.
(Lewis Wilson, CSIRO)

populations can be found earlier, during boll maturation. Flights of up to 15 km have been recorded. Adults will mate soon after arrival. The expanding population of developing nymphs is likely to cause economic damage.

Methods

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. Ensure sampling occurs at multiple sites spread throughout the field. The beat sheet is a suitable sampling method however as younger instars favour the lower canopy, visual searching is also a good complementary technique.

Bolls of varying ages should be cut open to confirm and monitor for signs of damage. Studies have shown that pale cotton stainer bug feeding causes small black marks on the outer surface of young bolls but almost no marking to older bolls. Similarly, warty growths may be found on the inside of the boll wall if young bolls are damaged, but older bolls will not have these. To confirm damage bolls need to be opened and seeds cut and examined for browned, dried damage areas. A week after damage the lint may begin to have a more yellow appearance and locks will be stuck to the boll wall – a good indication of pale cotton stainer feeding.

The mild, wet conditions that favour the survival of pale cotton stainers in cotton will also favour the occurrence of secondary infections by yeasts, *Alternaria* and bacteria in cracked bolls. These infections can cause tightlock and lint staining. The presence of pale cotton stainers when such damage occurs may be coincidental.

Thresholds

Action threshold during boll development

When adults and nymphs are observed in the crop and damage to developing bolls is detected, an action threshold of 3 pale cotton stainers/m is recommended. This threshold is based on the relationship between cotton stainer damage and the damage caused by green vegetable bugs. Both nymphs (usually 3rd to 5th stage nymphs) and adults cause similar amounts of damage.

Action threshold after first open boll

When adults and nymphs are observed feeding in open bolls, the threshold must consider the potential for quality downgrades of the lint as well as the loss of seed weight and seed viability. Where staining is observed a threshold of 30% of bolls affected should be used to prevent a colour downgrade.

Key beneficial insects

A range of natural enemies such as Tachinids (parasitic flies) and predatory reduviid bugs (e.g. assassin bugs) have been recorded in Africa. However, they have mainly exerted pressure when cotton stainers have been feeding on native hosts rather than in cropping situations. The role of natural enemies in the control of developing populations of pale cotton stainers in Australia has not been studied.

Selecting an insecticide

As an occasional pest, there are few products registered for their control. The synthetic pyrethroids lambda-cyhalothrin (Karate Zeon, Matador) and gamma-cyhalothrin (Trojan) are registered; check the labels of these products for more information. However their status as an occasional pest is influenced by their susceptibility to insecticides used for the control of Helicoverpa and other pests. Cotton stainers can sometimes be incidentally managed when mirids are controlled. 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.

Resistance profile

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, cultural controls, particularly of alternative hosts, between cotton seasons assist greatly in limiting population development.

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 where cotton stainers can access this food source over long periods. Controlling volunteer and ratoon cotton is important for limiting cotton stainer's access to alternative food source.

Further Information:

CSIRO, Narrabri

Simone Heimoana: (02) 6799 1592 or 0427 992 466

Rutherglen bug

Nysius vinitor Bergroth



This image shows the top and underside of Rutherglen bug adults (left) and nymphs (right). (Qld DAF)

The Rutherglen bug (RGB) is indigenous to Australia and is found throughout Australia's agricultural regions on a wide range of host plants, affecting a range of crops including fruits, vegetables, oilseeds and grains. Adults are 3-4 mm long, mottled grey-brown-black, and have clear wings folded flat over the back. Nymphs (juvenile bugs) are wingless, with a reddish-brown, pear-shaped body. Further information on identifying RGBs and their lifecycle can be found in the Pest and Beneficial Insects in Australian Cotton Landscapes guide.

Damage symptoms

Adult RGBs are often found on cotton, although past studies indicate that adults generally do not feed and are unable to reproduce on cotton. Starving nymphs, have been known to migrate from maturing sunflower or canola crops to feed in and damage border areas of adjacent cotton.

Little is known about the damage potential of RGB on crops other than sunflower, however, it has been reported that mass migrations of RGBs can suck cotton seedlings dry resulting in establishment problems and uneven stands. Experiments have shown that 20-50 RGB caged onto 5 day old bolls produced feeding marks on the green boll, however, these marks did not penetrate into the boll and caused no damage to the developing seeds or lint (see photos below)



Recent trial work conducted by Qld DAF and CSIRO found that RGBs did not contribute to fruit loss. Feeding marks on a 5 day old boll exposed to 20 Rutherglen bugs for 1 week and assessed at 13 days old. (Melina Miles Qld DAF and Tanya Smith, CSIRO)



Sampling

Even though there is no established threshold in cotton, it is important to monitor changes in the pest population with a weekly estimate of the number of RGBs/plant. Check for the presence of nymphs as well as adults. If nymphs are present, investigate if they are wide-spread or concentrated on the edge of a field. Where nymphs are present in seedling cotton, pay close attention to wilting or dying plants and the overall plant stand.

If high bug numbers are found in squaring or flowering cotton, monitor plant growth and fruit numbers. If feeding damage is seen on bolls, cut the fruit and check if damage extends into the boll. If damage such as blackened stamens or darkened seeds can be seen, the damage is unlikely caused by RGB and the crop should be monitored for other sucking pests.

Key beneficial insects

There is little data on the natural enemies of the RGB but spiders are thought to play a role.

Management and control

Growers should plan ahead with regard to their cropping sequence, anticipating potential migrations of pests from one finishing crop to another emerging one. RGBs can be controlled by removing the weeds they use as hosts and by ploughing a deep furrow around the emerging crop, preventing wingless nymphs from migrating from weeds or canola. Filling a furrow with water acts as a physical barrier to the migration of nymphs.

Overwintering habit

RGBs overwinter and breed on some winter crops and a wide variety of weeds particularly on mat-like weed growth at ground level, e.g. pigweed.

Alternative hosts

RGBs are important pests of sunflowers.

Host range

RGB feed and breed on many weeds, including pigweed, thistles, capeweed, fleabane and cudweed. RGBs thrive when winter and early spring conditions favour these weeds, followed by a dry late spring that forces bugs to migrate from dying weeds to surrounding crops. Field crops that are commonly infested include sunflowers, linseed, canola, wheat, sorghum, safflower and lucerne, as well as horticultural crops.

Soil pests at plant establishment

True Wireworms *Agrypnus* sp

False Wireworms *Gonocephalum* spp. *Pterohelaeus* spp

Black Field Earwig *Nala lividipes*

Symphyla *Hanseniella* spp

Damage symptoms

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 or soil constraints. See below for symptoms associated with specific pests.

Sampling

Sampling for soil insects is best conducted using a baiting technique. Soil digging can also be used for detecting presence of symphylans (see section below) however is ineffective for earwigs and wireworms.

Grain or potato baiting for soil insects 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 take medium sized potatoes and cut in half.
2. Bury a dessertspoon full of the seed under 1 cm of soil or bury the potato bait cut side down at each corner of a 5x5 m square at five widely spaced sites per 100 ha.
3. Mark the position of the baits as high populations of soil insects can completely destroy the baits.
4. One day after seedling emergence or 5-7 days after placing out potato baits, dig up remaining bait and count the insects. Feeding on the potato bait will be immediately obvious.

The type of seed used makes no noticeable difference when it comes to attracting soil-dwelling insects. Recent research has shown that medium sized potatoes cut in half and buried in the same manner with the cut side facing down will produce comparable results to grain baits.

Soil pest cultural aspects

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 pest insect numbers to decline due to a lack of food.

The influence of field stubble is contentious as high stubble loads within fields will promote the abundance of soil pests however, stubble can also provide a diversionary food source as well as increase the diversity of soil fauna such as predatory beetles (carabidae), centipedes and earthworms. The incorporation of grain 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

Damage symptoms

Larvae attack germinating seeds, the hypocotyl, roots and at the surface of young cotton plants resulting in seedling death, young plant 'felling' and patchy plant stands. The adult beetles can also damage seedlings by chewing at or just above ground level.

Threshold

Conduct bait sampling prior to planting to determine the abundance of wireworm. Although there are no specific thresholds for wireworms in cotton, densities of one or more larvae per baiting site are considered damaging for summer grain crops.

Management

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. Importantly, infestations of wireworm larvae detected after crop emergence cannot be controlled with baiting or surface spraying. Therefore this pest must be detected before planting for control actions to be effective.

Black Field Earwigs

Damage symptoms

Black field earwigs are an occasional pest of seedling cotton, predominantly feeding on germinating seed and seedling roots, resulting in poor establishment.

Threshold

Conduct bait sampling prior to planting to determine the presence of black field earwigs. No thresholds for black field earwigs have been defined for cotton. Thresholds used for maize and sorghum suggest that control maybe warranted when more than 50 earwigs are found across 20 baits or 2-3 earwigs per bait sample.

Management

If earwig numbers are high the application of insecticide treated grain baits at the time of sowing may offer protection. Notably the use of in-furrow insecticide treatments have been found to be generally ineffective for the protection of newly sown grain crops where dense populations are present. The efficacy of seed dressings for black field earwig control is unknown.

Symphylans

Symphyla are white, soft-bodied "millipede-like", soil inhabiting arthropods, 3-7 mm long with 12 pairs of legs and a pair of antennae. Symphyla are sensitive to light and are very active when exposed. Symphyla are relatively common in most soils where they generally feed on decomposing organic matter.

Symphyla have been associated with crop establishment issues in some fields within the Theodore irrigation district. However, whether crop damage is solely attributable to Symphyla or a broader complex of soil pests and disease has often been unclear.

Damage

Symphyla may feed on rootlets and root hairs. Continuous surface grazing can result in a characteristic 'witches broom' root system or a general lack of lateral root expansion. Symphyla activity is more common in well structured soils that enable easier movement through the profile. As feeding is confined to root tips and hairs, dry soil conditions will exacerbate the severity of damage symptoms by inhibiting root exploration of the soil profile. Typically Symphyla feed on the roots where the soil is moist and as the profile dries out, the continuous tip pruning of the roots can leave plants stranded in the top 10-15 cm of drier soil upon an otherwise full profile. Symphyla are very active and will move up and down in the soil profile to reported depths of up to 1 metre.

Symphyla damage in establishing cotton crops may first appear as plant patches showing slight symptoms of moisture stress and reduced vigour. Over time symptoms become more pronounced even though the subsoil moisture is adequate. Damage from other soil pests can often appear in the same way.

Sampling

The detection of Symphyla prior to planting is difficult as distribution within a field is generally patchy.

Where plants are showing symptoms of damage, conduct a basic soil survey to confirm the presence of Symphyla. Insert a shovel to full depth at the plant line on the hill and carefully lever the soil out so that it can be inspected more closely. Symphyla are delicate soft bodied creatures so avoid overly compacting the soil while sampling. Start with the soil from the bottom of the shovel, as Symphyla may be more common in the deeper, wetter part of the soil profile. Holding a soil clod in one hand, use your other hand to carefully break the soil apart while keeping a close eye on the inner surfaces for the movement of Symphyla. Symphyla are fast moving and will rapidly shift to avoid sunlight.

It is important not to confuse Symphyla with other soil organisms such as Diplurans or collembolan (springtails). Diplurans closely resemble

TABLE 10: Control of wireworm (Wireworm *Apyrpius variabilis* and False wireworm *Pterohelaeus* spp.)

Active ingredient	Insecticide group	Overall impact on beneficials*	Comments#
Phorate	Group 1B	High	Apply into the seed furrow at sowing. Maximum 1 application per season.
Chlorpyrifos	Group 1B	High	Use higher rate with extreme population numbers. Maximum 3 applications per season. Use minimum spray volume of 20 L per sown ha.
Bifenthrin	Group 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	Group 3A/1B	Very high	Apply as directed spray into the furrow at planting. Use higher rate with extreme population numbers. Maximum 1 application per season.

#For all control options ALWAYS refer to the label for instructions and to minimise impact on bees.

*For more details about impact on beneficial insects, refer to table 3 in this guide.



A Symphylan (left) is very similar in appearance to a Dipluran (right), but has legs all along its body like a millipede and lacks the Dipluran's long rear appendages. (Paul Grundy Qld DAF)

Symphyla but are distinguishable by their smaller size, more rapid movement and having legs confined to the upper body. Symphyla have legs along the entire body much like a millipede. Collembolans are more easily distinguished from Symphyla having more of a curved body and the capacity to jump when disturbed.

Symphyla thresholds & management strategies

There is no definitive information regarding the density at which Symphyla are likely to cause crop damage. However, recent crop surveys and pot trials suggest that Symphyla are unlikely to be the lone cause of crop establishment issues. Fields with establishment problems and high numbers of Symphyla have also been found to host high numbers of other soil pests such as wireworm and earwigs. Conditions in these fields were also suboptimal in terms of unfavourable temperatures and a drier than optimal soil profile which slowed plant development and by default increased the period whereby young plants were more susceptible to root feeding and damage. A fair conclusion from these fields would be that Symphyla exacerbated poor establishment but were not the primary driver for the poor plant stands observed. In the absence of other soil pests and diseases or more optimal field conditions the impact of Symphyla may have been minimal.

There are no recommended chemical control options for Symphyla. 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 were used in nearly all surveyed fields where establishment issues have been recently recorded which suggests that these products offer limited protection when high densities of soil pests are present.

For fields where Symphyla have been known to be abundant near Theodore, a useful strategy has been to plant these areas last so that the warmer conditions aid more rapid establishment. Plant roots that grow deeper into the profile more quickly are less likely to become stranded in dry soil through the root pruning by Symphyla feeding. If plants show signs of moisture stress where Symphyla are present, a quick flush with irrigation may assist plants that may have root systems that are becoming stranded in the drier surface profile due to root pruning. Irrigation can also decrease Symphyla activity in the upper profile for about 7-14 days which may also assist crop recovery.

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

Other soil pests

Cutworms (*Agrotis sp*) can be a pest of emerging cotton but the incidence of this pest causing economic damage to cotton fields has been rare. This pest is typically found along field margins that adjoin pastures or where cotton has been sown into recently sprayed out weedy fallows.

Whitegrubs which are the larvae of Scarabaeidae beetles have been found to feed on the roots of crops where they cause a loss of vigour and lodging. Damage in cotton is rare and likely only if sown into fields that were previously a weedy fallow or a summer sorghum crop. ■■■

Spider mites

Two-spotted spider mite – *Tetranychus urticae*

Bean spider mite – *T. ludeni*

Strawberry spider mite – *T. lambi*



The top of leaves showing two-spotted spider mite damage (left) and strawberry spider mite damage (right).

(Photo: C. Trapero Ramirez CSIRO)



The underside of leaves showing two-spotted spider mite damage (left) and strawberry spider mite damage (right).

(Photo: C. Trapero Ramirez CSIRO)

The two-spotted spider mite is the main pest species, the other two species do colonise cotton but seldom cause economic damage. Even in high numbers, *T. lambi* infestations result in very low levels of damage. Historically, two-spotted spider mite was the dominant mite species, but in recent years it has become less common and strawberry spider mite more common. These species differ in damage potential so correct identification of the species present is crucial for good decisions.

For more information on spider mites in cotton see this cottoninfo video <https://www.youtube.com/watch?v=oUcatfA00QM>

Damage symptoms

All three species feed on the underside of leaves but the damage symptoms are quite different.

Two-spotted mite – nymphs and adults cause damage that appears as brownish areas on the lower leaf surface, usually starting at the junction of the petiole and leaf blade or in leaf folds. These areas show reddening on the upper surface. If damage is allowed to continue leaves will become completely red and fall off.

Bean spider mite (adults of this species are red in colour) – damage results in white, intensively stippled areas on the leaf underside, but there is generally no reddening of the upper surface. Severe damage may result in some leaf shedding.

Strawberry spider mite – this species 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.

Sampling

Sampling protocols for mites in cotton are presented in full on page 38.

Look for the presence of any mite stages. Eggs and immature stages are difficult to see with the naked eye, so a hand lens should be used. Mites infest the underside of leaves. Sample the oldest leaf when plants are very young. As plants grow, choose leaves that are from 3, 4 or 5 nodes below the plant terminal.

Check which species is present. Two-spotted spider mite is yellowish, pale green and has 2 distinct dark green spots on either side. Adults of bean spider mite are a dark red colour. Strawberry spider mite is smaller than the other two spider mites and is pale green with 3 dark green spots on either side, however, as mites age, these spots can become blotchy and merge, making it more difficult to distinguish it from *T. urticae*.

More information on spider mite sampling can be found in this cottoninfo video <https://www.youtube.com/watch?v=2hB84S7p6vY>

Frequency

Sample at least weekly. Begin at seedling emergence. Sample more frequently if mite populations begin to increase, if conditions are hot and dry or if sprays which reduce 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. Refer to sampling protocol on page 38. It is helpful to plot the development of mite populations on a graph. This allows changes in mite population development to be seen at a glance.

Thresholds

Thresholds and yield loss charts have been developed for two-spotted mite. These probably over-estimate yield loss for bean spider mite. A threshold for strawberry mite has not been established.

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.

Seedling emergence to squaring

Mites are normally suppressed by predators, particularly by 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. Use Table 11 on page 39 to determine whether the rate of increase warrants control.



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

(Lewis Wilson, CSIRO)



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. Use Table 11 on page 39 for details.

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). Use Table 11 on page 39 for details.

Crop exceeds 20% open bolls

Control is no longer warranted.

Mite yield reduction charts

A simple relationship has been developed which allows prediction of yield loss from mites based on knowledge of the rate of population increase in the time remaining until defoliation. These 'look-up' charts have been provided in Table 11 on page 39 for areas with different season lengths:

Warmer – Bourke, Central Queensland, Macintyre Valley, St George, Mungindi and Walgett

Average – Dalby, Gwydir Valley, Lockyer Valley and Lower Namoi Valley

Cooler – Upper Namoi, Cecil Plains, Pittsworth, Macquarie Valley and Southern NSW

The charts use the rate of increase of the mite population. This 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. Go to 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 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 beneficial insects

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, 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. 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 (see Table 3 for information on this risk). This occurs because those sprays kill key beneficial species allowing resistant mite populations to flourish.

The 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 OP's, 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 continue to rise. The 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.

There has been no research yet that relates bean spider mite abundance to yield loss. However, if populations build to the point that leaves begin to drop then yield loss is possible and populations should be controlled.

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

Preferred winter weed hosts are turnip weed, marshmallow, deadnettle, medics, wireweed and sowthistle, although they can be found on almost any broad-leaved weed species. Alternative winter and spring host crops include safflower, faba beans and field peas.

Further Information:

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

NSW DPI Narrabri
Lisa Bird: (02) 6763 1128.

SAMPLING PROTOCOLS FOR MITES IN COTTON

Population Monitoring

1. Walk into the field about 40 m. (Early in the season it is also advisable to sample near the field edges to see if significant influxes of mites have occurred).
2. Take a leaf from the first plant on the right or left. The leaf should be from the third, fourth or fifth main-stem node below the terminal. If the plant has less than three leaves, sample the oldest. Note that early in the season, up to the point that 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 the opposite side to the previous one, and so on until you have 50 leaves. (Wait until you have collected all the leaves before scoring them).
4. Once all the leaves have been collected score each leaf by turning it over, looking at the underside, firstly near the stalk, then scanning the rest of the leaf. If mites of any stage (eggs or motiles) are present score the leaf as infested. A hand lens will be needed to see mite eggs because they cannot be seen with the naked eye.
5. Repeat this simple procedure at several widely separated places in the field to allow for differences in mite abundance within the field. Depending on the size of the field, 4-6 sites are needed to obtain a good estimate of mite abundance.
6. When finished sampling, calculate the percentage of plants infested in the field.

Additional recommendations for monitoring mites in seedling cotton

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

When more than 5% of plants are infested it is also advisable to count the numbers of mites on plants, and to score the mite damage level (i.e. estimate the percentage of the plants total leaf area that is damaged by mites).

Continue to monitor mite numbers, damage levels and infestation levels at least weekly, or more frequently if infestation levels are high (> 30% of plants 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 the 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.

After about 6-8 true leaves, specific mite counts and damage scoring can cease, but continue to use the presence/absence sampling method (points 1-6) until 20% open bolls.

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.
2. Collect 50 infested leaves per field. Only collect one sample per field. Keep samples from different fields separate. If mite numbers per leaf are very low, consider collecting up to 100 leaves.
3. Try to avoid collecting all the leaves from only 2 or 3 plants. Where possible collect infested leaves from different areas across the field.
4. Phone Grant Herron and let him know you are sending the sample. Avoid making collections and sending samples on Thursdays or Fridays.
5. Ensure samples are clearly labelled and that labels include 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.

Sending collections to

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

Sampling Tips

to save time in the field...

Aphids, mites and whitefly can all be sampled using the same leaves from the 3rd, 4th or 5th node below the terminal.

Assess for whitefly while collecting the leaves as adults are mobile. Then assess the collected leaves for both mites and aphids.

Collect leaves from several locations in the field.

While the whitefly sampling protocol requires a minimum of 10 leaves per location, aphid and mite sampling requires at least 20 leaves per location. Using 20 leaves will increase the accuracy of whitefly assessment.

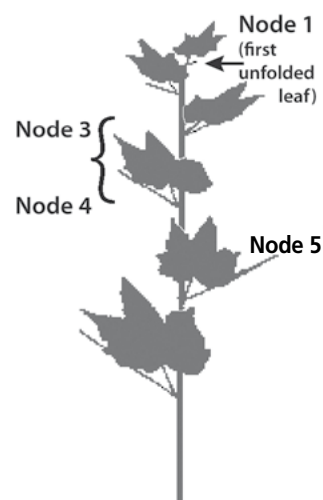



TABLE 11: Yield reduction caused by mites

The charts below can be used to estimate the percentage of yield reduction caused by mites, 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

**TABLE 12: Control of two-spotted spider mite (*Tetranychus urticae*)**

Active ingredient	Insecticide group	Mite resistance	Overall Impact on beneficials*	Comments#
Etoxazole	Group 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	Group 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	Group 12A	No resistance	Low	Treatment at higher infestation levels may lead to unsatisfactory results. Maximum 2 applications per season.
Abamectin	Group 6	Widespread – med/high	Moderate	Best results will be obtained when applied to low mite populations. Maximum 2 applications per season.
Emamectin benzoate	Group 6	CR Abamectin	Moderate	When applied for Helicoverpa control will reduce the rate of mite population development. Suppression only. Maximum 2 applications per season.
Propargite	Group 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	Group 19	No data	Moderate	Suppression when used for controlling Helicoverpa. Maximum 4 applications per season.
Dimethoate	Group 1B	No data	High	Will not control organophosphate-resistant mites. Do not harvest for 14 days after application. Do not graze or cut for stockfeed for 14 days after application. Maximum 2 applications per season.
Methidathion	Group 1B	No data	High	Apply when infestation is light to moderate, ensuring good coverage. Maximum 3 applications per season. If mite populations are high or conditions favour a build-up, repeat application in 5-7 days.
Phorate	Group 1B	No data	High	Use lower rate for short residual control at time of planting. For extended period of control use higher rates. Only use the highest rate on heavy soils when conditions favour good emergence. Maximum 1 application per season. Note that rates differ by state.
Bifenthrin	Group 3A	Widespread – med/high	Very High	Applications against Helicoverpa will give good control of low mite populations. Maximum 1 application per season.
Deltamethrin	Group 3A	CR Bifenthrin	Very High	Suppression only. Maximum 1 application per season.

#For all control options ALWAYS refer to the label for instructions and to minimise impact on bees.

*For more details about impact on beneficial insects, refer to table 3 in this guide. CR = cross resistance likely.



Thrips

Tobacco thrips – *Thrips tabaci*

Tomato thrips – *Frankliniella schultzei*

Western flower thrips – *F. occidentalis*

Damage symptoms

Thrips larvae and adults cause early season damage to terminals, leaves and stems. The most obvious damage is crinkling and reduced area of young leaves which is very visible. The feeding damage is a visible 'silvering' on the undersides of leaves. Thrips can also kill the growing terminal, which delays the plant's growth until it can establish a new terminal, but this only occurs when they are present at very high densities.

In some seasons thrips can also build to high numbers in flowers and on leaves in the mid-late season. High numbers on leaves can lead to stunting and damage especially along leaf veins. While recognised as a pest, both adults and larvae of all three thrips species are a key predator of spider-mite eggs.

For more information on thrips identification and damage see this cotton info video <https://www.youtube.com/watch?v=e8B0wpimUvA>

Sampling

Sample seedlings and count the number of thrips/plant. Check for the presence of thrips larvae as well as adults. The presence of larvae indicates that the population is actively breeding. This is important to establish as



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

crops that have had an insecticide seed treatment or in-furrow insecticide treatment may have adult thrips, as these continue migrating into the crop from surrounding vegetation, but no larvae and little plant damage. This indicates that the insecticide is effectively controlling the thrips while the presence of larvae would indicate poor control.

Score the severity of damage to the seedlings by estimating the percentage reduction in leaf area. Late season, thrips may reach high numbers in flowers and on cotton leaves, especially in crops where there has been either little or no insecticide use. These thrips help to control mites. Late season thrips damage rarely justifies control.

Frequency

Sample weekly from seedling emergence and continue sampling seedlings 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. It is always worthwhile to 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 observe and count the number of adult and larval thrips on 20-30 separate plants for every 50 ha of crop. At the same time assess leaf damage. When assessing leaf damage, if the average size of damaged leaves is less than 1 cm squared, then leaf area reduction is usually greater than 80%.

Check if thrips have killed the plant terminal. This is indicated by complete blackening of the embryonic leaves in the terminal. Thrips must be present in high numbers (>30/plant) for this to occur.

For more information on sampling and management of thrips see the following cottoninfo video <https://www.youtube.com/watch?v=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 being less likely to negatively affect beneficial species (predators or parasites) than an insecticide applied to the crop after emergence.

Thrips damage to leaves (very common) can result in delayed maturity or yield loss if very severe. In northern and central regions with warmer climates, the risk of delayed maturity or yield loss is low because plants

TABLE 13: Control of thrips

Active ingredient	Insecticide group	Overall impact on beneficials*	Comments#
Tobacco thrips (<i>Thrips tabaci</i>) and Tomato thrips (<i>Frankliniella schultzei</i>)			
Fipronil	Group 2B	Moderate	Regent will take 3-4 days to reach full effectiveness. Use higher rates under high pressure. Avoid repeated use of this insecticide group.
Phorate	Group 1B	High	Use low rates for short residual control at time of planting. Use high rates for extended period of control. Only use the highest rate on heavy soils when conditions favour good emergence. Maximum 1 application per season.
Dimethoate	Group 1B	High	Do not harvest for 14 days after application. Maximum 2 applications per season.
Western flower thrip (<i>Frankliniella occidentalis</i>)			
Spinetoram	Group 5	Low	Maximum 2 applications per season. It should be noted that every western flower thrips tested in Australia since resistance screening commenced has been pyrethroid resistant, so that group must be avoided. Maximum 2 applications per season. Refer to mandatory no spray zone on label.

#For all control options ALWAYS refer to the label for instructions and to minimise impact on bees.

*For more details about impact on beneficial insects, refer to table 3 in this guide.



can outgrow and compensate for thrips damage and yield loss due to thrips damage is only likely one year in 10.

In cooler, shorter season areas (Downs, Upper Namoi, Macquarie) the risk of delayed maturity and/or yield loss is higher because there is less time to compensate and yield loss may occur one year in every two. In the newer southern regions (Hillston, Griffith, Hay) the effect of thrips on maturity and yield loss is not well understood, however research to date indicates it is similar to the short season areas, both in terms of yield risks and thrips species – predominantly onion/tobacco thrips, a smaller proportion of tomato thrips, and a very small proportion of western flower thrips (WFT) during establishment. In both seasons in the commercial scale trials in southern NSW, thrips-treated plots did not have significantly different yields compared to the untreated plots.

In all instances a seed treatment or a 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. This is likely to effect neonicotinoid seed dressing efficacy (as anecdotally suggested by some growers). However, crops should be carefully monitored and if significant leaf damage continues past 6-8 nodes control may be required. Thrips populations will normally naturally decline in early December.

In some instances, populations of thrips will remain high and plant growth delayed by cool, wet weather. In these situations, 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 early season in cotton.

Thresholds

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

Thrips can also be found in cotton in the mid and late season. These are usually *Frankliniella* spp. Adult thrips can be found in flowers where they feed on pollen, but it is unlikely that they affect pollination or fruit set. Eggs are laid on leaves and the hatching larvae may cause damage to the undersides of leaves, resulting in distorted, smaller leaves. These larvae are also predatory and will eat spider mite eggs, often preventing mite outbreaks from developing. Research has shown that 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.

Key beneficial insects

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

Selecting an insecticide

The insecticide products registered for the control of thrips in cotton in Australia are presented in Table 13 page 41. If neonicotinoid resistance is suspected in tobacco thrips, phorate is a suitable at-planting alternative. When deciding whether or not to control thrips with an insecticide, an important consideration is the benefit of thrips to cotton crops as predators of spider mites. **It should be noted that every western flower thrips tested in Australia since resistance screening commenced has been pyrethroid resistant, so that group 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.



Whitefly

Silverleaf whitefly (SLW) or Middle East-Asia Minor 1 (MEAM1) (biotype B)

Bemisia tabaci

SLW is a major pest due to contamination of cotton lint by honeydew and resistance to many insecticides. Greenhouse whitefly (*Trialeurodes vaporariorum*) are a rare pest of cotton particularly as they are susceptible to many of the insecticides used to control other pests.

Damage symptoms

SLW adults and nymphs cause contamination of lint through their excretion of honeydew. In terms of detection, silverleaf whitefly honeydew is considered worse than aphid honeydew because in hot conditions, it can dry to a matte, non-sticky consistency on lint and contamination is not obvious. Trehalulose, the main sugar in SLW honeydew, has a lower melting point than the characteristic sugars of aphid honeydew, and during the processing stage can liquify due to friction causing machinery to gum up and overheat.

Sampling

Sample for Species and Population

Species: Verify which whitefly species are present before implementing any management strategies. Consider insecticide application history for the crop as a clue to species composition – if the crop has been sprayed in the last few weeks and whitefly numbers have increased rapidly then it is most likely SLW that are present.

Greenhouse whitefly can be visually differentiated from *Bemisia tabaci* by comparing their wing shape in adults and the presence/absence of hairs on the nymphs (see photographs this page). The different biotypes of *Bemisia tabaci* cannot be distinguished by eye. Biotypes other than MEAM1 have not been detected in widespread annual monitoring of Australian cotton.

Population: Once you have confirmed the presence of SLW, effective sampling is the key to successful management.

Frequency

Sampling on cotton before flowering is not essential but can be helpful in making decisions about product selection for control of other pests – particularly to try to conserve beneficial species that may help delay build-up of SLW or other pests.

Sampling to decide if SLW justify control should commence at flowering and occur twice weekly from peak flowering (1300 Day Degrees). Cotton development can be predicted using daily temperature data (day degrees, DD).

Species verification and resistance monitoring

Sending collections to Qld DAF Toowoomba

Pack the leaves in a paper bag and then inside a plastic bag. Pack this in an esky with an ice brick that has been wrapped in newspaper. Send by overnight courier to;

Jamie Hopkinson

Qld DAF

203 Tor Street, Toowoomba Qld 4350

Phone (07) 4529 4152 or 0475 825 340

Email: jamie.hopkinson@daf.qld.gov.au

Ensure samples are clearly labelled and include the sampling location and contact information.

1. Define your management unit

- A management unit can be a whole field or part of a field – no larger than 25 ha and should have a minimum of 2 sampling sites.
- Sample 10 leaves/site (20 leaves/management unit).

2. Choose a plant to sample

- Move at least 10 m into the field before choosing a plant to sample.
- Choose healthy plants at random, avoiding disturbed plants.
- Sample along a diagonal or zigzag line. Move over several rows, taking 5–10 steps before selecting a new plant.

3. Choose a leaf

- From each plant choose a mainstem leaf from either the 3rd, 4th or 5th node below the terminal of the plant, as shown in the diagram on page 38.
- Look at one leaf from each plant.

Estimate whitefly abundance

Adults

Binomial sampling (presence/absence) is recommended as it is less prone to bias than averaging the number of whitefly/leaf.

Score leaves with 2 or more whitefly adults as 'infested'. Score leaves with 0 or 1 whitefly adults as 'uninfested'. Calculate the percentage of infested leaves.

Sample the middle canopy for nymphs

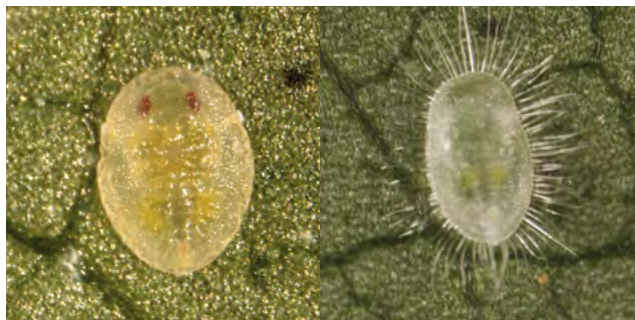
Check the whitefly population growth potential over the next 7–10 days by sampling the 8th node leaf for large nymphs with prominent red eye spots (4th instar and pupal stages), commonly known as red eye nymphs (RENS), using a hand lens. RENS will emerge as adults within 4–7 days. The 8th node leaf is easy to locate using the 1–5–8 rule: Locate the petiole of the 1st fully unfurled terminal leaf (size of a 50c piece or larger); the petiole of the 5th node leaf is directly across and down the main stem; the petiole of the 8th node leaf is directly below (and in line with) that of the 5th node leaf (watch a CottonInfo video on whitefly sampling online at https://www.youtube.com/watch?v=9Y_XOiDCjtg). The 9th/10th node leaves can also be used to sample RENS but they are deeper within the canopy and more difficult to locate/sample. Estimate the average number of RENS on 20–30 whole leaves within a management unit.

- Repeat at least twice a week for each management unit and determine if the average density of RENS/leaf is increasing between checks.
- Consistent (and significant) increases in REN density between checks provide a clear indication that the whitefly population in the crop will increase over the next 7–10 days.

Also monitor for the presence of honeydew on lower leaves, as if there is open cotton, this indicates some remedial action should be taken to prevent contamination of bolls.



Note the gap between wings for SLW (left) compared with overlapping wings for Greenhouse whitefly (right).
(Richard Lloyd, Qld DAF)



Note absence of hairs on SLW nymph (left) compared to presence on Greenhouse whitefly (right). (Richard Lloyd, Qld DAF)

Thresholds

A Threshold Matrix has been developed to assist in the interpretation of population monitoring data with the ultimate objective of minimising the risk of honeydew contamination on lint. Thresholds are based on rates of population increase relative to the accumulation of day degrees and crop development.

Recent research has found that in some seasons the matrix may underestimate early SLW populations and the exponential population growth may occur closer to open cotton. Disruption of beneficials will result in a sharper rise in adult numbers. As a result the matrix has been modified to:

1. Highlight the need to preserve beneficials to keep SLW low;
2. Bring forward 'control' decisions to before 1550 day degrees to ensure good management before cotton opens; and,
3. Highlight likely need to respond if low populations are increasing between multiple checks.

Frequent population monitoring is essential to use the Threshold Matrix effectively (see page 47).

The management of SLW in situations involving adult immigration into crops with open bolls and/or developmentally delayed crops with open bolls should be based on (a) expected time to defoliated leaf drop, (b) lint contamination level, and (c) SLW population growth rate (refer to Zone 3C table page 46). Once defoliant starts to take effect, adult SLW will generally leave the crop and falling leaves will take the nymphs with them. The likely efficacy and residual impact of insecticides also needs to be considered.

Consider time for product to be fully effective. Due to emerging resistance, pyriproxyfen is no longer recommended for crops with open cotton. Where the risk from contamination is high, early defoliation can be considered. Finally, honeydew on leaves is a good indicator of potential lint contamination. Refer to Managing Silverleaf Whitefly in Australian cotton fact sheet (available from the CottonInfo website) for more information, including considerations for managing populations that are not covered by the matrix.

TABLE 14: Control of silverleaf whitefly (*Bemisia tabaci* B-biotype)

Active ingredient	Insecticide 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	Group 7C	Widespread – low	Very low	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.
Diafenthiuron	Group 12A	Not detected	Low	Provides suppression of Silverleaf Whitefly. Apply when 10-20% of leaves infested. Suppression may not be satisfactory once population densities exceed 25% infestation, or when high numbers of adults are invading from nearby fields. Maximum 2 applications per season.
Afidopyropen	Group 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.
Cyantraniliprole	Group 28	Not detected	Moderate	Target early developing populations. Maximum 2 applications per season.
Spirotetramat	Group 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.
Emamectin benzoate/acetamiprid	Group 6/4A	Acetamiprid – 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	Group 4A	Unknown	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	Group 3A	Widespread – low Cross-resistance with other SP's.	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 and to minimise impact on bees. Refer to SLW Matrix for use window.

*For more details about impact on beneficial insects, refer to table 3 in this guide.



A Red Eye nymph. Check the middle canopy for Red Eye nymphs and pupa to estimate likelihood of population growth in the near term. (Photo: QDAF)

In the worst case scenario, where cotton lint has been contaminated with honeydew, delaying harvest may assist in breaking down honeydew or expose the crop to rainfall that will remove most of the honeydew. However, if conditions remain dry any reduction in the amount of honeydew on bolls will be slow, and there is a risk that contaminated cotton may still have sufficient honeydew to result in substantial penalties if harvested.

Key beneficial insects

Several species of whitefly parasitoids have been observed in Australia including several species of *Encarsia* and *Eretmocerus*. Predators of nymphs include big-eyed bugs, pirate bugs, lacewing larvae, apple dimpling bugs, brown smudge bugs and ladybird beetles.

Find out how to identify parasitised SLW nymphs in this cottoninfo video <https://www.youtube.com/watch?v=S00cedrGIQI>

Selecting an insecticide

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. There are several products registered for the control of whitefly in cotton in Australia. The SLW threshold matrix identifies the optimum times for tactical use of these products.

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. Resistance to pyriproxyfen is widespread and in most cases it is at a low level. Some locations have moderate levels of resistance. Resistance to neonicotinoids, including acetamiprid is rare and is currently at a low level. The SLW Threshold Matrix is designed to minimise the need to intervene with chemical control as well as to delay the development of resistance, and has been modified in light of emerging pyriproxyfen resistance. Resistance to spirotetramat has recently been detected at Bowen in NQ which demonstrates the need to be cautious with all SLW registered products. Compliance with the IRMS will ensure the products available for SLW control will remain efficacious into the future.

ENSURE ONLY A SINGLE APPLICATION OF PYRIPROXYFEN OCCURS 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. From north of Biloela, the winter generation time is 40–45 days while in the Macintyre, Gwydir and Namoi valleys, generation time increases to 65–70 days.

Silverleaf whitefly: examples of healthy and parasitised life stages





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 cucurbitaceae 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 populations moving out of cotton. Do not plant cotton near good 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. Paul Grundy: 0427 929 172

Qld DAF, Emerald – Richard Sequeria: (07) 49901 810 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.

ZONE 3C TABLE (refers to SLW Threshold Matrix, over page)

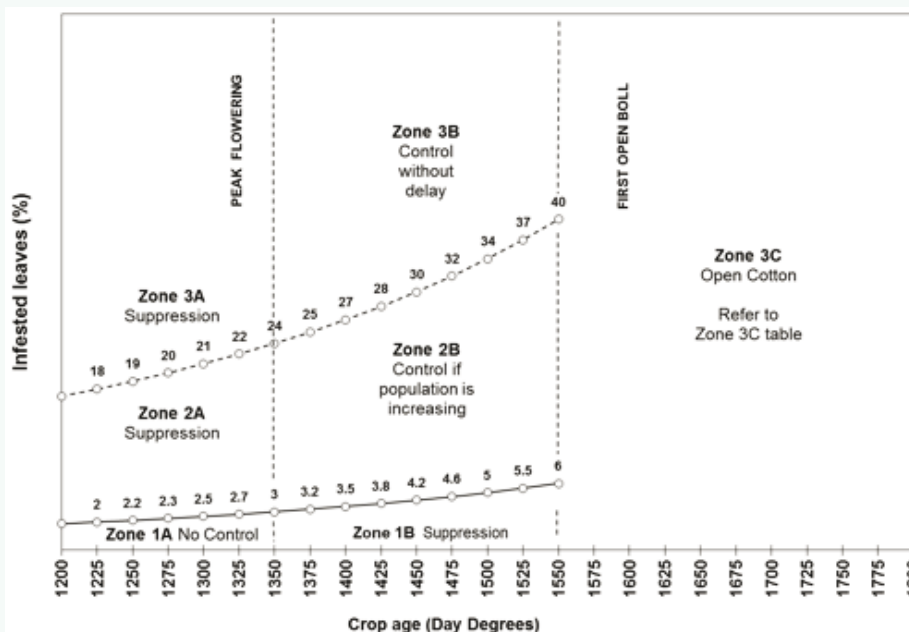
Time to defoliation (days)	Contamination level (visual diagnostic)	Action recommended
14 or less	No or light contamination	Adult population stable – no action; continue monitoring. Adult population increasing – knockdown insecticide in first 7 days if % infested leaves $\geq 10\%$ and/or large nymphs present on most lower canopy leaves and/or consider early defoliation; otherwise, no action and continue monitoring.
	Moderate contamination	Adult population stable – knockdown insecticide in first 7 days if % infested leaves $\geq 10\%$ and/or large nymphs present on lower canopy leaves; otherwise, no action and consider early defoliation if contamination level increasing. Adult population increasing – knockdown insecticide in first 7 days; consider early defoliation.
15-21	No or light contamination	Adult population stable – no action; continue monitoring. Adult population increasing – knockdown insecticide in first 7-14 days if % infested leaves $\geq 10\%$ and/or large nymphs present on most lower canopy leaves; otherwise, no action and continue monitoring.
	Moderate contamination	Adult population stable – knockdown insecticide in first 7-14 days if % infested leaves $\geq 10\%$ and/or large nymphs present on lower canopy leaves; otherwise, no action and consider early defoliation if contamination level increasing. Adult population increasing – knockdown insecticide in first 7 days and defoliate early if resurgence is evident.
>21	No or light contamination	Adult population stable – no action; continue monitoring. Use control/knockdown insecticide* in first 7 days if % infested leaves $\geq 10\%$ and/or large nymphs present on most lower canopy leaves; otherwise, no action and continue monitoring.
	Moderate contamination	Adult population stable – use control/knockdown insecticide* in first 7 days if % infested leaves $\geq 10\%$ and/or large nymphs present on lower canopy leaves; otherwise, no action and consider early defoliation if contamination level increasing. Adult population increasing – use control/knockdown insecticide* in first 7 days; consider early defoliation if honeydew level appears to be increasing beyond 14 days after insecticide application.
Severe contamination		Salvage: Knockdown &/or defoliate asap; delay picking – rain will help remove honeydew from bolls.

*NOTE – Highly disruptive products, such as bifenthrin, may result in SLW flaring 10-14 days after application. Pyriproxyfen is not recommended on open cotton due to emerging resistance. The systemic action of Spirotetramat and moderate impact on beneficials may be advantageous after row closure, however, ensure thorough coverage and use of adjuvant as per label. Spirotetramat controls nymphs and has sterility effect on females but won't provide knockdown of adults. Support resistance management by not using more than one application of Spirotetramat per season.

Refer to the SLW Booklet for visual diagnostics <https://www.cottoninfo.com.au/sites/default/files/documents/SLW%20booklet%20-%20May%202018.pdf>



SLW THRESHOLD MATRIX



NOTES

Sampling protocol Sample 20 leaves 3rd, 4th or 5th node below the terminal/25 ha weekly from first flower (777 DD) and twice weekly from peak flowering (1300 DD). Convert to % Infested leaves. Infested leaves are those with 2 or more adults. Uninfested leaves are those with 0 or 1 adult.

Day Degrees Daily Day Degrees (DD) are calculated using the formula; $DD = [(Max\ ^\circ C - 12) + (Min\ ^\circ C - 12)] \div 2$

Zone 1A No control **Zone Aim: Preserve beneficials to keep SLW population low.**
 • Do consider opportunities to suppress SLW when controlling other pests particularly between 1350 and 1550 day degrees (prior to row closure).
 Chemistry: Insecticide use is not warranted for fields with low SLW densities.

Zone 2A, 3A & 1B Suppression **Zone aim: Preserve beneficials to keep SLW population low.**
 • Consider opportunities to suppress SLW when controlling other pests.
 • If a low density population is present throughout flowering and boll filling stages leading into the open boll stage, refer to Zone 3C table (page 46) for management guidelines
 Chemistry: Aim for selective/soft.
 • Oils.
 • Sero-X.
 • Cyantranilprole (single application).
 • Afidopyropen.

Zone 2B & 3B Control **Zone aim: Targeted SLW control to avoid risk of lint contamination and avoid the need for further control'**
 • SLW control decisions should be made during this period based on the matrix and other crop factors. If the population is in zone 3B during this period control should be enacted without delay.
 • If the population is zone 2B this is an indication that SLW control is likely to be necessary. A decision to control would be confirmed by a continued increase in population between sample points during this period as well as increased signs of honey dew and nymph densities in lower canopy.
 • Zone 2B and 3B is the ONLY windows for pyriproxyfen. It can only be used ONCE and there is no longer confidence about efficacy in use beyond 1550 DD (Cutout/row closure). Refer also to Regional 30 day window for Pyriproxyfen usage. Pyriproxyfen will be supported by presence of beneficial insects, so avoid use of disruptive chemistries prior to use.
 • Timing of application needs to allow time for products such as Pyriproxyfen and spirotetramat to become active (15-20 days) and take effect prior to the onset of boll opening.
 Chemistry: Partial selectivity.
 • Pyriproxyfen (IGR) (Refer to recommended regional 30 day window).
 • Diafenthiuron (vapour activity).
 • Cyantranilprole (if used twice in succession within 10-15 days).
 • Spirotetramat (use adjuvant as per label).

Zone 3C Open cotton **Zone aim: Avoid honeydew contamination**
 • Once there is open cotton, the ideal period for control has passed and the risk of honeydew contamination is heightened.
 • Management decisions should be based on:
 • time-to-defoliation;
 • lint contamination level; and,
 • population growth rate and size.
 • Refer to Zone 3C table (page 46).
 • For more complex situations including late maturing crops and those with an extended period of maturity refer to CottonInfo SLW booklet.
 Chemistry: Partial selectivity to broad spectrum.
 • Diafenthiuron (knockdown).
 • Cyantranilprole (knockdown/control).
 • Afidopyropen (suppression).
 • Spirotetramat (control nymphs).
 • Dinotefuran (high rate) (knockdown).
 • Acetamiprid/emamectin (knockdown).
 • Bifenthrin (pyrethroid) (knockdown).

Products listed in order of selectivity based on Table 3 (pages 10-11)



Other pests

TABLE 15: Control of cotton leafhopper (jassids) *Amrasca terraereginae*

Active ingredient	Insecticide group	Overall impact on beneficials*	Comments#
Chlorantraniliprole/Thiamethoxam	Group 28/4A	Low	Suppression only. Do not use as first foliar if neonicotinoid seed treatment used. Maximum 2 applications per season.
Clothianidin	Group 4A	Moderate	Apply when numbers reach threshold levels requiring treatment. Maximum 2 applications per season. Do not use as first foliar spray if neonicotinoid seed treatment used.
Phorate	Group 1B	High	Use low rates for short residual control at time of planting. Use high rates for extended period of control. Only use the highest rate on heavy soils when conditions favour good emergence. Maximum 1 application per season.
Dimethoate	Group 1B	High	Apply when pests appear and repeat as required. Maximum 2 applications per season.
Gamma-cyhalothrin	Group 3A	Very high	Apply at recommended threshold levels as indicated by field checks. Maximum 1 application per season.
Lambda-cyhalothrin	Group 3A	Very high	Apply at recommended threshold levels as indicated by field checks. Maximum 1 application per season.

#For all control options ALWAYS refer to the label for instructions and to minimise impact on bees.
*For more details about impact on beneficial insects, refer to table 3 in this guide.

TABLE 16: Control of rough bollworm (*Earias huegeli*)

Active ingredient	Insecticide group	Overall impact on beneficials*	Comments#
Chlorantraniliprole	Group 28	Low	Target brown eggs and hatchling to 2nd instar larvae before they become entrenched in terminals or bolls. Maximum 3 applications per season.
Alpha-cypermethrin	Group 3A	Very high	It is essential to detect and treat infestations before larvae are established or concealed in bolls deep in the canopy. Use higher rate if larger larvae are present. Maximum 1 application per season.
Cypermethrin	Group 3A	Very high	It essential to treat infestations in the early stages before larvae are established or concealed in bolls deep in the canopy. Maximum 1 application per season.

#For all control options ALWAYS refer to the label for instructions and to minimise impact on bees.
*For more details about impact on beneficial insects, refer to table 3 in this guide.

TABLE 17: Control of pink spotted bollworm (*Pectinophora scutigera*)

Active ingredient	Insecticide group	Overall impact on beneficials*	Comments#
Chlorpyrifos	Group 1B	High	Qld only. Apply when 10-15 moths are trapped on two consecutive nights to prevent infestation of bolls by larvae. Maximum 3 applications per season.
Deltamethrin	Group 3A	Very high	WA & Qld only. Apply at first sign of activity before larvae enter boll. Maximum 1 application per season.
Esfenvalerate	Group 3A	Very high	Central Qld only. Apply at this rate when pink spotted bollworm is only pest present. Maximum 1 application per season.
Gamma-cyhalothrin	Group 3A	Very high	Qld & NT only. If <i>Helicoverpa</i> are not present apply when more than 10 adult moths are caught in pheromone traps on 2 consecutive nights. Maximum 1 application per season.
Lambda-cyhalothrin	Group 3A	Very high	As above. Maximum 1 application per season.

#For all control options ALWAYS refer to the label for instructions and to minimise impact on bees.
*For more details about impact on beneficial insects, refer to table 3 in this guide.

Integrated Pest Management (IPM) in cotton

Fiona Anderson (Crop Consultants Australia)

Acknowledgements: Adapted from a previous version by Sandra Williams (CSIRO and CottonInfo)

What is IPM?

The objective of IPM is to use knowledge of pest biology, behaviour and ecology to implement a range of tactics throughout the year in an integrated way that suppresses and reduces their populations. This systems approach considers tactics to suppress or avoid pests across the farm and surrounding areas, and tactics to manage pest and beneficial insect populations in the crop, including the responsible use of insecticides. Because all pests have other animals that eat them, such as predators or parasites (known as beneficials or natural enemies), building and conserving populations of beneficials is at the heart of IPM.

To conserve natural enemies, a pest management decision needs to be well informed, supported by good sampling, valid control thresholds and knowledge of the beneficials present and their activity. Finally, if insecticides are required, they are selected based on the Insecticide Resistance Management Strategy (to avoid resistance), how effective they are on the pest (to ensure adequate control) and their risk (soft) to the beneficial population (so beneficials can be conserved) and to bees.

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.

Elements of best practice IPM are:

1. Know your enemy and your friends.
2. Keep the big picture in mind.
3. Keep it clean.
4. Know your numbers.
5. Aim to grow a healthy crop.
6. How many insects can be tolerated.
7. Choose insecticides wisely to conserve beneficials.

What can I do to avoid or suppress pests on my farm?

1. Know your enemy and your friends

Knowledge of pest ecology can identify sources of potential infestation and non-insecticidal management strategies to control the pest before problems develop. For instance, management of weed hosts and choice of crop rotation may reduce pest abundance. Understanding the ecology of key beneficial insect species and their preferred prey is also valuable. It is equally important to recognise signs of parasitic activity, as many parasitoids are too tiny and secretive to find in a field check. For example, whitefly parasitoids, *Encarsia* and *Eretmocerus* lay their eggs into whitefly nymphs. These small wasps complete their development by using (and

eventually killing) the whitefly. The pale yellow/green Whitefly nymphs will turn brown or black (*Encarsia*) or yellow/brown (*Eretmocerus*) when parasitised.

Consider how your IPM strategy can target different mechanisms of pest survival. For information about key pests and mites of Australian cotton go to page 12. Refer to the Australian Cotton Production Manual and the 'Guide to Pests and Beneficials in Australian Cotton Landscapes' for more information.

If you would like to participate in workshops or training on IPM, contact your CottonInfo Regional Extension Officer (see inside back cover).



Brown mirid (L), green mirid (centre) and apple dimpling bug are known to damage squares to varying degrees. Apple dimpling bug is generally regarded more as a predator of heliothis eggs and mites. (Photos 1 & 2 Moazzem Khan, Qld DAF; Photo 3 Cheryl Mares, CSIRO)

2. Keep the big picture in mind

Insects live in landscapes, not on farms. Management across farms can impact on both pests and beneficials. This extends beyond cropping land, as areas of complex, perennial vegetation can be an important host for beneficials.

Insect management decisions should always be made considering the potential impact on beneficial populations in surrounding areas. Sometimes it is necessary to use a disruptive control method in one part of a farm but it may be possible to promote rapid reinfestation of beneficials by how we manage the surrounding area.

Sharing your strategies and coordinating tactics with neighbouring farmers will increase the success in implementing IPM. Some regions successfully use Area Wide Management groups to coordinate strategies including weed management, conserving beneficials, delaying use of disruptive insecticides, reducing the risk of drift between farms, shared adherence to IRMS, planting windows and maintenance or enhancement of local native vegetation areas.

3. Keep it clean

Many cotton pests rely on weed hosts and cotton volunteers prior to migrating into cotton fields.

Pests that gain the greatest advantage from weeds are those that are unable to hibernate/over winter when conditions are unfavourable, such as spider mites, cotton aphids, mirids and silver leaf whitefly. Some weeds and cotton volunteers or ratoons can also act as a reservoir for plant viruses such as cotton bunchy top disease. Weed hosts should be managed in non-crop areas such as field borders, roadways, irrigation channels and in perennial vegetation and pastures, as well as in fallows. Refer to pages 12-48 for details of hosts of key insect and mite pests of Australian cotton.

Cotton volunteers are the worst weeds in terms of pest risk. A 'zero tolerance' approach to cotton volunteers throughout the year is required – refer to pages 79-82 for more information.



Think of the farm and surrounding vegetation as a whole system. (Photo: Greg Kauter, formerly Cotton Australia)

What can I do to manage pests in my crops?

4. Know your numbers

Regularly sample and correctly identify pest and beneficial populations. Observe beneficial activity (e.g. thrips in mite colonies, parasitised aphid mummies, ladybird beetle, hoverfly, lacewing larvae in aphid colonies).

Ensure you can identify key pests, beneficials, signs of parasitism and types of plant damage. This information forms the backbone for making pest control decisions. A key resource is the 'Cotton Pest and Beneficials in Australian Cotton Landscapes'. This is available through www.cottoninfo.com.au or by contacting your CottonInfo Regional Extension Officer. Some insects are difficult to see with the naked eye – a 10X power hand lens in your pocket is an invaluable tool to quickly and simply check pest species. These are available from Australian Entomological Supplies. Some species, such as greenhouse whitefly and SLW cannot be differentiated in the field. Refer to the relevant insect and mite pest section (pages 12-48) for industry contacts on who can help with identification.

If you suspect you have an exotic pest or disease on your farm, immediately contact the Exotic Plant Pest Hotline 1800 084 881.

Guidelines for the beneficial to pest ratio

Research has determined the beneficial to pest ratios for *Helicoverpa* management in cotton for conventional and Bt cotton crops. The most common predators found in cotton farms feed on a wide range of pests and are therefore classified as general predators. Therefore, the beneficial to pest ratio calculated for *Helicoverpa* may also be enough to manage other secondary pests.

Calculation of the beneficial to pest ratio per metre for *Helicoverpa*:

$$\text{Ratio} = \frac{\text{beneficials}}{(\text{Helicoverpa eggs} - (\% \text{ parasitised}) + \text{VS} + \text{S})}$$

where VS = very small and S = small larvae

The calculation does not include *Helicoverpa* medium (M) and large (L) larvae since many of the common predatory insects are not effective on these larger life stages.

Total beneficials per metre (visual check) should be used in calculating the beneficial to pest ratio. However, to be confident in the ratio, at least three insects of the most common beneficials (ladybird beetle, red and blue beetle, damsel bug, big-eyed bug, assassin bug, brown shield bug and lacewings) should be present. The beneficial to pest ratio calculation includes parasitoids as *Trichogramma* spp. wasps can be important in controlling *Helicoverpa* in crops.

To monitor egg parasitism by *Trichogramma* spp. Collect brown eggs and keep them at room temperature (about 25°C) until they hatch (healthy) or turn black (parasitised). From this procedure, the calculation of the percentage of parasitised eggs can be used in the beneficial to pest ratio. Collecting white eggs gives an underestimate of parasitism because they may have just been laid and not had enough time to be found by *Trichogramma* spp.

Insects

5. Aim to 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 the effects of pests 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 yield expectations and climatic conditions.

Damage monitoring should be conducted as frequently as pest sampling and includes:

- Leaf area loss or discoloration;
- Tip damage;
- Fruit retention or fruiting factor; and,
- Boll damage.

Refer to 'Management of key insect and mite pests' section for pest specific damage thresholds. Fruit load is a key aspect in determining crop yield and maturity. The loss of fruit during squaring and early flowering is less critical to yield than fruit loss later in the season. Cotton development can be predicted using daily temperature data (day degrees, DD). Monitoring crop vegetative and reproductive growth compared to a potential rate of growth and development enables crop managers to determine when growth is not optimal and manage accordingly.

6. How many insects can be tolerated

Economic thresholds based on research, are available for most major pests in cotton. These thresholds should be used in conjunction with information on forecast, crop stage, plant damage and beneficial abundance to make decisions about the need to spray.

Economic thresholds are defined as the pest density or damage level at which control must be implemented to prevent economic loss.

Thresholds should be considered in context of other factors that may influence the need to spray. For instance, if pest abundance is just over threshold but damage is low and beneficial populations are high it is practical to delay control several days. This is a low risk strategy to allow time for beneficials to manage the pests to below threshold levels, thereby



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avoiding a potentially disruptive spray and reducing insecticide costs and selection for resistance.

Conversely, if pest damage is high and there are low numbers of beneficials then immediate control with an insecticide may be the best option. Refer to the 'beneficial to pest ratio' on page 50 to assist these decisions by indicating a ratio above which the pest is likely to be effectively controlled by the beneficial population.

Thresholds for cotton aphid, two-spotted mite and silverleaf whitefly are based on cumulative population changes and require comparison of multiple samplings to determine if action thresholds have been reached.

Knowledge of the pest and the environment is important in determining whether a spray is warranted. For example, two spotted mite populations can be suppressed by cool conditions, however they will increase rapidly when it is hot and dry. While some thresholds only require monitoring of one lifecycle stage, it can be useful to be aware of all life stages. For example, the silverleaf whitefly threshold is based on presence/absence of adult whitefly, however monitoring nymphs can help to identify if a population has built up within the crop or has migrated in recently.

7. Choose insecticides wisely to conserve beneficials

Spraying is often the final resort in an IPM program, however product choice will have a large impact on the strategy for the remainder of the season. When choosing an insecticide (or miticide), in addition to the efficacy against the targeted pest, it is very important to consider the 'selectivity'. Some insecticides are very selective and have very little impact on beneficial insects (often referred to as 'soft') while others are highly disruptive to beneficial populations ('broad-spectrum' or 'hard'). The relative selectivity of all insecticides available for use in cotton can be found in Table 3 pages 10-11. Refer also to the IRMS (see pages 61-64).

The selectivity of the insecticide helps to assess the risk that following its use, populations of other pests may 'flare' (increase rapidly). For example, where a mirid population has increased above threshold during flowering and an insecticide is required, the best choice depends not only on your budget, but the product's selectivity relative to the types of beneficials you have and want to conserve.

Within the IRMS there are several options available at this time with differing selectivity profiles. According to Table 3, pages 10-11, the neonicotinoid product, clothianidin (tradenam Shield), 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 (multiple tradenames such as Regent) with salt, will reduce predatory bug populations, and conserve ladybird beetles, but have an unknown impact on the key wasp parasitoids of whitefly. It is important to note that for many products Table 3 (pages 10-11) considers rate as well as product.

Lower registered rates of a product may provide sufficient efficacy against the target pest, while minimising impact on beneficials. 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.

Bees are particularly susceptible to many of the insecticides used on cotton farms, such as abamectin, fipronil, indoxacarb, pyrethroids and profenofos. The productivity of hives can be damaged if direct contact with foraging bees occurs during the application. This occurs if foraging bees carry residual insecticide back to the hive after the application or when insecticide drifts over hives or neighbouring vegetation which is being foraged by bees. Always look for and follow label directions regarding impact on bees and refer to page 143 for more information on how to manage the risk to bees.

III

TABLE 18: Friends in the field

	Heliothis	Aphid	Mealybug	Spider Mites	SLW	Green Mirid	Jassids	Thrips	Notes
Red and blue beetle	X	X			X				Red and blue beetles are also predators of slow moving insects. The larvae feed on small worms and other soil organisms.
Ladybird beetles		X	X	X	X		X	X	Ladybird beetles also feed on scale insects.
Apple dimpling bug (yellow mirid)				X	X				ADB can also cause damage, but threshold is 5 times greater than green mirids. Monitor fruit retention.
Damsel bug	X	X		X		X			
Big-eyed bug	X	X		X	X	X			
Brown smudge bugs	X		X	X	X				
Glossy shield bug	X								Also predators of other caterpillars.
Predatory shield bug	X					X			Also predators of other caterpillars.
Minute pirate bugs				X	X			X	
Assassin bug	X					X			Also predators of other caterpillars.
Lacewings	X	X	X	X	X			X	Larvae stage is the predator.
Spiders	X			X	X	X	X		Spiders can eat both good and bad insects.
Parasitoids	X	X	X		X				Species of parasitoid are specific in pests targeted. Monitor for parasitized pests.
Hoverfly larvae and Silverfly larvae		X							The adult will lay on the crop when there are aphid colonies.
Thrips				X	X				Can be an early season pest.

Hard on mirids Soft on beneficials



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Insecticide Resistance Management Strategy (IRMS) for 2019–20

Sally Ceeney, Cotton Australia

Acknowledgements: Susan Maas (CRDC); Lisa Bird, Grant Heron (NSW DPI); Sharon Downes, Lewis Wilson, Simone Heimoana (CSIRO); Paul Grundy, Melina Miles, Jamie Hopkinson (Qld DAF)

The use of pesticides selects for resistance in pest populations. The cotton industry IRMS seeks to manage the risk of resistance in all major pests of cotton including aphids, mites, SLW and Helicoverpa, both in conventional and Bt cotton. Additional resistance management requirements are also in place for managing the risk of Helicoverpa developing resistance to Bt cotton (pages 73–75). Below, the key elements of the IRMS are described and questions regarding the design and reasons for the IRMS are answered. In this document, the term ‘insecticide’ refers generally to pesticides used for insect or mite control. The resistance risk management for silverleaf whitefly is built into the Silverleaf Whitefly Threshold Matrix (page 46).

Checklist

- Use recommended thresholds for all pests to minimise insecticide use and reduce resistance selection. Refer to pages 12–48.
- Monitor retention as well as pest numbers.
- Avoid repeated applications of products from the same insecticide group, including Bt products, even when targeting different pests. Rotate between groups. Consider seed treatment as a ‘spray’ and do not apply a first foliar spray from the same insecticide group as the seed treatment.
- Do not exceed the maximum recommended use limits indicated on the Insecticide Resistance Management Strategy charts for cotton (see pages 61–64).
- Do not respray an apparent failure with the same product or another product from the same insecticide group. Rotate to a different group.
- For all pest species, aim to use the most selective insecticide options first, delaying the use of broad spectrum insecticides for as long as possible. On the IRMS charts the options are arranged from top to bottom in order of selectivity. Applying the most selective option helps to conserve beneficial insects, and reduces the chance of mite, aphid and silverleaf whitefly outbreaks.
- Mites should be monitored for species as well as abundance as strawberry mite is becoming much more prevalent than 2-spotted mite. Base miticide decisions on mite threshold only and do NOT use miticides as ‘insurance sprays’. Use IPM principles including avoiding the use of broad-spectrum insecticides to control other pests, to avoid flaring mites.
- Avoid early season use of dimethoate. When targeting mirids, it is particularly important to avoid early season dimethoate use as it will select catastrophic pirimicarb resistance in aphids.
-

- Control weeds and volunteer cotton on farm to minimise alternative hosts for mites, aphids and silverleaf whitefly through winter and particularly in the lead up to cotton planting.
- Cultivate cotton and residues of alternative host crops as soon as possible after harvest to destroy overwintering Helicoverpa pupae, particularly if crops are defoliated after 9 March (Northern Regions) and 31 March (Central and Southern Regions). For Bollgard 3 cotton fields, crop destruction and pupae busting must be in accordance with the Bollgard 3 RMP.
- Comply with any use restrictions placed on insecticides applied to other crops. This will reduce the chance of prolonged selection for resistance over a range of crops.
- Always follow label directions.

Your questions answered

How was the 2019–20 IRMS decided?

The development of the IRMS is driven by the Transgenic and Insect Management Strategies (TIMS) Committee as advised by the TIMS Insecticide Technical Panel. TIMS is a part of Cotton Australia. The results from the insecticide and miticide resistance monitoring programs, carried out during the season, are used to inform the committee of any field-scale changes in resistance levels. Extensive communication and discussion with cotton growers and consultants is undertaken in all regions of the Australian cotton industry before TIMS finalises their recommendations. Communication is critical for ensuring that the IRMS is practical and can be implemented.

How do insects develop resistance?

Resistance is an outcome of exposing pest populations to a strong selection pressure, such as an insecticide. Genes for resistance naturally occur at very low frequencies in insect populations. The genes remain rare until they are selected for by a toxin, either from an applied pesticide or from within Bt cotton. Once a selection pressure is applied, resistance genes can increase in frequency as the insects carrying them are more likely to survive and produce offspring. If selection continues, the proportion of resistant insects relative to susceptible insects may continue to increase until reduced effectiveness of the toxin is observed in the field.

On the IRMS chart, what do the colours for the various products represent?

In the IRMS charts, the different colours for the various products correspond to maximum usage restrictions. For example, Abamectin and Enamectin (Affirm) can individually have a maximum of two applications, however a maximum of only three applications is allowed from Group 6 insecticides. In addition to colours please be aware of additional restrictions at side and footnoted. Insecticide groups are listed on page 64. Rotate to an insecticide from a different mode of action group.

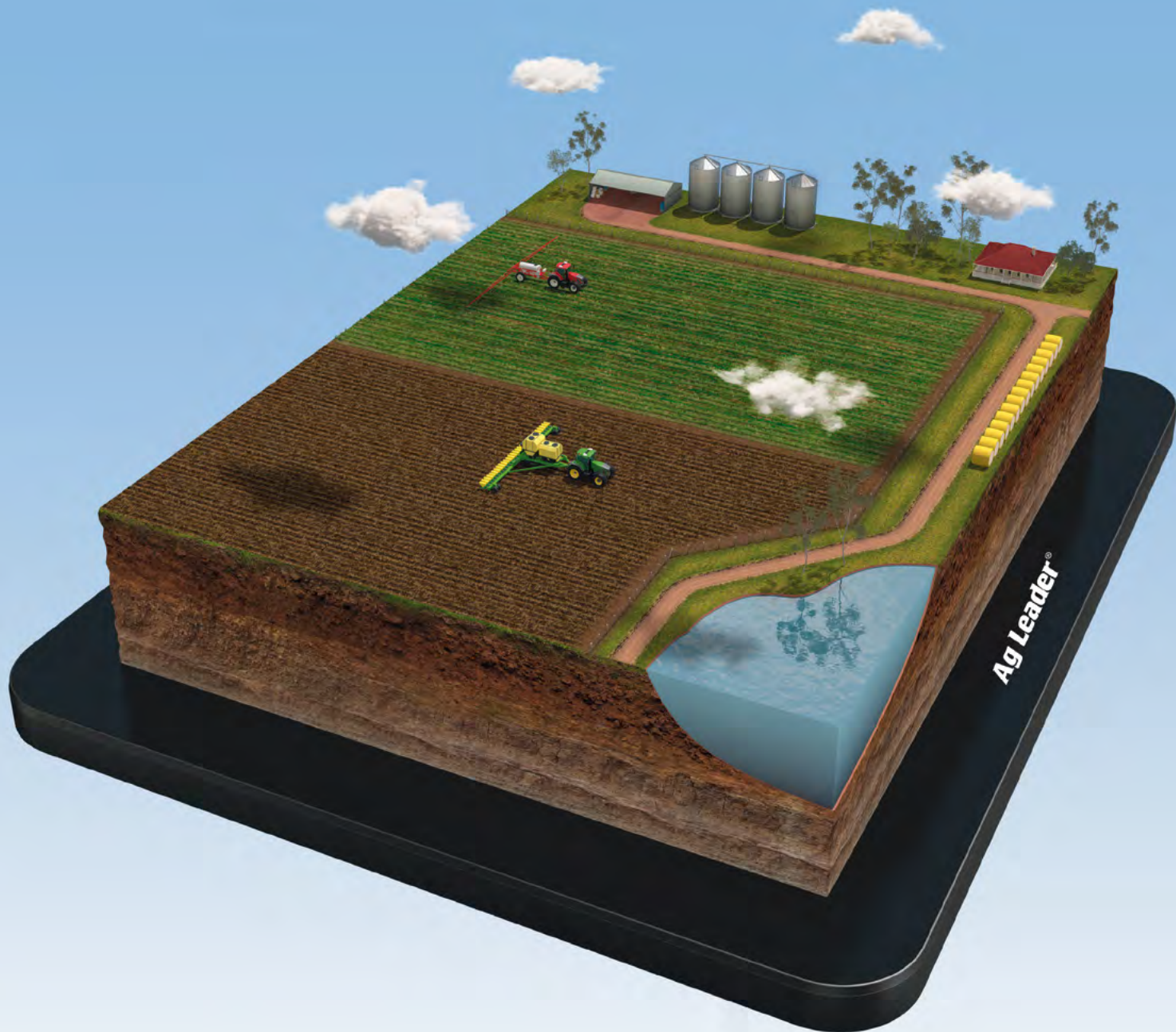
What is the scientific basis of the IRMS?

The basis of the IRMS is to minimise selection across consecutive generations of the pest. Pest life cycles therefore determine the length of the ‘windows’ around which the IRMS is built. As the life cycles of Helicoverpa and the sucking pests are very different, the strategy for one will not manage resistance for the other.

Helicoverpa

Ideally the length of the ‘windows’ would be 42 days (average time from egg to moth) to minimise the selection pressure across consecutive generations. Most chemicals are restricted to windows of between one and two 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.

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Sucking pests – mites and aphids

The resistance strategy for the short life cycle pests depends on rotation of insecticides/miticides between different chemical groups (different modes of action) to avoid selection over successive generations. Non-consecutive uses 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

Mirids are not known to have developed resistance to insecticides in Australian cotton. However it is possible that resistance could develop and the industry has begun resistance monitoring in mirids. As the IRMS includes all insecticides registered for use in cotton, the principles behind the IRMS are also applied to mirids. Many of the products registered for mirid control in cotton include registration for the control of other pests. It is critical that mirid control decisions also consider sub-threshold populations of other pests that are present in the field. Using dimethoate for the control of mirids can inadvertently select for both dimethoate and pirimicarb resistance in aphids. Use of clothianidin (Shield) for mirid control can inadvertently select for neonicotinoid resistance in aphids. Do not apply a first foliar spray from the same insecticide group (4A) as the seed treatment. When selecting an insecticide for mirid control, consider the options that are left open for subsequent aphid control, in case the need arises.

Silverleaf Whitefly (SLW)

The IRMS includes all commercially available products registered for use in cotton, including SLW. Inclusion is based on the SLW threshold matrix which is designed to minimise the need to intervene with chemical control as well as to delay the development of resistance. Refer to the SLW Threshold Matrix, page 46, for additional industry recommendations on the best way to utilise the available products with the lowest risk of developing resistance. Refer to CottonInfo and Cotton Australia websites for details of the CGA-nominated voluntary pyriproxyfen application window for 2019–20.

Why is IPM important for resistance management?

IPM principles help to prevent the over-reliance on chemical control of pests that will lead to insecticide resistance and render insecticidal control options ineffective. The resistance benefits from preserving beneficials are particularly important for mites and SLW where there is increasing concern about resistance to key products. Early season pest decisions can flare these pests. 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 49 for more information.

How do refuges help manage resistance to the toxins contained in Bt cotton, and do they help manage resistance to insecticides in *Helicoverpa*?

Growing refuge crops is a pre-emptive resistance management strategy that is implemented to retard the evolution of field-scale resistance to Bt cotton. The success of the refuge strategy depends on the majority of the general population being susceptible (SS) to the toxins in Bt-cotton. When a susceptible moth mates with a resistant moth (RR), the offspring carry one allele from each parent (RS). These offspring are referred to as heterozygotes. In the cases of Bt resistance that have so far been identified, heterozygotes are still controlled by Bt cotton.

Refuges are able to help manage Bt resistance through the generation of SS moths. If RR moths are emerging from Bt cotton fields, they are

more likely to mate with SS moths if a refuge has been grown. The RS offspring is susceptible to Bt cotton and an increase in the frequency of RR individuals can be delayed.

This is not always the case for resistances to other insecticides. For many of the conventional insecticides (to which resistance has already developed), resistance mechanisms are functionally dominant. This means that heterozygotes (RS) survive the application and can make up a large part of the resistant population. In such circumstances the dilution effect created by refuges is far less effective.

While refuges cannot assist 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. Unsprayed refuges will produce moths that have not been exposed to insecticide selection pressure.

Why is there a Northern, and Southern/Central IRMS?

The IRMS has always accounted for pest movement among different cotton growing regions. For example several field studies have shown that *Helicoverpa* moths can travel large distances. Recently, some genetic work showed that mirids move long distances between regions. Insecticide resistance in one region can therefore spread to other regions by pest migration. The TIMS Committee designs the IRMS to reduce the chance that pests moving between regions would be reselected repeatedly by the same insecticide group. This is done by limiting the time period over which most insecticides are available. The two strategies accommodate the different growing seasons from central Queensland through to southern NSW.

Why do we need an IRMS in conventional cotton when there are such large areas of Bt cotton?

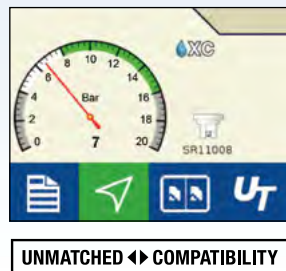
Whenever insecticides are used there is selection pressure for resistance. In Bt cotton, aphids, mites, mirids and silverleaf whitefly are no longer secondary pests. More often than not, it is this range of pests that require intervention with foliar insecticides to protect cotton yield and quality and as such there is a risk of resistance developing in these populations. The IRMS chart seeks to directly manage the risk of resistance in pests as well as reduce risk of inadvertent selection of non-target pests.

Large areas of Bt cotton will not change the frequencies of resistance genes being carried by *H. Armigera* moths. The same proportion of resistant and susceptible moths will continue to lay eggs in cotton – be it non-Bt or Bt cotton. Hence the likelihood of resistance development to foliar and soil applied insecticides remains the same, even if the overall size of the *Helicoverpa* population is reduced. Continuing to follow the IRMS will ensure that the industry retains the ability to control *Helicoverpa* effectively with insecticides on conventional cotton both now and in the future. The IRMS should always be consulted when making a spray decision, even in Bt cotton.

When do stage windows start and stop?

The date shown on the strategy charts are for the start of each stage, and end at midnight on the day before the start of the next window. For those individual insecticides and miticides that start or end outside window boundaries, the start and end date are specified and the same principles apply.

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What do the terms cross-resistance and multiple resistance mean? How can they be minimised?

Cross-resistance occurs when selection for resistance against one pesticide also confers resistance to another pesticide, either from the same mode of action group 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 (i.e. without selection pressure).

Multiple resistance simply means that an insect is resistant to more than one mode of action 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. The strategy is designed to manage both of these occurrences. 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. The use of alternative chemistries should minimise the number of pirimicarb resistant aphids being exposed to dimethoate.

Is pupae busting in conventional cotton still important for resistance management?

Yes. Pupae busting is an effective, non-chemical method of preventing resistance carryover from one season to the next. The pupae busting guidelines for sprayed conventional cotton are based on the likelihood that larvae will enter diapause before a certain date, allowing for removal of pupae busting operations in field specific situations. The model was developed from field research conducted on the Darling Downs by Qld DAF and has broad application to farming systems in eastern Australia. The web tool predicts the timing of diapause.

Post Harvest Pupae Destruction statement

Sprayed conventional cotton crops defoliated after 9 March (Northern Region) and 31 March (Central & Southern Region) are more likely to harbour insecticide resistant diapausing *H. Armigera* larvae and should be pupae busted as soon as possible after picking and no later than the end of August.

How does the use of insecticide mixtures fit in the IRMS?

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

The use of mixtures to overcome the effects of resistance requires very careful consideration. As a general rule, mixtures are unnecessary in situations where individual products provide adequate control.

Several criteria need to be met for mixtures to be effective.

Components of the mixture should:

- Be equally persistent;
- Have different modes of action i.e. are from different chemical groups;
- Not be subject to the same routes of metabolic detoxification; and,
- Be tank-mix compatible.

In addition, the majority of the pest population should not be resistant to any component of a mixture, as this may render it a redundant or 'sleeping partner' in terms of insect control. When very heavy *Helicoverpa* pressure occurs in non-Bt cotton and egg parasitism percentages is low, include an ovicide (e.g. amitraz and methomyl) in sprays to take the pressure off larvicides. When targeting sprays against eggs and very small larvae, do not expect 100% control with any insecticide or mixture of insecticides. If larval numbers are reduced below threshold then the treatment should be regarded as effective. Some mix partners provide more than additive kill (synergism), but this is not always the case. The Croplife Australia Insecticide Resistance Management Group, recommends that no two compounds from the same chemical group/mode of action be included in a mixture (www.croplife.org.au/industry-stewardship/resistance-management/).

It is illegal to use rates above those recommended on the label of an insecticide 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.

Can emergency changes be made to the IRMS during the season?

Yes, the TMS Troubleshooting Committee (TTC) was established by TMS to act on its behalf to respond quickly to requests to vary the Strategy temporarily for specific regions. The TTC is not able to approve major changes to the Strategy – that is the role of the TMS Committee.

What is the process for requesting a within-season change to the IRMS?

The TMS Troubleshooting Committee (TTC) has put in place a clear process for handling requests for within-season changes to the IRMS.

A request to temporarily alter the Strategy for a district or part of a district can be initiated by any grower or consultant, but it will not be considered by the TTC unless it is presented with clear evidence of having been discussed and gained majority support at a local level. This will include:

- Evidence that the local consultants who might be affected by the requested alterations have discussed them and are in agreement.
- A request from the local Cotton Growers Association (CGA) that outlines the problem and the preferred solution.
- Evidence that all reasonable efforts have been made to apply the alternatives available within the strategy.

Contact someone on the TMS Trouble Shooting Committee (see Table below) to make a request. All members of the TTC will be consulted on the request and asked to respond within a specified time frame. A decision will then be made and a response issued as soon as practical. All reasonable efforts will be made to meet this level of response in a timely manner, however it should be recognised that complex or poorly communicated requests may take longer to resolve.

The granting of a request by the TTC to temporarily alter the Resistance Strategy applies to a specific district. It does not confer the same temporary changes to other districts unless they have also lodged a request to the TTC in the manner outlined above. TTC changes for a region have a limited duration and do not carry over from one season to the next.

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Considerations following a suspected spray failure

In the event of a suspected pest control failure, don't panic as it is important to assess the situation carefully before deciding on a course of action. The presence of live pests following an insecticide application 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?

Products such as thiodicarb, foliar Bt, NPV and indoxacarb are stomach poisons and may not give maximum control until 5–7 days after application. Similarly, propargite, abamectin, pyriproxifen and diafenthiuron are slow acting and may take 7–10 days or longer to achieve maximum control. In some instances pest infestation levels remain high following a treatment but little if any economic damage to the crop occurs (e.g. if the pests are sick and have ceased feeding).

When diagnosing the cause of an insecticide failure, it is important to remember that there are a wide range of variables that influence insecticide

efficacy. These include 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. For every insecticide application, it is the interaction of all of these factors that determines the outcome. While it will not be possible to optimise all of these variables all of the time, when more compromises are made, there is a greater likelihood that efficacy will be unsatisfactory.

It is also important to maintain realistic expectations of the efficacy that can be achieved. For example, do not expect satisfactory control of medium and large *Helicoverpa* larvae late in the season, regardless of the insecticide treatment used. If a field failure is suspected to be due to insecticide resistance, collect a sample of the surviving pest from the sprayed field using the industry guidelines and send to the relevant researcher.

- **For *Helicoverpa*, Lisa Bird (02) 6763 1128.**
- **For mites and aphids, Lisa Bird (02) 6763 1128**
- **For whitefly, Jamie Hopkinson (07) 4529 4152.**

Sending samples for testing can 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 up with an application of the same insecticide group alone or in mixture (at any rate). Rotate to an insecticide from a different mode of action group. ■■■

TIMS TROUBLESHOOTING COMMITTEE CONTACTS 2019–20

Name	Telephone	Email
Lisa Bird, NSW DPI	0438 623 906	lisa.bird@dpi.nsw.gov.au
Sally Ceeney, Cotton Australia (Chair person)	0459 189 771	sallyc@cotton.org.au
Jamie Hopkinson, QDAF	(07) 4529 4152	Jamie.Hopkinson@daf.qld.gov.au
Simone Heimoana, CSIRO	(02) 6799 1592	Simone.Heimoana@csiro.au

Insecticide Resistance Management Strategy 2019–20

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

NORTHERN REGIONS: Belyando, Callide, Central Highlands, Dawson

INCREASING

SELECTIVITY

DECREASING

CONSIDER IMPACT ON BENEFICIALS & BEES (table 3 CPMG)

Stage 1	Stage 2	Stage 3	Stage 4
	1-Nov	1-Dec	1-Jan
Helicoverpa viruses (Virus)			
Pirimicarb Group 1A			
Paraffinic Oil (Canopy, Biopest)			
	Pyriproxyfen Group 7C		Use an alternative from open cotton
Sero-x			
Etoazole (Paramite)			
	Buprofezin Group 16		
GROUP 28: Max 4/season	Chlorantraniliprole (Altacor) Group 28		
	Cyantraniliprole (Exirel) Group 28		
Afidopyropen (Versys) Group 9D			
start date = canopy closure		Diafenthiuron Group 12A	
Pymetrozine (Chess) Group 9B			
Indoxacarb Group 22A		Dec-31	
Spinetoram (Success Neo) Group 5			
Spirotetramat (Movento) Group 23			
Sulfoxaflor (Transform) Group 4C			
Flonicamid (MainMan) Group 29			
Abamectin Group 6			Group 6: Maximum of 3 / season
Emamectin Group 6			
start date = squaring		Propargite Group 12C	
Amitraz Group 19			
Fipronil Group 2B		Refer to label statement about bees	
Neonicotinoids (Acetamiprid, clothianidin, dinotefuran, imidacloprid, thiamethoxam) Group 4A			
	Chlorantraniliprole +Thiamethoxam (Voliam Flexi2) Group 4A + Group 28		
Acetamiprid + Emamectin (Skope) Group 4A + Group 6			
Phorate	Note 1		Carbamates (methomyl, thiodicarb) Group 1A
<div><div></div>Avoid repeated use of same group</div> <div><div></div>No more than 1 application</div> <div><div></div>No more than 2 applications</div>	Feb-01		Dimethoate Group 1B
			OPs (chlorpyrifos, methidathion) Group 1B
			Synthetic Pyrethroids (bifenthrin) Group 3A

Note 1

Note 3, 9.

Note 3

Note 3, 10

Note 2

Note 8

Residual bee risk

Note 2, 4

Consider risk to each group

Consider risk to each group

Note 5

Note 1

Note 3, 7

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: Cross check with Silverleaf Whitefly Threshold Matrix in the 2019/20 Cotton Pest Management Guide.

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: Sprayed conventional cotton crops defoliated after March 9 are more likely to harbour diapausing *Helicoverpa armigera* and should be pupae busted as soon as possible after harvest and no later than the end of August to reduce resistance risk.

Note 7: High resistance is present in *Helicoverpa armigera* populations. Expect field failures.

Note 8: Addition of abamectin to mirid sprays has caused high level resistance in mites. Base miticide decisions on thresholds only.

Note 9: Resistance to pyriproxyfen has not been detected in CQ despite a long history of use. As such a regional window is not required. The SLW risk associated with the wide planting period should be managed through adoption of IPM and limiting pyriproxyfen use to no more than 1 application per season.

Note 10: Resistance to spirotetramat detected in non-cotton area. Recommended limiting to 1 application, except for usage for mealybug which may require two applications 14 days apart. Use adjuvant as per label.

ALWAYS FOLLOW LABEL DIRECTIONS

CONSIDER IMPACT ON BENEFICIALS & BEES; (TABLE 3, COTTON PEST MANAGEMENT GUIDE)

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

PUPAE BUST AFTER HARVEST.

Insecticide Resistance Management Strategy 2019–20

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 3 CPMG)

Stage 1	Stage 2	Stage 3	Stage 4
15-Nov	15-Dec	15-Jan	15-Feb
Helicoverpa viruses (Virus)			
Pirimicarb Group 1A			
Paraffinic Oil (Canopy, Biopest)			
		Pyriproxyfen - Regional 30 day window Group 7C	Use an alternative from open cotton
Sero-X			
Etoxazole (Paramite)			
	Buprofezin Group 16		
GROUP 28: Max 4/season	Chlorantraniliprole (Altacor) Group 28		
	Cyantraniliprole (Exirel) Group 28		
Dicofol			
Afidopyropen (Versys) Group 9D			
start date = canopy closure		Diafenthiuron Group 12A	
Pymetrozine (Chess) Group 9B			
Indoxacarb Group 22A		Jan-31	
Spinetoram (Success Neo) Group 5			
Spirotetramat (Movento) Group 23			
Sulfoxaflor (Transform) Group 4C			
Flonicamid (MainMan) Group 29			
Abamectin Group 6			Group 6: Max. 3/season
Emamectin Group 6			
start date = squaring	Propargite Group 12C		
Amitraz Group 19			
Fipronil Group 2B	Refer to label statement about bees		
Neonicotinoids (Acetamiprid, clothianidin, dinotefuran, imidacloprid, thiamethoxam) Group 4A			
	Chlorantraniliprole +Thiamethoxam (Voliam Flexi) Group 4A + Group 28		
Acetamiprid + Emamectin (Skope) Group 4A + Group 6			
Phorate	Note 1		
<div><div></div> Avoid repeated use of same group</div> <div><div></div> No more than 1 application</div> <div><div></div> No more than 2 applications</div> <div><div></div> No more than 3 applications</div> <div><div></div> No more than 4 applications</div>		Feb-01	
		Carbamates (methomyl, thiodicarb) Group 1A	
		Dimethoate Group 1B	
		OPs (chlorpyrifos, methidathion) Group 1B	
		Synthetic Pyrethroids (bifenthrin) Group 3A	

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: Cross check with Silverleaf Whitefly Threshold Matrix in the 2019/20 Cotton Pest Management Guide.

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: Sprayed conventional cotton crops defoliated after March 9 are more likely to harbour diapausing Helicoverpa armigera and should be pupae busted as soon as possible after harvest and no later than the end of August to reduce resistance risk.

Note 7: High resistance is present in Helicoverpa armigera populations. Expect field failures.

Note 8: Addition of abamectin to mirid sprays has caused high level resistance in mites. Base miticide decisions on thresholds only.

Note 9: 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 10: Resistance to spirotetramat detected in non-cotton area. Recommended limiting to 1 application, except for usage for mealybug which may require two applications 14 days apart. Use adjuvant as per label

ALWAYS FOLLOW LABEL DIRECTIONS

CONSIDER IMPACT ON BENEFICIALS & BEES; (TABLE 3, COTTON PEST MANAGEMENT GUIDE)

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

PUPAE BUST AFTER HARVEST.

IRMS Guidelines

In every population of every pest species there is a small proportion of individuals with resistance to an insecticide. The use of an insecticide controls the susceptible insects, leaving behind resistant individuals. These resistant individuals can then build up as a larger proportion of the population. Over-reliance on an insecticide can lead to an increase in the proportion of resistant individuals to the point that the insecticide fails to provide satisfactory control. This simple scenario is more complex in a field situation as products applied against a target pest not only selects for resistance in that pest but in other pests also present at the same time. 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 SLW to pyriproxyfen.

The IRMS includes all actives commercially available for use in cotton at the time of publication. The IRMS should be consulted for EVERY insecticide/miticide decision.

Principles underlying the IRMS

- Monitor pest and beneficial populations.
- Monitor fruit retention.
- Use recommended thresholds for all pests.
- For all pest species, 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 products from the same insecticide group, even when targeting different pests. Rotate between groups.
- Do not respray an apparent failure with the same product or another product from the same insecticide group. Rotate to a different group.
- Control weeds and cotton volunteers in fields and around the farm all year to minimise pest hosts.
- Pupae bust cotton as soon as possible after harvest.

How to use the 2019–20 IRMS

Region

There are two IRMS regions. Central and Southern Regions have been combined. The Northern Region covers Central Qld where stage dates accounts for the early planting and quicker crop development.

Stage

The dates shown on the strategy charts are for the start of each stage (e.g. 15 December is the start of Stage 2 for Central & Southern region). For those individual insecticides and miticides that start or end outside window boundaries, the start &/or end dates are listed.

Selectivity

The products listed 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 in the table represent the maximum number of applications per crop per season for any given product. Additional restrictions to product use can be found on the right hand column of the table, with links to specific footnotes. Avoid repeated applications of products from the same insecticide group, even when targeting different pests. Rotate between groups.

Insecticide Resistance Management Strategies in grains

Resistance management strategies have been developed for four key grains pests: *Helicoverpa armigera*, Green peach aphid, Red Legged Earth Mite and Diamond Back Moth. These strategies should be used in conjunction with the Cotton IRMS and are available at <https://ipmguidelinesforgrains.com.au/ipm-information/resistance-management-strategies/>. For other resistance management strategies and list of insecticide MOA groups refer to CropLife Resistance Management webpage: www.croplife.org.au/resources/programs/resistance-management/

Key Changes for the 2019–20 cotton season

- **Continuation of Pyriproxyfen window.** Resistance to Pyriproxyfen in SLW is a significant concern for industry. 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. The TIMS committee will again work with each region to identify an appropriate window and these dates will be published on CottonInfo and Cotton Australia websites. Limit Pyriproxyfen use to no more than ONE application per season. Refer to the SLW Threshold Matrix when making SLW control decisions. IPM, including removal of winter hosts and preserving beneficials is critical to supporting SLW resistance management.
- **Spirotetramat reduced to one application per season.** Resistance to spirotetramat in SLW has been detected in horticulture crops in a non-cotton region. 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 – two applications 14 days apart is an allowable exception.
- **Inclusion of Buprofezin.** Buprofezin usage is allowable under permit for mealybug suppression. As there is high risk of incidental selection of resistance in SLW populations usage is limited to 1 spray per season. As there has only been 1 year of impact on beneficials, the order in the IRMS may change in the future.
- **Inclusion of acetameprid in neonic grouping.** Rare, low level resistance to Acetamiprid has been detected in SLW. Avoid consecutive neonicotinoid sprays, use higher label rate for SLW control.
- **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. Refer to label for statement about bees
- **Northern Region Stage dates.** Dates have been changed due to high adoption of early planting dates.

In-season troubleshooting

Ratification of the IRMS prior to the start of each season is the responsibility of Cotton Australia's 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 further information contact Cotton Australia (02 9669 5222).

TABLE 19: Insecticide groups with resistance rating

Active ingredient (proprietary trade names)	Insecticide group	Chemical group	Resistance rating
Helicoverpa viruses (Gemstar, VIVUS Max)	Not a member of a group	Nucleopolyhedrovirus NPV	L
Paraffinic Oil (Canopy, Biopest)	Not a member of a group	Petroleum spray oil	L
Dicofol	Not a member of a group	UN – Unknown mode of action	L
Amorphous silica (Abrade)	Not a member of a group	Not a member of a group	L
Methomyl Pirimicarb Thiodicarb	GROUP 1A INSECTICIDE	Carbamate\	H
Chlorpyrifos Dimethoate Methidathion Phorate	GROUP 1B INSECTICIDE	Organophosphates	M
Fipronil	GROUP 2B INSECTICIDE	Phenylpyrazoles (Fiproles)	M
Alpha-cypermethrin Beta-cyfluthrin Bifenthrin Cypermethrin Deltamethrin Gamma-cyhalothrin Lambda-cyhalothrin Zeta-cypermethrin	GROUP 3A INSECTICIDE	Synthetic Pyrethroids	H
Acetamiprid (Intruder, Scope#) Clothianidin (Shield) Imidacloprid (multiple, includes seed treatments) Dinotefuran (Starkle) Thiamethoxam (multiple, includes seed treatments Voliam Flexi#)	GROUP 4A INSECTICIDE	Neonicotinoids	M
Sulfoxaflor (Transform)	GROUP 4C INSECTICIDE	Sulfoximine	L
Spinetoram (Success Neo, Spinosad)	GROUP 5 INSECTICIDE	Spinosyns	L
Abamectin Emamectin (Affirm, Scope#)	GROUP 6 INSECTICIDE	Avermectins	H abamectin L emamectin
Pyriproxyfen (Admiral, Avante, Lascar, Muligan)	GROUP 7C INSECTICIDE	Pyriproxyfen	H
Pymetrozine (Chess)	GROUP 9B INSECTICIDE	Pymetrozine	L
Afidopyropen (Versys)	GROUP 9D INSECTICIDE	Afidopyropen	L
Flonicamid (MainMan)	GROUP 29 INSECTICIDE	Flonicamid	L
Etoxazole	GROUP 10B INSECTICIDE	Etoxazole	L
Foliar <i>Bacillus thuringiensis</i> (Dipel)	GROUP 11 INSECTICIDE	Bt microbials	M
Diafenthiuron (Pegasus, Receptor, Aphinox)	GROUP 12A INSECTICIDE	Diafenthiuron	L
Propargite	GROUP 12C INSECTICIDE	Propargite	L
Amitraz	GROUP 19 INSECTICIDE	Amitraz	L
Buprofezin	GROUP 16 INSECTICIDE	Buprofezin	
Indoxacarb	GROUP 22A INSECTICIDE	Indoxacarb	H
Spirotetramat	GROUP 23 INSECTICIDE	Spirotetramat	M
Chlorantraniliprole (Altacor) (Voliam Flexi#) Cyantraniliprole (Exirel)	GROUP 28 INSECTICIDE	Diamides	H

#Voliam Flexi has actives from both Group 28 and Group 4A.

* Skope has actives from both Group 4A + Group 6 insecticide

Source: CropLife Australia Insecticide Resistance Management Review Group, 2016; <http://www.croplifeaustralia.org.au/>

Preamble to the Bollgard 3 Resistance Management Plan (RMP)

Sally Ceeney, Cotton Australia

Acknowledgements: Nicola Cottee (formerly Cotton Australia); Susan Maas (CRDC); Sharon Downes (CSIRO); Kristen Knight (Bayer)

Resistance is the greatest threat to the continued availability and efficacy of Bt cotton in Australia. Even though the proteins in Bt cotton are delivered in the plant tissues, there is still the selection for the survival of resistant individuals. The RMP was established by regulatory authorities to mitigate the risks of resistance developing to any of its proteins. As it is difficult to be precise about the probability of resistance developing in *Helicoverpa* to the proteins contained in Bt cotton the industry implemented a pre-emptive management plan that aims to prevent field level changes in resistance.

A key component of the RMP for the first generation of Bt cotton, INGARD was a limitation on the area of INGARD cotton that could be planted. This restriction limited selection for resistance to the Cry1Ac protein. The industry has so far been able to preserve the efficacy of this gene. When Bollgard II cotton replaced INGARD in 2004–05, the constraint on the area of transgenic cotton was removed. Crops with multiple toxins should be more robust because it is unlikely that insects will be resistant to more than one toxin, especially if the toxins being 'stacked' 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 variety is introduced. Bollgard 3 cotton contains Cry1Ac, Cry2Ab and Vip3A. For *H. Armigera* and *H. Punctigera* the assumed baseline frequency of Cry2Ab resistance genes in populations was substantially higher than expected.



H. Armigera. (Melina Miles, Qld DAF)

CSIRO have found that in *H. Armigera* the frequency of genes conferring resistance to the new protein in Bollgard 3 (Vip3A) may be as high as 1 in 20 moths. Not only is this higher than expected, it is much greater than the starting frequencies for Cry2Ab. Vip3A resistance genes have also been detected in *H. Punctigera* at a frequency that is higher than expected and higher than the starting frequencies for Cry2Ab.

Computer Simulation models of resistance development indicate that it will be more difficult for a pest to develop resistance to all of the insecticidal proteins. However, it is not impossible for *Helicoverpa* to adapt to this technology. With over 90% of the industry using BT technology, it is imperative that the RMP is implemented effectively to ensure the longevity of the product.

The 5 Elements of the Bollgard 3 RMP

The five elements of the RMP impose limitations and requirements for management on farms that grow Bollgard 3 cotton. These 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. The following section is aimed at informing how the RMP was developed, how it is intended to be used and assessed for its effectiveness in managing resistance. For full details of how to practically implement the RMP, please refer to the RMP document, your Technology Service Provider (TSP) or your Monsanto Regional Business Manager.

Your questions answered

How do we test whether the RMP is effective?

To evaluate the effectiveness of the RMP, CSIRO, with funding support from CRDC, implement a monitoring program every other year; Bayer also invests in an annual program that monitors field populations of moths for resistance for all the proteins contained in Bollgard 3 cotton (Cry1Ac, Cry2Ab and Vip3A). The data provides an early warning to the industry of the onset of resistance to the proteins in Bollgard 3. The results are used to make decisions about the need to modify the RMP from one season to the next to ensure its ongoing effectiveness at managing resistance.

Two sorts of tests have been conducted. F2 screens (F1 and F2 are frequency screenings for first and second generation moths) involve testing the grandchildren of pairs of moths raised from eggs collected from field populations, and therefore take about 10 weeks to run. This method was incorporated into the monitoring program by CSIRO in 2002 and Monsanto (now Bayer) in 2003 and detects all previously isolated and potentially new types of resistances but is very labour intensive.

In 2004 CSIRO developed protocols for testing the frequency of resistance using a modified and shorter version of the F2 method called an F1 test. F1 screens involve testing the offspring of single-pair matings between moths from resistant strains maintained in the laboratory and moths raised from eggs collected from field populations. They take around 5 weeks to conduct. This method assumes that the various isolates of Cry2Ab, Cry1Ac and Vip3A detected so far are of the same kind. These protocols were immediately adopted by Bayer and are now the main focus of both monitoring programs. During the following two years CSIRO performed experiments which verified that each of the isolates of Cry2Ab detected until then, was the same type of resistance, and subsequently adopted F1 tests.

In 2013 CSIRO and Bayer, shifted to performing only F1 screens to focus on the frequencies of the known resistances. In addition to screening F1 families against the toxin of interest (e.g. Cry2Ab), they introduced screens against all classes of Bt toxins (e.g. Cry1Ac and Vip3A) in an effort to detect any novel forms of resistance that carry dominance. Every 4 or 5 years CSIRO will incorporate F2 screens into the program to check for any new recessive forms of resistance. Bayer will continue to perform F2 screens on an annual basis.

The data in the following sections is sourced from Bayer's annual program and the industry funded CSIRO program. There is currently no resistance to Bollgard 3 that affects its performance against *H. Armigera* or *H. Punctigera*. 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. The following sections refer to the frequencies of these recessive resistance genes which currently are not at a level which impacts performance of the technology.

What is the current situation for Bt resistance in *H. Armigera* in Australia?

A gene is present in field populations of *H. Armigera* that has the potential to confer high-level resistance to Cry1Ac. This gene occurs at a low frequency which is probably less than 5 in 10,000 (<0.0005 or 0.05%). It does not confer cross-resistance to Cry2Ab or Vip3A and in certain environments is largely recessive. It also has a high fitness cost (i.e. resistant individuals develop slowly and are more likely to die) but this disadvantage is not likely to greatly impact on the development of resistance. In addition, Dr Robin Gunning (NSW DPI) suggests that other resistance mechanisms may be present in *H. Armigera*.

A gene that confers high level resistance to Cry2Ab is present in field populations of *H. Armigera*. This gene does not confer cross-resistance to Cry1Ac or Vip3A. The most extensively studied colony of insects with this resistance (called SP15) appears to be as fit as susceptible insects. The resistance in such colonies is recessive. The mechanism conferring resistance to Cry2Ab in *H. Armigera* is likely to be an alteration of a binding site in the gut of the insect. Results with *H. Armigera* show that the current estimate of Cry2Ab resistance frequency for F1 screens is approximately 2 in 100 (0.02, 2%) or less.

What is the current situation for Bt resistance in *H. Punctigera* in Australia?

Before 2008–09 more than 4000 genes from *H. Punctigera* had been screened and none had scored positive for resistance to Cry1Ac. However, since 2008–09 at least 9 individuals which carry a gene that confers resistance to Cry1Ac have been isolated from field populations of *H. Punctigera*. F2 tests indicate that the frequency of this gene is less than 1 in 1000 (0.001, 0.1%). It is not cross-resistant to Cry2Ab or Vip3A. F1 tests against *H. Punctigera* for Cry1Ac resistance currently detect a frequency of 5 in 1000 (0.005, 0.5%) or less.

A gene that confers high level resistance to Cry2Ab is present in field populations of *H. Punctigera*. This gene does not confer cross-resistance to Cry1Ac or Vip3A. The most extensively studied colony of resistant insects (called Hp4–13) demonstrates the same broad characteristics as the SP15 strain of Cry2Ab resistant *H. Armigera*. The resistance is recessive, occurs at a high level, and is due to an alteration of a binding site in the gut of the insect. Based on F1 screens the current frequency of Cry2Ab genes in *H. Punctigera* is approximately 1 in 100 (0.01, 1.0%).



H. Punctigera. (Melina Miles, Qld DAF)

Why is there a high baseline frequency of Cry2Ab genes in field populations?

The high frequency of individuals carrying the Cry2Ab resistance gene in field populations is unexpected because, until the widespread adoption of Bt cotton, there has presumably been little exposure of *Helicoverpa* to this toxin and therefore little selection for resistance. Although the Cry2Ab toxin from Bt is present in some Australian soils, it is not common. In contrast, the Cry1Ac toxin is far more common in Australian soils, yet resistance to this toxin in *Helicoverpa* is rare. Mutations that confer resistance to Cry2Ab may occur in field populations of *Helicoverpa* at a very high rate.

Collection of *H. Punctigera* moths from inland regions were made in winter 2009 to see if these populations, which would have had little exposure to Bt cotton, carried resistance to Cry2Ab. F1 screens conducted by CSIRO on these populations showed that they carried the same Cry2Ab resistance gene present in the cropping areas but at a much lower frequency of 5 in 1000 (0.005, 0.5%) compared to a sample from cropping populations collected at the same time (5 in 100, 0.05, 5%). We did not have an F1 resistance frequency for Cry2Ab in *H. Punctigera* prior to the widespread adoption of Bt cotton.

Is the frequency of Cry2Ab genes increasing in field populations of *H. Armigera*?

Both CSIRO and Bayer data sets, analysed independently, show that there is no significant difference in the frequencies of Cry2Ab resistance alleles over the longer term; although the frequencies in 2010–11 were higher than in previous years, they have since declined. Irrespective of changes through time, the frequencies of Cry2Ab in *H. Armigera* are higher than expected and this finding is a concern.

Is the frequency of Cry2Ab genes increasing in field populations of *H. Punctigera*?

CSIRO and Bayer data sets, analysed independently, show that there is no significant difference in the frequencies of Cry2Ab resistance alleles over the longer term; although the frequencies in 2008–09 were higher than in previous years, they have since declined. Irrespective of changes through time, the frequencies of Cry2Ab in *H. Punctigera* are higher than expected and this finding is a concern.



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Why has *H. Punctigera* shown potential to develop resistance to Cry2Ab when it has no history of resistance to insecticide sprays?

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. The decline in Cry2Ab resistance frequencies in *H. Punctigera* in 2009–10 may reflect some dilution due to immigration of inland individuals but this hypothesis is difficult to test.

What is known about resistance to Vip3A protein in *H. Armigera* and *H. Punctigera*?

Monitoring for resistance to the Vip3A protein has revealed that resistance genes for this protein already exist in *H. Punctigera* and *H. Armigera*. Data obtained by CSIRO suggest that the frequency of Vip3A resistance genes in *H. Punctigera* is around 1 in 100 (0.01, 1%). This estimate is based on F2 screens (2009–12). The frequencies of Vip3A resistance alleles in *H. Armigera* obtained from F2 screens are higher than those for *H. Punctigera*, at 3 in 100 (0.03, 3%). Therefore, as with Cry2Ab, there is an unexpectedly high frequency of individuals in field populations that carry a gene conferring resistance to Vip3A protein.

In 2010–11 Monsanto (now Bayer) began screens for Vip3A resistance genes in both *Helicoverpa* and estimate from a small sample a frequency for *H. Armigera* based on F1 screens of 1 in 100 (0.01 or 1%). The estimate of Vip3A resistance frequency for *H. Punctigera* based on F1 screens is also 0.5 in 100 (0.005 or 0.5%).

Is the current RMP adequate for controlling further increases in resistance frequencies?

There have been no reported field failures of Bt cotton due to resistance in Australia. However the finding of a higher than expected baseline frequency of Cry2Ab and Vip3A is a major concern. It is imperative that all users of Bollgard 3 steward the technology responsibly. In particular, it is critical that closer attention is paid to managing Bollgard 3 associated refuges, and that if required, effective pupae busting occurs in a timely fashion.

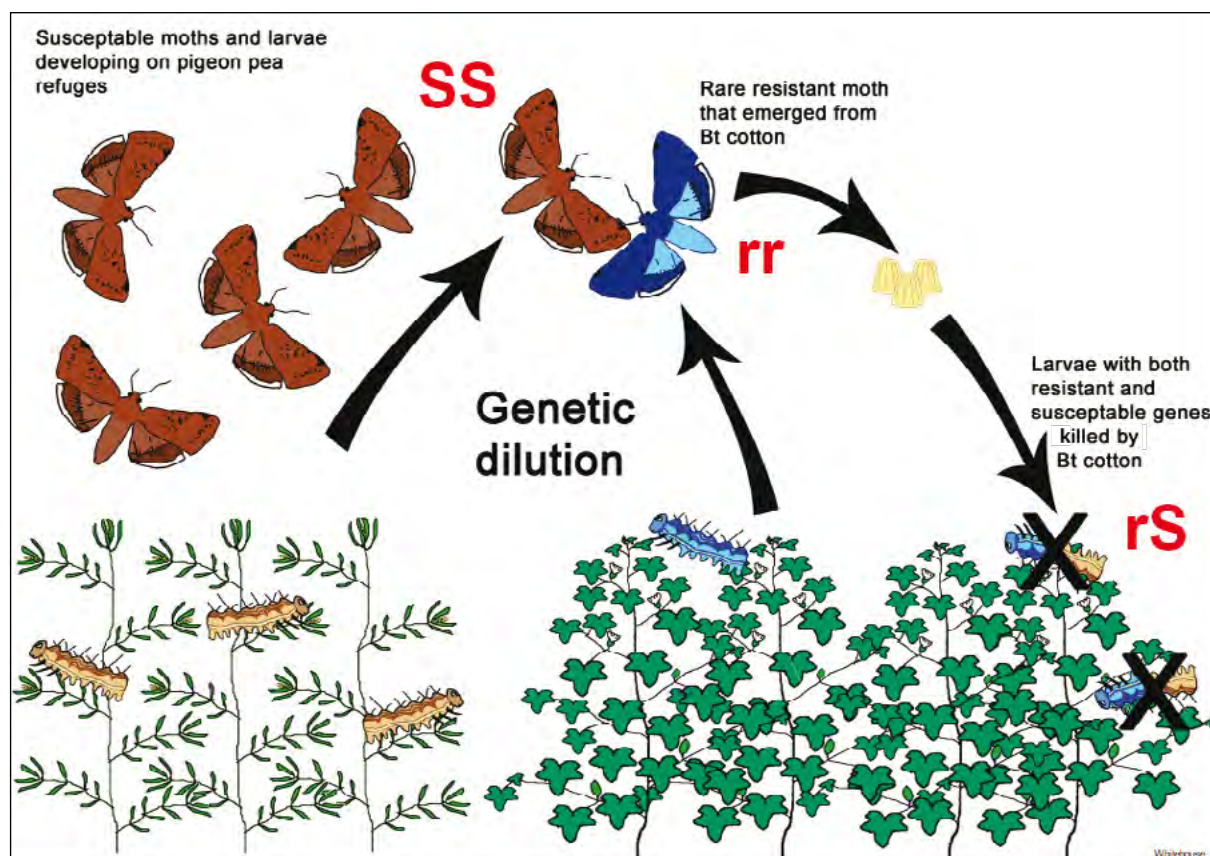
In addition, Bayer and the TIMS Bt Technical Panel will continue to work together to annually assess new information on resistance frequencies in *Helicoverpa* species and to extend knowledge of tactics for Bt resistance management to provide background information and recommendations for the Cotton Australia convened TIMS Committee. If required, additional measures could be taken in response to significant increases in resistance frequencies to any of the toxins contained in Bollgard 3 cotton by *Helicoverpa* to mitigate the risk of levels being attained that would lead to field failures.

RMP tactics

1. Refuges

What is the purpose of refuges?

The aim of refuge crops is to generate significant numbers of susceptible moths (SS) that have not been exposed to selection pressure from the Bollgard 3 proteins to provide genetic dilution during the season. Moths produced in the refuge crops will disperse to form part of the local mating population where they may mate with any potentially resistant moths (RR) emerging from Bollgard 3 crops. This reduces the chance that resistant moths will meet and mate. The offspring from matings between one



resistant and one susceptible moth will carry one gene from each parent (RS) and are referred to as heterozygotes. In the cases of Bt resistance that have so far been identified, heterozygotes are still controlled by Bt cotton. Therefore, the critical function of the refuge is to dilute the frequency of RR individuals within the population. It is crucial that the timing of the production of moths from refuges matches that of Bollgard 3 crops. While the use of planting windows and use of two or three Bt genes are aimed at reducing selection pressure for Bt resistance, the use of refuge crops is to try to balance or counter the selection that will still occur.

How were the current requirements for refuge crops determined?

The relative sizes of refuge crops required in the RMP are based on models and knowledge of *Helicoverpa* moth emergence for different crop types. The likely moth productivity of the different refuge options has been determined through large-scale field experiments.

In these experiments, a refuge of 10% unsprayed cotton was considered as the reference point for a farm. On average, pigeon pea produced twice as many moths as the same area of unsprayed cotton, hence only a 5% refuge, half that of an unsprayed cotton refuge of pigeon pea, is required for Bt cotton.

The refuge requirements for Bollgard 3 have been reduced to 5% unsprayed cotton and 2.5% pigeon pea. This reduction represents 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. Improving the production potential of each individual refuge is an integral component of the RMP. Research is underway to identify areas of improving refuge performance and better understanding of the contribution of refuges to resistance management. Growers must ensure that on farm refuge management is a priority. Guidelines on refuge management are provided in the RMP and in the Pigeon Pea agronomy guide on page 76.

Bollgard 3 refuges must be a minimum of 0.5 ha and at least 24 m wide. This is to account for possible insecticide drift onto the refuge.

How can the 'effectiveness' of an individual refuge be evaluated?

The productivity of refuges will vary considerably across regions and seasons. It is not possible to place a value on the effectiveness of each refuge. 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. Managing resistance is a population level activity, and every refuge makes an important contribution to the overall RMP for the valley and, because *Helicoverpa* disperse widely, on a larger scale 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.

Why is the location of refuge crops important?

For the refuge principle to be successful, refuge crop areas must be in close proximity to the Bollgard 3 crop(s) to ensure that it is highly likely that moths emerging from the Bollgard 3 crop will mate with susceptible moths from the nearby refuge crop. *Helicoverpa* moths are capable of migrating long distances, but during the summer cropping season a significant part of the population may remain localised and move only a few kilometres within a region. The level of movement will depend on the mix of crops and their attractiveness at the time of moth emergence. For

this reason the best location for a refuge crop is close as possible to the Bollgard 3 crop, within 2 km. Having the refuge separated by a gap (like a road or drain) from the adjacent Bollgard crop would be ideal as it will minimise large larvae potentially moving from the refuge and being exposed to the Bollgard crop.

With regard to refuge crops, what does the term 'unsprayed' mean?

The term 'unsprayed' encompasses all management activities which are likely to reduce the survival of *Helicoverpa* in these crops. Insecticides with activity against *Helicoverpa* cannot be used in unsprayed refuges. Food sprays cannot be used in unsprayed refuges as these aim to reduce *Helicoverpa* survival through increased predation and parasitism. Similarly, *Trichogramma* and other biological control agents cannot be released in unsprayed refuges as they too aim to reduce *Helicoverpa* survival.

2. Volunteers

Why is it important to control conventional cotton volunteers or ratoon plants in Bollgard 3 cotton?

In terms of the RMP, it is important to prevent the establishment of conventional cotton in Bollgard 3 fields because larger larvae that have grown on conventional cotton plants are moderately tolerant to Bollgard 3. If large larvae migrate to neighbouring Bollgard 3 plants, those that are heterozygotes (RS) may survive and contribute to increasing the frequency of resistance genes in the *Helicoverpa* population. In the cases of Bt resistance that have so far been identified, heterozygotes are controlled by Bollgard 3 cotton. By removing conventional volunteers from Bollgard 3 fields, heterozygotes will have no opportunity to grow large enough to be able to tolerate Bollgard 3 plants and therefore contribute their resistance genes to the next generation of moths.

Why is it important to control Bollgard 3 cotton volunteers or ratoon plants in conventional cotton and all refuges?

The same logic applies as in the previous question. The presence of Bollgard 3 cotton volunteer plants in a conventional crop or refuge exerts a selection pressure for Bt resistance. Heterozygous (RS) larvae that emerge from eggs laid on conventional cotton may grow and during their development move onto Bollgard 3 cotton volunteers. In this way RS larvae become exposed to Bt proteins 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

Why do we need a Bollgard 3 cotton planting window?

The purpose of restricting the planting window is to limit the number of generations of *Helicoverpa* that will be exposed to Bollgard 3 cotton in any one season which is especially important in warmer growing regions. This measure effectively restricts the selection pressure on *Helicoverpa* to develop resistance to Bollgard 3 cotton.

Why has the planting window been widened for Bollgard 3?

In developing the Bollgard 3 RMP, new research and modeling identified that planting windows were not particularly efficient at limiting the number

of generations of *Helicoverpa* exposed to Bt cotton and that the end of the season, especially late crops, were identified as having the highest potential to increase resistance risk due to increased length of exposure. For this reason, it was decided to shift the focus 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, through the use of planting windows. Planting windows still remain an important mitigation tactic for Bollgard 3 however, particularly in warmer climates where cotton and *Helicoverpa* can survive and reproduce all year round.

4. No Bollgard 3 sprays

Why is it important that foliar Bt sprays are not used on refuges?

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

Given that few larvae survive in Bollgard 3, why is it important to pupae bust?

Pupae busting is a highly effective mitigation tactic for reducing resistance risk, provided it is performed well and at the right time. Cultivating between seasons prevents any moths that developed resistance in the previous year from contributing to the population in the following year. Although we expect few larvae to survive in Bollgard 3 cotton, those that do are most likely resistant and these are precisely the ones that must be killed so that the next generation of moths (emerging the following spring) are not enriched with resistant individuals. The pupae busting guidelines are based on the likelihood that larvae will enter and remain in diapause based on the *Helicoverpa* Diapause Induction and Emergence model that was developed from field research.

By 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. March 31 has been selected as the first average date where the likelihood of diapause occurring is 50%. Growers who defoliate before this date 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.

Am I required to pupae bust in my refuges?

Unsprayed refuges do not need to be pupae busted. 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. It is recommended that sprayed refuges are pupae busted to manage resistance to conventional products (see Post Harvest Pupae Destruction statement, page 58).

Why are there requirements for trap cropping in central Queensland?

In central Queensland *Helicoverpa* pupae produced late in the cotton season do not remain in the soil, but emerge within 15 days of pupating. Pupae busting is not an effective resistance management tool in these warmer areas and 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. Thus 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 in the trap crop. The egg and larval stages can last 30+ days. 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.

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 the survivors included *H. Armigera* and *H. Punctigera*.

Work conducted by CSIRO and Bayer demonstrated that these larvae did not survive on Bt cotton due to Bt resistance or because of the absence of Bt genes in the cotton. Recent work suggests that larvae exhibit strong behavioural responses to the Bt proteins in Bt cotton plants. Detection and avoidance of the Bt toxins results in frequent movement of larvae, potentially 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 in Bt cotton, can result in a proportion of larvae becoming established.

For resistance management reasons, it is recommended that if larvae reach thresholds in Bollgard 3 fields they should be controlled by spraying. However work conducted by Bayer suggests that it is unlikely that there will be a yield penalty associated with larvae survival in Bollgard 3 fields. This is supported by a study that used the distribution of larval damage in fields that carried larvae at the current thresholds as the basis for an artificial damage experiment.

The work showed that 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 we monitor the distribution and proportions of fields that are affected by surviving larvae, and the number of fields that are sprayed to control *Helicoverpa*. 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 61–64). The beneficial/pest ratio (described on page 50) should also be given careful consideration when the application



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of an insecticide is being considered. If an insecticide is required, aim to choose the most effective product that is the least disruptive to the beneficial complex (refer to pages 10–11). 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 any larvae <3 mm long or eggs, 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 21.

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 <http://www.monsantoglobal.com/global/au/products/Pages/cotton-stewardship.aspx> ■■■

BOLLGARD 3 RESISTANCE MANAGEMENT PLAN

Developed by Monsanto Australia Limited

The Resistance Management Plan is based on three basic principles: (1) minimising the exposure of *Helicoverpa* 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 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 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 December 31 each year, unless otherwise specified in this Resistance Management Plan.

Central Queensland

All Bollgard 3 crops and refuges must be planted into moisture or watered-up between August 1 and October 31 each year, unless otherwise specified in this Resistance Management Plan. 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 Tables 3 and 4 (below).

2. Refuges

Growers planting Bollgard 3 cotton will be required to grow a refuge crop that is capable of producing large numbers of *Helicoverpa* 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* from each of the refuge types as described in Tables 1 and 2 (below) 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 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*. 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*, or any other caterpillar species, contact Monsanto Australia immediately. With prior approval from Monsanto Australia, a non-Bt heliocyte 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* larvae.

BOLLGARD 3 RESISTANCE MANAGEMENT PLAN

General conditions for all refuges

- (a) Refuge crops are to be planted and managed so that they are attractive to *Helicoverpa* 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 the Refuge Management Guide for all unsprayed refuges.
- (d) Once Bollgard 3 cotton begins to flower, the corresponding refuge must not be cultivated.
- (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. In Central Queensland, soil disturbance of refuge crops must only occur when the trap crop is being destroyed (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 (calculated as defined in the Technology User Agreement).

3. Control of volunteer and ratoon cotton

Volunteer and ratoon cotton may impose additional selection pressure on *Helicoverpa* 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*.

Growers must ensure that volunteer and ratoon plants are removed as soon as possible 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* pupae destruction in fields with a higher probability of carrying overwintering 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 completed by July 31 for all valleys except for 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.

Central Queensland

Crop destruction

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

BOLLGARD 3 RESISTANCE MANAGEMENT PLAN

End of season management of refuges/trap crops

End of season pupae busting practices are not effective in the Central Queensland region as *Helicoverpa* 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 (below) shows the requirements for the late summer pigeon pea trap crop. Dryland Bollgard 3 growers who do not have any irrigated cotton on their farm should contact Monsanto Australia for alternative options.

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

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

Criterion	Trap crop*
Minimum area & dimension (Requirement)	A minimum trap crop of 1% of planted Bollgard 3 cotton crop is required. If sprayed conventional cotton is grown on that farm unit: the trap crop must be at least 48 m x 48 m. If no sprayed conventional cotton is grown on that farm unit: the trap crop must be at least 24 m x 24 m.
Planting time	The trap crop should preferably be planted 4 weeks after the associated Bollgard 3. Note: if growers choose to plant their trap crop to coincide with the planting of pigeon pea refuges, they must manage the trap crop in such a way that it remains attractive to <i>Helicoverpa</i> 2-4 weeks after final defoliation.
Planting rate**	35 kg/ha (recommended establishment greater than 4 plants per metre)
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 5% pigeon pea refuge area managed to become the late summer trap crop can only be sprayed with virus after the first defoliation of Bollgard 3 cotton.
Irrigation	The refuge/trap crop must be planted into an area where it can receive the additional irrigation required to keep the trap crop attractive to <i>Helicoverpa</i> 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* 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*, 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 “Preamble to the Bollgard 3 Resistance Management Plan” page 65.

Unsprayed pigeon pea refuge agronomy

Sally Ceeney, Cotton Australia

Acknowledgements: Susan Maas (CRDC); Mary Whitehouse (CSIRO); Kristen Knight (Bayer); Paul Grundy (Qld DAF); Sharna Holman (Qld DAF & CottonInfo)

Establishing and growing an attractive refuge is a mandatory component in the Resistance Management Plan (RMP) for Bollgard 3. The purpose of a refuge is to generate significant numbers of *Helicoverpa* moths which have not been exposed to selection pressure from any of the Bt proteins. Attractive, fully irrigated, unsprayed flowering pigeon pea will, on average, produce twice as many moths as the same area of unsprayed cotton. As well as producing high numbers of moths, it is also crucial that the timing of production of moths from refuges matches that of 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. Growers should 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, therefore select fields that have good post-irrigation/rainfall drainage. Avoid fields that were sown to cotton during the previous season as this will 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 a refuge. Similarly, selecting fields with a low weed seed bank also enables easier management of weeds that can compete with pigeon peas and reduce refuge effectiveness.

Ideally, refuges should be sown in a field area adjacent to the Bollgard 3 cotton crop. Be mindful to ensure sufficient separation to avoid the drift of herbicides or insecticides applied to the cotton or other crops onto the refuge area.



Larvae in pigeon pea refuge. (Photo: Johnelle Rogan)

As with many other legumes, pigeon pea can have allelopathic effects on subsequent crops which should be taken into account when making field selections.

Crop establishment

Timing

Similar to mung and soybeans 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 Bollgard 3 for irrigated crops.

Sowing and inoculation

Nitrogen fixation by legumes such as pigeon pea is optimal in soils with very low residual soil N. The use of peat based group J inoculation formulations on seed just prior to planting will help to ensure effective rootzone colonisation by active strains of rhizobium bacteria. Effective nodulation of the root system can reduce crop susceptibility to water logging. To ensure efficacy of inoculant, follow all label requirements and directions regarding storage, handling and application.

Over a period of 20 years the continual recycling and saving of seed from undamaged refuges has caused an evolutionary shift towards pigeon peas that flower much later or at times not at all. This problem has been redressed with the release of Sunrise™ a new variety of pigeon peas. Sunrise™ exhibits excellent vigour under furrow irrigation across a range of soil types, and should commence flowering by early January or typically within 75 days of sowing. Sunrise™ is strongly indeterminate and has the ability to repeat flower, particularly after sustaining insect attack.

Sunrise™, seed production is being undertaken annually by Associated Grains to ensure that the planting seed that is 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 the range of 25–40 kg/ha being guided by germination statistics and field conditions at the time of planting. Growers concerned about crop residues should consider using planting rates at the higher end of the recommended range as this will result in plants with thinner stalks, which makes later crop destruction much easier.

Pigeon peas row spacing should match that of the corresponding Bt cotton crop.

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 original determinate Quest, and on average generate 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.



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Crop nutrition

Pigeon pea requires inoculation with Group J inoculant. Nodulation will be limited in high nitrogen soils. A well-grown crop of pigeon pea can add up to 38 kg/ha of nitrogen. 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 addition of phosphorus and zinc. Like cotton, pigeon pea is highly arbuscular mycorrhiza (AM) dependent and in long fallow situations, it may even be more responsive to P and Zn.

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, cultivation can inadvertently kill (the Bt-susceptible) *Helicoverpa* pupae present in the soil at the time. For this reason, 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. Selecting a site with good drainage, avoiding irrigation prior to heavy rainfall predictions and only watering every second row can be useful strategies for reducing the risk of water logging. In principle, growers should use the same best management tactics on pigeon pea as those being used for their 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, it is important to ensure crops do not become moisture stressed as this reduces attractiveness and truncate 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 apply the first in crop irrigation as the plants begin to show flower bud development. 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 adjacent cotton which will prolong flowering and ensure rapid regrowth after insect attack.

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 Qld, 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. Growers in Central Queensland using pigeon pea for trap crop purposes should refer to the late summer pigeon pea trap crop requirements of the RMP for full details.

Note – No crop product or crop residue is to be fed to livestock.

III

TABLE 20: Herbicides available for use in pigeon pea (registered or permit number Per13758)

Active Ingredient	Mode of Action	Comment
Prometryn*	C	Apply up to the maximum rate pre planting and incorporate, or as a post-emergent directed spray towards the base of established plants (Per13758)
Trifluralin	D	Apply up to the maximum rate pre planting and incorporate. NSW and ACT only.
Butroxydim *	A	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. (Per13758)
Fluazifop-p*	A	
Haloxifop*	A	
Sethoxydim*	A	Apply specified rate as a post-emergence spray over the top of the pigeon pea crops. (Per13758)
Clethodim*	A	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. (Per13758)
Quizalofop*	A	Refer to permit for growth stages of species and critical comments. (Per13758)
Diquat	L	Harvest aid
Diquat/paraquat	L	Apply pre-sowing, in minimum 50–100 L water. Apply specified rates for certain weeds at particular growth stages, refer to label.
Pendimethalin	D	Incorporate into the soil within 24 hours of application. Use higher rate on heavy textured soils or those high in organic matter. May be applied by aerial or ground spraying. In Macquarie Valley area, only apply by air when ground is too wet for ground application.
Metribuzin	C	Furrow irrigated: apply after furrowing out, within 2 weeks before sowing and incorporate. For post-emergence: apply to actively growing seedling stage weeds provided crop plants have at least 2 trifoliolate leaves. Do not spray if rain is likely to fall within several hours. Overhead irrigated: apply pre-emergence then irrigate.

* Use of these products is under permit (Per13758).

NOTE: 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 only. No crop product or crop residue is to be fed to livestock. Refer to all labels and permit conditions. Please go to www.apvma.gov.au to check allowable usages.

Management of volunteer and ratoon cotton

Sharna Holman, Qld DAF and CottonInfo
Susan Maas, CRDC
Frank Taylor, Nufarm

Controlling volunteer and ratoon cotton is an essential part of good integrated pest and disease management and general farm hygiene. The industry encourages zero tolerance of ratoon cotton (cotton that has regrown from left over root stock from a previous season) and volunteer cotton (cotton that has established unintentionally) as these plants can provide a 'green bridge' to enable pests and diseases to carry over 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 before control can occur. 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, 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.

Best practice...

- Plan to control volunteers 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 cultivation implements are set up to cultivate both hill and furrow, to avoid leaving uncultivated strips.
- Manual removal of plants (i.e. chipping) may be necessary where isolated plants remain in non-field areas.
- Always Come Clean. Go Clean.

Cultural

- Broadacre cultivation will control seedling volunteers as well as large volunteers in a fallow situation. Effective cultivation will only occur if the cultivation implement cultivates both the furrow and hill avoiding strips being left uncultivated. Cultivation will also manage other weeds besides seedling volunteer cotton which makes it an excellent non-chemical control to include within an integrated weed management program. The disadvantage of cultivation is that it only controls established seedlings, is slow and can cause moisture loss or soil damage if conducted at the wrong time.
- Seedling volunteers can be controlled reasonably well with less invasive physical removal such as kelly chains. These break the seedling cotton stems and can be particularly useful close to planting.
- Where isolated plants remain during a fallow and in non-field areas, spot spraying and physical removal by chipping can be effective.
- In-crop cultivation with sweeps that lift or till out volunteers and other weeds are effective tools for control when volunteers are small.
- Aim to plant refuge crops into fallow areas, rotation fields that have not been planted to cotton in the previous season.

Ten reasons why ratoon and volunteer cotton must go:

1. Mealybugs survive from one season to the next on these food sources, infesting crops earlier in the following season.
2. Cotton aphids with resistance to neonicotinoids survive between seasons on these plants, reducing insecticide effectiveness.
3. Bunchy top disease can be transmitted by Cotton aphids from infected ratoons to new cotton crops.
4. Silverleaf whitefly survive between seasons on these plants, resulting in earlier infestation in the following season.
5. They provide a winter host for Pale cotton stainers and solenopsis mealybugs.
6. Inoculum of soil-borne diseases such as Black root rot, Fusarium and Verticillium builds up in ratoons, as does the population of parasitic nematodes such as *Rotylenchulus reniformis*, the reniform nematode.
7. Ratoon and volunteer plants place extra selection pressure on Bt.
8. Fields with ratoons from Bt cotton are unsuitable for planting refuge crops, as the refuge cannot be effective if contaminated with Bt cotton plants.
9. Removing ratoons may be a costly exercise, but it is cheaper than the costs of dealing with the problems resulting from not removing them.
10. They are a biosecurity risk. Ratoons harbour pests and are a potential point of establishment for exotic pests.

Chemical

- Pre-watering is a method used to establish volunteers prior to planting, providing a window for appropriate herbicide control.
- While glyphosate is effective at controlling seedling (up to 2nd leaf stage) non-glyphosate tolerant volunteers, the widespread adoption of Roundup Ready Flex® cotton, which has a gene allowing the tolerance of over-the-top applications of polyphosphate, eliminates the use of glyphosate as a potential control herbicide.
- With all contact herbicides, excellent spray coverage is essential for adequate control. This often means high (e.g. 100 L/ha) water volumes per hectare. Coverage can often be compromised due to shading, stubble and lint. Ensure appropriate spray quality which may vary depending on the product selected, but generally a medium-coarse spray quality would be adequate at 100 L/ha.
- Rotation cropping enables residuals to be included in the mix and is a good cultural control. Where rotations are planned, ensure that good control is achieved as cotton plants hidden within subsequent crops can continue to harbour pests and disease and won't be as obvious as bare fallows.
-

- Most herbicide options work best on seedling volunteers. However recent research has found identified three herbicide options for the control of large (15 to 30 node) volunteer and ratoon cotton plants.
- Table 21 provides a list of herbicides that have registration for control of volunteer cotton. Not all brands of these actives have volunteer cotton on the label. Refer to label for specific use information.
- Ensure label directions are followed, especially where volunteers are located near water ways.
- For more detailed information on chemical options for controlling volunteer cotton, see WEEDpak, section F4.

Ratoon cotton

Ratoon cotton is normally a product of minimum tillage where either conventional cotton is double cropped back to a winter cereal, or cotton is grown consecutively, from one season to the next. In theory, ratoon cotton should not occur due to the requirement of harvested cotton to be controlled with adequate cultivation and soil disturbance as soon as practical after picking. This usually involves some sort of mulching and/or root cutting followed by cultivation to destroy the cotton root system.

TABLE 21: Herbicides that have registration for control of volunteer cotton

Active ingredient	Mode of Action group	Comments (always refer to product labels)
Amitrole + ammonium thiocyanate	Q	See label for rain fastness. Apply in 50-100 L/ha water. Addition of 0.25% LI700 may improve results. Tank mix with glyphosate. Sowing can occur immediately after application. Bleaching of isolated crop leaves may be seen after emergence.
Amitrole + paraquat	Q + L	Can be applied after an initial spray of a glyphosate herbicide (Double Knockdown). Refer to label for spot spray rates.
Bromoxynil	C	Apply in minimum of 80 L/ha water for Roundup Ready cotton. See label for rain fastness. Refer to label for restrictions on spray quality & condition.
Carfentrazone-ethyl	G	Apply minimum spray volume of 80 L/ha. 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	Apply in 50-100 L water/ha. For best results, spray in the evenings or in humid conditions.
Flumetsulam	B	Do not apply post-emergent treatments if rain is likely within 4 hours. Do not irrigate (any method) treated crop or pasture for 48 hours after application. May be banded (>40%) over the row or broadcast. Minimum spray volume 150 L/ha for optimum results.
Flumioxazin	G	Do not apply post-sowing pre-emergent. Apply no later than 1 hour prior to sowing or post sowing up to 2 days before first crop emergence. Can be tank mixed with glyphosate to control other weeds that may be present. Refer to label for adjuvant details.
Glufosinate-ammonium	N	Good coverage is essential. Do not apply more than three applications per season.
Metribuzin	C	Registered for control of volunteer cotton in pigeon pea. Refer to label for critical comments.
Fluroxypyr	I	Summer fallow.
Saflufenacil	G	Do not apply post-sowing pre-emergent. Use a spray volume of 80-250 L/ha. Increase water volume if weed infestation is dense and/or tall. See label for mandatory no spray zone.
pyraflufen-ethyl (Sledge)	G	Fallow – apply to cotton seedlings up to 8 leaf. Apply by ground rig only. Good spray coverage is essential.

TABLE 22: Herbicides that have registration for control of large 15 to 30 node volunteer cotton and ratoon cotton

Active ingredient	Mode of Action	Rates	Comments
Fluroxypyr	I	1 L/ha followed by 1 L/ha OR	For control of large cotton plants or ratoon cotton a sequential application of 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 Comet or 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 broadcast application and L/100L (spot spraying rate) for optical sprayers.
 Label changes are expected for this product, refer to <https://portal.apvma.gov.au/pubcris>.

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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. As part of an integrated weed management strategy, recent research has identified three herbicide options for the control of large volunteer or ratoon cotton plants in fallow.

There are registrations now in place for controlling large (15 to 30 node) volunteer cotton and ratoon cotton in fallow. Please refer to Table 22 for further information. The product must be used in accordance with the label instructions. It is important that ratoon and volunteer cotton is managed as part of an integrated weed management strategy, with these plants providing a high risk for disease and pest management.

ALWAYS FOLLOW LABEL DIRECTIONS

For more information:

Australian Cotton Production Manual: Chapter 13, Integrated Disease Management and Chapter 23, Managing cotton stubble/residues.
www.cottoninfo.com.au/publications

WEEDpak: www.cottoninfo.com.au/publications

Come Clean. Go Clean: www.cottoninfo.com.au/publications

Managing ratoons and volunteers: www.cottoninfo.com.au/publications
and another video *Keep your farm free from pests, weeds and diseases: Come Clean. Go Clean.

Come Clean. Go Clean.

Rogue cotton plants in the farming community:

Checking your farm for volunteer plants:

www.youtube.com/cottoninfoaustr

III

Herbicide resistance management in Australian cotton farming systems

Eric Koetz, NSW DPI

Acknowledgements: Susan Maas (CRDC); Annabelle Guest (AGDel); Ian Taylor (CRDC); Jeff Werth, Sharna Holman (Qld DAF); Graham Charles, Jon Baird (NSW DPI); David Thornby (Innokas Intellectual Services).

Introduction

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 have been grouped according to their mode of action (the process they affect) which is represented by a letter code on the label and are ranked according to their resistance risk. Research has shown that weeds can develop resistance to any single control tactic used alone, not only herbicidal ones. For example, regular mowing of annual bluegrass, *Poa annua*, in golf courses selected *Poa* strains for lower grass seed heads, essentially a resistance to mechanical control.

There are currently 500 unique cases (species x mode of action) of herbicide resistant weeds globally across 256 species (149 dicots and 107 monocots). Weeds have evolved resistance to 23 of the 26 known herbicide sites of action and to 167 different herbicides. Costs of weed control in cotton in the US have increased from \$150 to \$400 per acre due to the evolution of resistance to glyphosate. 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. 17 weed species have now been confirmed as glyphosate resistant (refer Table A), 11 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. June 2018.
<http://www.glyphosateresistance.org.au>

I. Heap, The International Survey of Herbicide Resistant Weeds. June 2018.
<http://www.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 the 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 Herbicide Resistance Management Strategy was developed by the TIMS herbicide technical panel to help the Australian cotton industry manage the risk of herbicide resistance, and in particular to manage 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.

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BYGum www.cottoninfo.com.au

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.

TABLE A: Confirmed glyphosate resistant weeds in Australia

Weed species	Year first documented	Number of confirmed populations as at March 2019
Annual ryegrass (<i>Lolium rigidum</i>)	1996	854
Barnyard grass (<i>Echinochloa colona</i>)	2007	103
Liverseed grass (<i>Urochloa panicoides</i>)	2008	4
Flaxleaf Fleabane (<i>Conyza bonariensis</i>)	2010	64
Windmill grass (<i>Chloris truncata</i>)	2010	11
Wild radish (<i>Raphanus raphanistrum</i>)	2010	2
Great brome (<i>Bromus diandrus</i>)	2011	5
Sowthistle (<i>Sonchus oleraceus</i>)	2014	23
Red brome (<i>Bromus rubens</i>)	2014	1
Sweet summer grass (<i>Moorochloa eruciformis</i>)	2014	1
Prickly lettuce (<i>Lactuca serriola</i>)	2014	1
Feathertop Rhodes grass (<i>Chloris virgata</i>)	2015	5
Tridax daisy (<i>Tridax procumbens</i>)	2016	1
Tall fleabane (<i>Conyza sumatrensis</i>)	2017	3
Winter grass (<i>Poa annua</i>)	2017	2
Willow-leaved lettuce (<i>Lactuca saligna</i>)	2017	2
Northern barley grass (<i>Hordeum glaucum</i>)	2018	2

Preston, C. The Australian Glyphosate Sustainability Working Group. Online. Internet. Friday 6 Jul 2018 Available <http://www.glyphosateresistance.org.au>

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 B and C show resistance has also been identified in Group L (paraquat) and I (2,4-D) herbicides to weeds common in cotton farming systems. The HRMS has been updated with notes to address risks from other MOA.

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 (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 grass selective herbicides can quickly lead to development of Group A resistance.

A NSW DPI survey has confirmed resistance in windmill grass (*Chloris truncata*), feathertop Rhodesgrass (*Chloris virgata*) and barnyard grass (*Echinochloa crus-galli*) 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.



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

How to use the HRMS

Given that modelling shows glyphosate resistance takes around 18 years to develop when used alone in an irrigated cotton cropping system and 14 years in dryland, it is important to identify the likelihood of resistance development in your own operation. The HRMS table (pages 88-89) 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.



Glyphosate resistant barnyard grass was confirmed in 2007. This infestation had a 'blow-out' as the previous summer period was extremely wet and prevented access to the paddock and hence no effective treatment at an early growth stage. (Photo: T.Cook NSW DPI)

TABLE B: Species that have developed resistance to paraquat in Australia

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

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

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.

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 hence multiplies. Strategies are best aimed at driving down the seed bank and preventing seed bank replenishment.

Seed bank control key:

- Very high control = <10 seeds/m²
- High control = 10-100 seeds/m²
- Medium control = 100-500 seeds/m²
- Low control = 500-1500 seeds/m²
- Very low control = >1500 seeds/m²



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. The tool 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.

TABLE C: Weed species with populations resistant to 2,4-D

Species	Common Name	Year	State	Situation	Herbicide	Also resistant to MOAs
<i>Raphanus raphanistrum</i>	Wild radish	1999	Western Australia	Winter cereal	2,4-D	
		2006	South Australia	Winter cereal	2,4-D, MCPA	B, F
		2009	Victoria	Winter cereal	2,4-D	B
		2010	Western Australia	Winter cereal	2,4-D	B, F, M
		2011	Victoria	Winter cereal	2,4-D	
		2011	New South Wales	Winter cereal	2,4-D	
<i>Sisymbrium orientale</i>	Indian hedge mustard	2005	South Australia	Winter cereal	2,4-D, MCPA	B
		2015	South Australia	Winter cereal	2,4-D	F
		2016	Victoria	Winter cereal	2,4-D	
		2016	Victoria	Winter cereal	2,4-D	B, F
<i>Sonchus oleraceus</i>	Sowthistle	2015	Victoria	Winter cereal	2,4-D	
		2015	South Australia	Winter cereal	2,4-D, dicamba, clopyralid	
<i>Arctotheca calendula</i>	Capeweed	2015	South Australia	Winter cereal	2,4-D	

C.Preston. The Australian Sustainability Working Group. May 2018. www.glyphosateresistance.org.au/

What does herbicide resistance look like?

Resistance begins with the survival of one plant and the seed that it produces. Early in the development of a resistant population, resistant plants are likely to occur only in isolated patches. These are often surrounded by dead 'susceptible' plants of the same species, or other species usually controlled by the herbicide applied. This is the critical time to identify the problem. For other resistance mechanisms, the symptoms may appear as a 'sick' plant that subsequently recovers and may look similar to 'underdosing' or poor application. If a higher application rate is required to kill these individuals in subsequent years this indicates non-target site resistance is present. Many of the symptoms of herbicide resistance can also be explained by other causes of spray failure. Evaluate the likelihood of other possible causes of herbicide failure. Resistant weed seeds can also be transported in to 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, e.g. within Group A, Dim v Fop herbicides. Generally, seed is collected from the suspect plants and is sent for testing (see below).

An alternative sampling method is to collect actual plants out of the field for the 'Quick test'. This process is limited to grass weeds only and is best targeted at seedlings/ 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 either 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

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 resistance 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 spreading.

Refer to Weed Management Tactics page 92.

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

III

Herbicide Resistance Management Strategy

Explanatory Notes:

2019–20

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 on farm, 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 2 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 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 (eg 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
 - Rotate herbicide mode of action groups
 - Always follow label recommendations
 - Consider other aspects of crop agronomy

Assessing your own risk

Information on how to get weeds tested for resistance, refer to page 87 CPMG.

For a 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
<div> <div>High - Resistance risk - Low →</div> <div>← Decreasing - Survivor control - Increasing →</div> </div>	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
<div> <div>High - Resistance risk - Low →</div> <div>← Decreasing - Survivor control - Increasing →</div> </div>	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 provide 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 seedbank 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 resistance has been confirmed and is widespread in the following cotton weeds;

- Windmill grass
- Awnless barnyard grass
- Fleabane
- Sowthistle
- Feathertop Rhodes grass
- Liverseed grass
- Annual ryegrass is a significant issue in Southern valleys and is emerging as a problem in Northern NSW. There are reports of cross resistance to glyphosate and Group A herbicides.
- Group A resistance is widespread throughout broadacre farming systems and is increasing in cotton farming systems, especially in hard to control weeds such as Feathertop Rhodes grass and Windmill grass.
- Emerging herbicide resistance to Group L (paraquat) has been reported in other farming systems, especially in grasses. Resistance has not been reported in cotton farming systems, however the increase in double knock strategies makes it essential that **all survivors** of a double knock involving paraquat need to be controlled. A population of Flaxleaf fleabane in viticulture has tested as resistant.
- Increasing use of Group I herbicides in summer fallows is a concern with a population of sowthistle reported as resistant to 2,4-D in winter cereals.

Weeds to watch out for!

Common weeds of cotton with a high risk of herbicide resistance

Make herbicide decisions early – target young growth stages

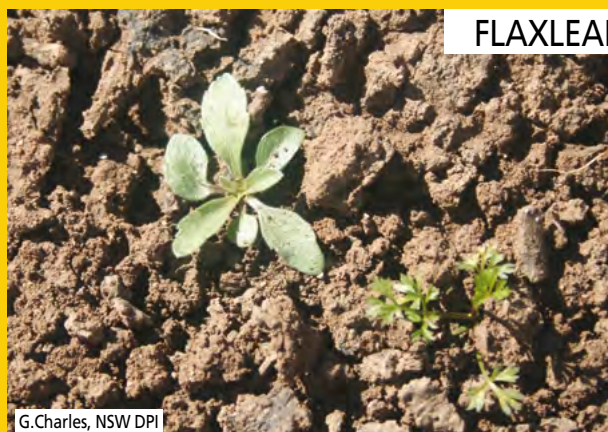


SWEET SUMMER GRASS

M.Conway, DAF Qld



M.Conway, DAF Qld



FLAXLEAF FLEABANE

G.Charles, NSW DPI



G.Charles, NSW DPI



LIVERSEED GRASS

G.Charles, NSW DPI



G.Charles, NSW DPI



FEATHER TOP RHODES

G.Charles, NSW DPI



G.Charles, NSW DPI

Too late for glyphosate – control before seed set

Weeds to watch out for!

Common weeds of cotton with a high risk of herbicide resistance

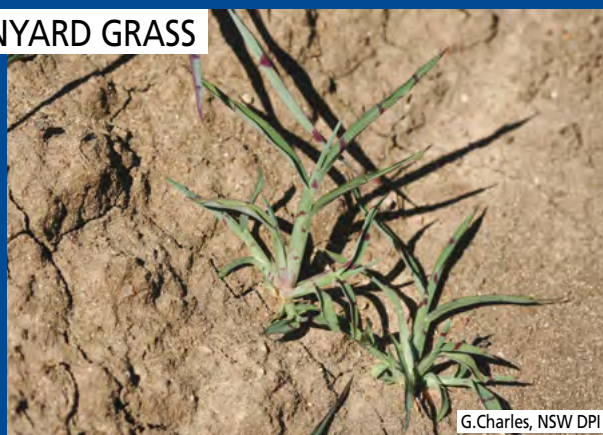
Make herbicide decisions early – target young growth stages

Too late for glyphosate – control before seed set



AWNLESS BARNYARD GRASS

G.Charles, NSW DPI



G.Charles, NSW DPI



COBBLER'S PEG

G.Charles, NSW DPI



G.Charles, NSW DPI



COMMON SOWTHISTLE

G.Charles, NSW DPI



G.Charles, NSW DPI



MILKWEED

G.Charles, NSW DPI



G.Charles, NSW DPI

Weed management tactics

Eric Koetz, NSW DPI

Acknowledgements: Susan Maas, Ian Taylor (CRDC); Jeff Werth, David Thornby, Sharna Holman (Qld DAF); Graham Charles, Jon Baird (NSW DPI)

Develop a strategy

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.

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) 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

In developing a strategy it is important to 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. The Weed ID guide and WEEDpak are key resources that can assist with these decisions.

It is important to identify particular problem areas. Managing these patches more intensively may help to prevent a problem weed or resistance spreading.

Time your tactics

Often the timeliness of a weed control operation has the largest single impact on its effectiveness. Herbicides are far more effective on rapidly growing small weeds, and may be quite ineffective in controlling large or stressed weeds.

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

Think about the whole farming system

In developing a strategy it is important to consider weed management in the context of other in-crop agronomic issues, other crops and across the whole farm.

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. Research has shown that in irrigated crops, weed-free periods of 8-9 weeks from planting cotton provide enough time for the crop to out-compete most later emerging weeds and significantly reduced weed seed production. Refer to the Weed Thresholds in the Australian Cotton Production Manual for more information.

Plan weed management to fit with other operations

Look for opportunities in the cropping system to time operations to combine weed control tillage. These include pupae busting, incorporation of fertilisers, seed bed preparation and maintaining irrigation furrows.

Consider impact of weeds on the whole farming system

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. Certain weeds that host diseases can also allow inoculum to build up in the soil increasing the risk for subsequent crops.

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. Having a mix in 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 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, rotation crops should be considered similar to a fallow, with the aim to use at least 2 non-glyphosate tactics with the crop.

Non-crop areas

Non-crop areas on the farm such as channels, tail drains, fence lines and roadsides can be a source of development and introduction of 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 to manage weeds in non-crop areas.

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 emergencies. Biosecurity: <http://cottoninfo.com.au/>

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. Spray applications should be monitored soon after a control is implemented, 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.

It is critical to the longer term success of an IWM strategy that survivors not be allowed to set seed.

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	Pre/at plant	Post-emergent #	Survivor control
Strategic cultivation Double knock Optical Sprayers Patch management Cover crops Non glyphosate options *** Group C (bromoxynil, terbutylazine) Group G (flumioxazin) pyraflufen, saflufenacil Group H (isoxaflutole) Group L (paraquat, paraquat/diquat) Group I/Q (amitrole/paraquat) Group N (glufosinate) Group I (2,4-D, dicamba, fluroxypyr)	Cultivation Knockdown MOA Group C (bromoxynil, terbutylazine) Group D (chlorothal dimethyl) Group G (pyraflufen, flumioxazin, saflufenacil, oxyflufenrolin) Group I (dicamba, fluroxypyr) Group L (paraquat, paraquat/diquat) Group I/Q (amitrole/paraquat) Group N (glufosinate) Residual MOA * Group C (flumeturon, prometryn, terbutylazine) Group D (pendimethalin, trifluralin) Group K (S-metolachlor, metolachlor)	In-crop cultivation Manual chipping Rogueing Post-emergent OTT MOA Group A * (sethoxydim, clethodim, butoxydim, propanilazafop, haloxyfop) Group K (S-metolachlor**) Group Z (MSMA) Lay-by, directed or shielded spray Group C (flumeturon, prometryn, terbutylazine, diuron) Group D (pendimethalin, metolachlor) Group G (flumioxazin**)	Aim for 100% control Cultivation, chipping or spot spraying
NO SURVIVORS			
In fallow survivor control	Pre-plant survivor control	Post-emergent	Post harvest
Cultivation, chipping or spot spraying Refer above for NON glyphosate options Optical sprayer	Cultivation, chipping or spot spraying flumioxazin carfentrazone-ethyl bromoxynil	Inter-row cultivation, chipping or spot spraying	Root cutting for crop destruction Cultivation, chipping or spot spraying carfentrazone-ethyl bromoxynil fluroxypyr
Survivor control			
Aim for 100% control			

Comments

Survivors **MUST** be controlled by another tactic prior to seed set

Read and follow label directions

Rotate herbicide Mode of Action

Come Clean. Go Clean. to stop weed seeds.

Scout fields to look for weed survivors

Keep accurate field records

Ensure effective volunteer/ratoon management

DO NOT rely on glyphosate to control weeds in non-field areas

Weed management requires a farming systems approach, winter, summer and non-field areas.

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

Mix full rates of different MOA, and rotate to alternative MOA in following years

★ Refer to label for plant back restrictions to following crop

** Limited formulations are registered for this use. Please check label.

*** APVMA permits: 1 4439, 85049, 1 3460, 12941 for fallow use

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. See In-crop Tactics on following page.

Manual chipping

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

TABLE 23: Herbicide plant-backs from rotation crops to cotton (this is a guide only – always read and follow product label directions)

Herbicide active ingredient	MOA	Plant back to cotton	Plant-back to cotton Notes
Aminopyralid + fluroxypyr	I	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	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	6 months 18 months	Following treatments of up to 1.4 kg/ha. Following treatments of 1.4 kg/ha to 3.3 kg/ha.
Atrazine + S-metolachlor	C+K	6 months 18 months	When rates up to 3.2 L/ha are used. When rates up to 3.2 L/ha are used. On alkaline soils, a bioassay or analytical test should be undertaken.
Chlorsulfuron	B	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	3 months 6 months 24 months	When rates up to 30 g/ha are used. When rates of 30-120 g/ha are used When rates above 120 g/ha are used. For all rates at least 100 mm rain required during plant-back period.
Diuron	C		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	0 months 2 months	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 years	For NNSW 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	10 months	Must have 800 mm of rainfall or irrigation
Imazethapyr	B	22 months 18 months	Dryland cotton. Irrigated only. (Providing rainfall and irrigation exceeds 2000mm)
Isoxaflutole	H	7 months	350 mm rainfall (do not include flood/furrow irrigation) between application and planting the subsequent crop.
Mefenpyr-diethyl + iodosulfuron-methyl sodium	B	12 months	Rainfall of less than 500 mm may result in extended re-cropping intervals for summer crops sown in the following season.
Metribuzin	C	6 months 12 months	Rates < 1.5 L/ha. This could be longer if there have been long dry periods between crops. Rates > 1.5 L/ha.
Metsulfuron-methyl + mefenpyr-diethyl	B	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	5 months	+ 150 mm rainfall. Less total rainfall between application and planting of the following crop than 150mm may require extended plant back period.
Picloram + 2,4-d	I	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	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.
Triasulfuron	B	15 months 18 months	Soil pH Less than 7.5, 700 mm rainfall between application and sowing the plant back crop. Soil pH 7.6-8.5.
Triclopyr + picloram + aminopyralid	I	4 months 6 months	0.2 L/ha. During drought conditions (<100 mm rainfall in a 4 month period) the plant-back is significantly longer. 0.4 L/ha.

Spot spraying

Spot sprayers may be used as a cheaper alternative to manual chipping for controlling low densities of weeds in-crop. Ideally, weeds should be sprayed 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 of the field and difficult to get to, such as roadside culverts.

New weed detection technologies provide an opportunity to use spot spraying across (optical sprayers; eg: WEEDit®, WeedSeeker®) large areas of fallow. This can provide opportunity to reduce herbicide costs, while still ensuring robust label rates are applied to problem weeds. Refer to the herbicide label for plant-back limitations relevant to the rate applied. Applicators should 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>

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.

Knockdown herbicides from Group C (bromoxynil), Group G (carfentrazone, flumioxazin, oxyfluorfen), Group I (2,4-D, dicamba, fluroxypyr), Group L (paraquat, paraquat/diquat), Group M (glyphosate), Group N (glufosinate) and Group Q (amitrole) can be used to target weeds that have emerged in the field. This can be made more effective when used as a double knock.

Residual herbicides remain active in the soil for an extended period of time (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 complete. Broadleaf and grass weeds can be targeted with residual herbicides from Group C (fluometuron/prometryn, fluometuron, prometryn, terbutylazine) which predominantly target broadleaf weeds and Group D (pendimethalin, trifluralin) or group K (S-metolachlor) which predominantly target grass weeds.

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 incorporation through 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 for use of residuals. How the herbicide moves in the soil following incorporation will be dependent upon 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 it

EFFICACY OF KNOCKDOWNS IN FOUR WINTER FALLOW FIELD EXPERIMENTS, MEASURED AT 6 WEEKS AFTER TREATMENT, WHEN APPLIED TO 1- AND 3-MONTH-OLD WEEDS (THE RANGE OF EFFICACY ACROSS THE EXPERIMENTS IS IN BRACKETS)

Herbicide	Weed control (%)			
	1-month-old weeds		3-month-old weeds	
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)

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 (Toowoomba, Qld DAF).

is encouraged that you 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, moisture can be a big factor, however it is not only 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 the breakdown of residuals, compared with a period of rain that moistens the soil surface for days. Refer to product labels for more information. If growers are concerned 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 the treated and untreated area, 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. It is important to 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 avoid allowing 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 pages 98-99 for more information.

Grass selective herbicides (Group A) can be applied over the top of cotton. This group has a high risk of resistance and repeated use leads to the development of Group A resistance. It is important that in managing

glyphosate resistance, that resistance to other herbicides doesn't develop. Use Group A herbicides sparingly and ensure any survivors are controlled before they set seed, using another tactic, such as manual chipping.

Some metolachlor registrations now include over the top use in-crop from 4 node up to 18 node crop growth and can be used with glyphosate. This provides 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 prometryn, diuron, terbutylazine, flumioxazin, and pendimethalin. Check label to confirm usage is allowed for each product and for crop safety directions.

In-crop cultivation, and if required chipping, provides 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. Care should be taken in set-up to minimise the crop damage. Inter-row cultivation can increase issues with fusarium wilt.

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 the crop residues and weeds as soon after picking as practical greatly reduces the opportunity for these weeds to set seed. Refer to management of volunteers and ratoons (page 79).

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 summer weeds are only exposed to one mode of herbicide action. The Herbicide Resistance

TABLE 24: Plant-backs to cotton for herbicides used in seedbed preparation

Herbicide 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.

TABLE 25: Herbicides with unknown plant-back periods to cotton

Active ingredient	MOA	Registered for use in
Imazamox + imazapyr	I	Clearfield crops (all other – 34 months).
Metsulfuron methyl	B	Cereal crops: wheat, barley, triticale. Legume crops: chickpeas (desiccant).
Sulfosulfuron	B	Cereal crops: wheat, triticale.
Tribenuron methyl	B	Fallows.

Where fields have been treated with herbicides with no plant-back recommendations to cotton, firstly determine the tolerance of cotton grown through to maturity on a smaller scale before sowing larger areas.

TABLE 26: Cotton herbicide plant-backs to rotation crops

Herbicide 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	Fab bean	Field pea	Lab Lab	Lupin	Lucerne	Mungbean	Pigeon pea	Soybean	Canola
chlorthal dimethyl	8	8	8	8	8	8	8	8	8	8	8	8	8	8	FH	FH	8	FH	8
diuron	24	24	24	24	24	24	24	24	24	24	24	24	24	24	12	24	24	24	24
fluometuron	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
halosulfuron-methyl	24	2	24	24	2	24	3	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
norflurazon ²	24	21	NI	24	21	24	24	NI	3	NI	24	NI	NI	NI	NI	21	NI	3	NI
pendimethalin	6	0 ³	12	12	12	NI	NI	NI	NI	NI	NI	NI	NI	NI	6	NI	NI	NI	6
prometryn	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
trifloxysulfuron sodium	6	22	22	6	22	22	6	22	18	22	7	22	22	22	22	9	15	15	22
trifluralin	12	12	12	12	12	12	12	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

NI = no information

Further information in Weed control in Summer and Winter Crop Publications from NSW DPI.

■ **Weed management tactics** – sponsored by



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. Refer to Table 23, Herbicide plant-backs from rotation crops to cotton. 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.

For more information:

Refer to IWM tactics on page 93.

Refer to Table 28 “Registered Cotton Herbicides”, Pages 101.

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

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Cotton Weed Control Options

Eric Koetz, NSW DPI

Acknowledgement: Sharna Holman (Qld DAF and CottonInfo)

Registration of a herbicide is not a recommendation for the use of a specific herbicide in a particular situation. Growers must satisfy themselves that the herbicide they choose is the best one for the crop and weed. Growers and users must also carefully study the container label before using any herbicide, so that specific instructions relating to the rate, timing, application and safety are noted. This information is presented as a guide to assist growers in planning their herbicide programs.

IMPORTANT — avoid spray drift

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

- Planning your crop layout to avoid sensitive areas, including homes, school bus stops, waterways, grazing land and non-target crops.
- Ensuring that all spray contractors have details of any sensitive areas near spray targets.
- Consulting with neighbours to minimise risks from spraying near property boundaries. Keep neighbours informed of your spraying intentions near property boundaries. Make it clear that you expect the same courtesy from them.
- Carefully following all label directions.
- Paying particular attention to wind speed and direction, air temperature and time of day before applying pesticides using buffer zones as a mechanism to reduce the impact of spray drift or overspray.
- Keeping records of chemical use and weather conditions at the time of spraying.
- Adhere to the new 2,4-D application regulations.

Spray Log Books

To assist in record keeping for pesticide applications, Spray Log Books can be purchased from:

- Qld DAF, cost \$8.80 plus postage and handling. Contact Qld DAF in Toowoomba – 07 4529 4200 or; in Dalby – 07 4669 0800 to place an order.
- NSW DPI – Yanco 1800 138 351.

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TABLE 27: Control of weeds in dry channels

Active ingredient	Mode of Action group
Amitrole + ammonium thiocyanate	Q
Glyphosate	M
Imazapyr + glyphosate	B + M
Pendimethalin	D
Flumioxazin	G

Herbicide tolerant 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.

Monsanto 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 usage in Roundup Ready Flex can be used OTT of Roundup Ready Flex cotton. Usage must be in accordance with the label. Registered glyphosate products may be applied over the top (OTT) of Roundup Ready Flex cotton 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 in a total of 4 applications as illustrated in Figure A (page 100). Crops that are intended for seed production must not have an application of glyphosate past the 60% bolls open stage.

The full-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

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. 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. Weeds species with natural tolerance to glyphosate will be selected for with repeated glyphosate applications, resulting in species shift. The most effective, economic and sustainable weed management system for growers will, therefore, be achieved using an integrated (IWM) approach. Refer to weed section pages 96-100 for detailed information on integrated weed management recommendations.

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 the 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 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. Whilst 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 check for the presence of survivors and to 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 the pre-harvest application redundant. 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 the previous 3 seasons. Consultants/growers can test five of the major weeds (Annual Ryegrass, Awnless Barnyard Grass, Liverseed Grass, Red Pigweed, Milk (sow) thistle) present in cotton systems for resistance to key herbicides under 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 cotton@monsanto.com for further details.

Testing will be anonymous. Bayer will not be provided with grower identification information.

Managing Roundup Ready Flex volunteers

A major consideration in the development of an IWM plan for Roundup Ready Flex 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 79-82 for more information.

Application guidelines

Timing options

The glyphosate label for OTT usage in Roundup Ready Flex permits:

- 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 between crop emergence and 60% boll open stage, with a maximum of 1.5 kg/ha being applied in any single spray event.
- An option for a pre-harvest application, alone or in tank mix with Dropp, once the crop is 60% open. The maximum herbicide rate for pre-harvest use is 1.5 kg/ha. Application may be made by ground rig sprayer or by aircraft.
- Not more than four applications and 6.0 kg per hectare of glyphosate may be applied through all growth stages of Roundup Ready Flex cotton in any one growing season.

Tank-mixtures with other herbicides or insecticides are not recommended for over-the-top applications of glyphosate due to the potential for reduced weed control or crop injury. (Refer to Label for Directions for use – Roundup Ready Flex cotton).

Over-the-top applications

Before an over-the-top 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 a minimum of a COARSE spray quality (American Society of Agricultural Engineers, ASAE S572) at the target. For aerial application, nozzles and pressure settings must be selected to deliver a minimum of a COARSE spray quality (ASAE S572) 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 can be found on Monsanto Australia's Cotton Stewardship page www.monsanto.com/global/au/products/pages/cotton-stewardship.aspx

Roundup Ready Flex Cotton Weed Management Guide

Roundup Ready Flex Cotton Weed Resistance Management Plan

www.weedsmart.org.au/

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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.

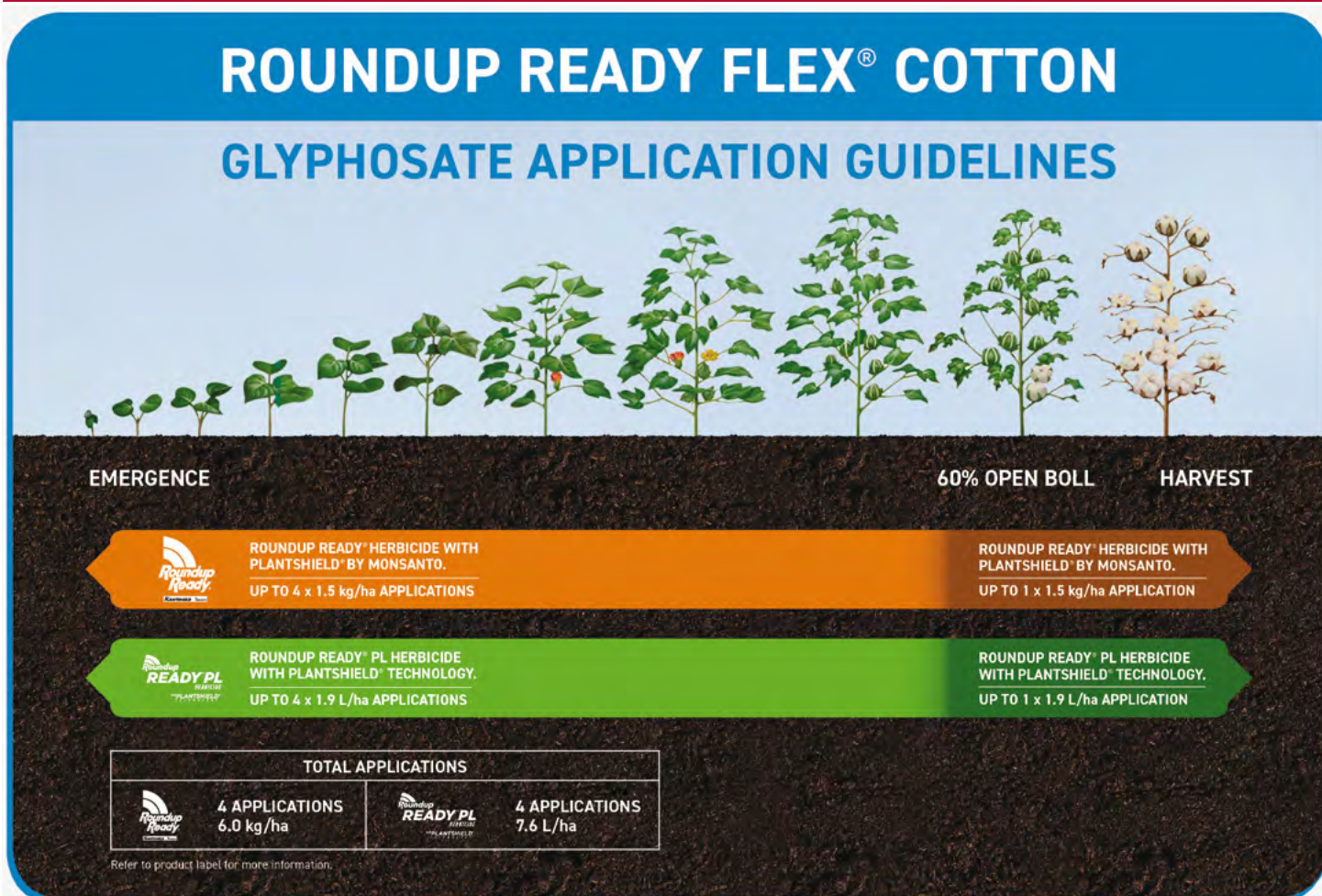


TABLE 28: Registered cotton herbicides -Fallow, At Planting, In crop. Resistance rankings and frequency

Herbicide active ingredient	Pre plant	At plant	Post plant	Mode of Action	Years to resistance	Resistance status
MSMA	N	N	Y	Z	N/A	Rare
Amitrole + paraquat	Y	N	N	Q+L	>15	Rare
Amitrole + ammonium thiocyanate	Y	N	N	Q	N/A	Rare
Paraquat	Y	Y	Y	L	>15	Occassional
Paraquat + Diquat	Y	Y	N	L	>15	Occassional
Glufosinate-ammonium	Y	N	N	N	10-15	Rare
Glyphosate(a).	Y	Y	Y	M	>12	Widespread
s-Metolachlor or Metolachlor (b)	Y	Y	Y	K	>15	Rare
2,4-D (c)	Y	N	N	I	10-15	Occassional
Dicamba (c)	Y	N	N	I	10-15	Rare
Fluroxypyr	Y	N	N	I	10-15	Rare
Fluroxypyr+ aminopyralid	Y	N	N	I	10-15	Rare
Triclopyr	Y	N	N	I	10+	Rare
Triclopyr + picloram	Y	N	N	I	10+	Rare
Triclopyr + picloram + aminopyralid	Y	N	N	I	10+	Rare
Carfentrazone-ethyl	Y	N	N	G	10	Rare
Flumioxazin (d)	Y	N	Y*	G	10	Rare
Oxyfluorfen	Y	N	N	G	10	Rare
Saflufenacil	Y	N	N	G	N/A	Rare
Norflurazon	Y	N	N	F	15+	Occassional
Pendimethalin (e)	Y	Y	Y	D	10-15	Occassional
Trifluralin	Y	Y	N	D	10-15	Occassional
Chlorthal dimethyl	Y	Y	Y	D	10-15	Occassional
Bromoxynil	Y	N	N	C	10-15	Occassional
Diuron	Y	Y	Y	C	10-15	Rare
Fluometuron	Y	Y	Y	C	10-15	Rare
Fluometuron + prometryn	Y	Y	Y	C	10-15	Rare
Prometryn	Y	Y	Y	C	10-15	Rare
Isoxaflutole (c)	Y	N	N	H	10	Rare
Halosulfuron-methyl	N	N	Y	B	4	Widespread
Trifloxysulfuron sodium	N	N	Y	B	4	Widespread
Butoxydim	N	N	Y	A	6-8	Widespread
Clethodim	N	N	Y	A	6-8	Widespread
Fluazifop-p	N	N	Y	A	6-8	Widespread
Haloxypop	N	N	Y	A	6-8	Widespread
Propaquizafop	N	N	Y	A	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 (R) formulation.
- c) See label for rainfall required before plant back period begins.
- d) Valor® formulation only.
- e) Rifle® formulations.

Refer to Tables 23-26, pages 94 and 96 for plant back period to cotton.

Integrated Disease Management

Tim Green, NSW DPI and CottonInfo

Acknowledgements: Susan Maas (CRDC); Stephen Allen (CSD); Karen Kirkby, Peter Lonergan, Duy Le, Aphrika Gregson (NSW DPI); Linda Smith, Linda Scheikowski, Sharna Holman, Murray Sharman (Qld DAF)

Developing an Integrated Disease Management (IDM) strategy for your farm

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

Appropriate disease control strategies should be implemented regardless of whether or not a disease problem is evident, as the absence of visible symptoms does not necessarily indicate an absence of disease.

IDM at planting

Preparing optimal seed bed conditions

- Plant into well prepared, firm, high beds to optimise stand establishment and seedling vigour.
- Position fertiliser and herbicides in the bed to prevent damage to the roots.
- Drain fields and do not allow water to back up and inundate plants.

Sowing date/temperature

Sowing in cool and/or wet conditions favours disease. Therefore it is best to plant when temperatures are 16°C and rising. Refer to the Australian Cotton Production Manual (ACPM) for more information on crop establishment.



Rhizoctonia seedling disease is favoured by cool, wet weather.
(Alison Seyb, formerly DPI NSW)

Plant resistant varieties

For back to back fields, disease risks are higher, increasing the importance of using a range of IDM strategies such as planting resistant varieties.

There are a number of varieties that have good resistance to Verticillium wilt or Fusarium wilt (higher V and F ranks respectively). In addition to resistance,

consider the seedling vigour of a variety, particularly when watering up or planting early. Refer to CSD variety notes for more information. Avoid growing susceptible varieties in fields that contain infected residues.

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

Replanting

Replanting decisions should be made on the basis of stand losses, not on the size of the seedlings. Refer to the ACPM for more information on crop establishment.

IDM in crop

Fungicides

All cotton seed sold in Australia for planting is treated with a standard fungicide treatment for broad spectrum disease control. Other examples of fungicides include seed treatments for seedling disease control and foliar sprays for the control of Alternaria leaf spot on cotton in specific regions.

Irrigation scheduling

Applying water prior to planting provides better conditions for seedling emergence than watering after planting. Watch for signs of water stress early in the season if the root system has been weakened by disease and irrigate accordingly. Avoid waterlogging at all times, but especially early and late in the season when temperatures are cooler. Irrigations late in the season that extend plant maturity can result in a higher incidence of Verticillium wilt. Tail water should also be managed to minimise the risk of disease spread.

Agronomic management

High planting rates can compensate for seedling mortality, but a dense canopy favours development of bacterial blight, Alternaria leaf spot and boll rots. Avoid rank growth and a dense canopy by optimising nutrition, irrigation, and with the use of growth regulators when required.

If Black root rot is present, either sow early to get the crop in on time (in short season areas) or anticipate a delayed harvest to allow catch up (in longer season areas).

Balanced crop nutrition

A healthy crop is more able to express its natural resistance to disease. Adopt a balanced approach to crop nutrition, especially with nitrogen and potassium. Excessive nitrogen will increase the severity of Fusarium and Verticillium wilt. Furthermore it will greatly increase the risk of boll rot, particularly in fully irrigated situations. Potassium is important for natural plant defences with deficiency being associated with 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

It is important to monitor and record each disease's incidence, prevalence, and severity. This allows for a comparison over time to influence management strategies (see below for in-season troubleshooting). Train farm staff to look for and report unusual symptoms and if a suspect cotton plant is located, contact your state department cotton pathologist.

Qld DAF pathologist, Linda Smith – 0457 547 617

NSW DPI pathologist, Duy Le – 0439 941 542

NSW DPI pathologist (south), Tim Green – 0477 497 114

Exotic Plant Pest Hotline 1800 084 881

Refer to the Cotton Symptoms Guide or page 117 for instructions on how to send a sample.

In-season disease trouble shooting

Early season

- Conduct an early season disease survey 4 weeks post planting.
- Compare number of plants established per metre with number of seeds planted per metre. Refer to the ACPM for more information on crop establishment and replanting considerations.
- Walk the field and look for plants that show signs of poor vigour or unusual symptoms.
- Examine roots by digging up the seedling – never pull the seedling from the ground.

During and late season

- Conduct a late season disease survey after the final irrigation but before defoliation.
- Walk the field and look for plants that are dead, show signs of poor vigour or have unusual symptoms.
- Cut stems of plants, laterally and vertically, and examine for discolouration.

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, Black root rot, Tobacco Streak Virus and Alternaria leaf spot can also infect common weeds found in cotton growing areas. Refer to WEEDpak F5 Table 1 for weeds known to be hosts of cotton pathogens.

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.

Crop residue management

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. Crop residues should therefore be managed carefully to minimise carryover of pathogens.

If Fusarium wilt is known to be present in a field, residues should be slashed and retained on the surface for at least one month prior to mulching, in order to disinfect the stalks through UV light exposure.

In all other circumstances (including the presence of Verticillium wilt and other diseases), crop residues should be incorporated as soon as possible after harvest to provide a host free disease period.

Crop rotations are utilised to assist in disease management

Successive crops of cotton can contribute to a rapid increase in disease incidence, particularly if susceptible varieties are used. A sound crop rotation strategy should be employed using crops that are not hosts for the pathogens present.

The pathogen that causes Verticillium wilt has a large host range. Likewise most legume crops are hosts of the Black root rot and Fusarium wilt pathogens e.g. mungbeans and soy beans. Some alternative crops such as vetch, canola and mustards can provide a biofumigation effect against Black root rot under specific management regimes. Cotton is highly dependent on mycorrhiza, specialised fungi which form beneficial associations with plant roots and can act as agents in nutrient



Aerial photo of fusarium damage.

exchange. Bare fallow for more than 3 to 4 seasons or removal of top-soil (especially more than 40 cm), such as in the development of a bankless channel system, may result in a severe lack of mycorrhiza. A cereal or green-manure crop may restore sufficient mycorrhizal fungi.

The Cotton Rotation Crop Comparison Chart (page 78 of the ACPM) lists the potential disease implications of rotation crops with cotton and can assist in developing a rotation strategy.

IDM all year round

Control of insect vectors

Diseases caused by a virus or phytoplasma are often preventable by controlling the vector that carries the pathogen. Cotton bunchy top (CBT) can be transmitted by aphids feeding on infected plants that then migrate to healthy plants. Transmission of Tobacco streak virus (TSV) to plants relies on the virus from infected pollen entering plant cells through the feeding injury caused by thrips. Control of insect vectors should consider IPM principles and resistance risks (see IPM chapter page 49).

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

Come Clean. Go Clean.

Minimise the risk of moving pathogens on or off your farm, from field to field, or farm to farm by having a strategy to ensure the clean movement of machinery. Refer to Table 31 (page 124) for agricultural detergents/degreasers and agricultural decontaminants. Come Clean Go Clean steps for cleaning down vehicles can be found on page 125.

NOTE: A fact sheet on available washdown products is available from <https://www.cottoninfo.com.au/biosecurity>

Minimise spillage and loss when transporting modules, hulls, cotton seed or gin trash.

Ensure all staff and visitors are aware of the requirements to 'Come Clean-Go Clean' (see the fact sheet at www.cottoninfo.com.au/publications).

For more information, resources and tools see:

myBMP www.mybmp.com.au

CottonInfo www.cottoninfo.com.au/publications/cotton-symptoms-guide

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Regional disease update 2018–19

Linda Smith, Linda Scheikowski & Dinesh Kafle (QLD DAF),
Duy Le, Aphrika Gregson & Tim Green (NSW DPI),
Sharna Holman (QLD DAF & CottonInfo) & all the **Regional Extension Officers** (CottonInfo)

National disease surveys

Commercial cotton crops across New South Wales and Queensland were inspected in October – December 2018 and January – April 2019. The incidence and severity of those diseases present were assessed and field history, ground preparation, cotton variety, planting date and seed rate were recorded for each of the 64 and 50 fields that were surveyed in NSW and Queensland respectively.

Seasonal weather conditions play a major role in determining the relative incidence, severity and importance of those diseases of cotton that occur in Australia. Conditions can also affect the amount of trash present at planting due to reduced stubble breakdown. Another dry season saw a significant quantity of cotton trash, particularly in back to back fields. Moisture is needed for microbial activity, which is responsible for stubble breakdown as well as reduction of soil-borne pathogen inoculum in the soil. The dry conditions also limited the area sown for dryland and irrigated production and insufficient water available to complete final irrigations.

The endemic diseases monitored include seedling diseases (caused by *Rhizoctonia solani*, *Pythium* spp. and *Fusarium* spp.), Black Root Rot (BRR), Fusarium wilt (FW), Verticillium wilt (VW), Alternaria leaf spot (ALS), Tobacco Streak Virus (TSV), Cotton bunchy top (CBT) and Boll rots, plus anything unusual. The survey records incidence (how often disease is observed in a field) and severity (measure of symptoms observed/degree of disease impact).

During these disease surveys particular attention was given to surveying fields for the presence/absence of exotic diseases including Cotton Leaf Curl Virus, Blue disease and Texas root rot. None of these diseases and/or pathogens were observed.

This work is being undertaken as part of the Digital Technologies for Dynamic Management of Disease, Stress and Yield Program, a project under the Australian Government Department of Agriculture and Water Resources Rural R&D for Profit programme.

Key findings early season

Central Queensland

Emerald

A total of 8 fields across 6 farms were surveyed in Emerald. No evidence of BRR spores were observed on the samples collected. A low incidence of ALS was evident, with *Alternaria* spp. isolated from necrotic lesions on the leaves. A high incidence of plant death due to *Sclerotium rolfsii*, which causes a collar rot, was observed in one field under pivot. Several other fields not included in the survey were also suffering from a high incidence of this disease. If this disease continues to seasonally be of concern, assessment will be included as part of the annual disease surveys. *Rhizoctonia* sp. and *Fusarium* spp. were also isolated from seedling samples, which form part of a seedling disease complex. In general

however, seedling disease was low. The mean seedling mortality was 27%. Plantings were significantly reduced in Emerald due to lack of water.

Theodore

A total of 11 fields across 5 farms were surveyed in Theodore. Six of the 11 fields surveyed had BRR. The severity was very low with only a trace (0.1%) of tap root necrosis observed. One field that has a history of FW, had an incidence of 2.5%, and was the only field in which FW was detected. A low incidence of *Rhizoctonia*-like rot was present at 0.8%, ranging from 0–3.25%. There was some poor root growth evident that was symptomatic of soil compaction, however generally root growth looked normal. Some fields were cloddy with uneven plant growth. There were some issues in plant growth that appeared to be related more to bed formation than disease. The mean seedling mortality was 35%.

St George

A total of 8 fields across 7 farms were surveyed early season. Patchy growth as a result of marginal water across some fields was evident. Samples collected from 2 out of 8 fields surveyed had remnants of BRR spores on roots as plants were at the stage of growing out of this disease when surveyed. FW was the main concern early season, being detected in 50% of fields surveyed. The average FW incidence was 5.4%, with the lowest incidence being 3% and the highest 30% (Figure 1). The vegetative compatibility group (VCG) was determined to be VCG 01111 (which is the original name of this strain identified from the Darling Downs) for all isolations of this pathogen. The high incidence of FW was particularly evident after a rain event, reminding us that under conducive conditions this pathogen can still cause significant disease and not to become complacent with IDM. A very low incidence of seedling disease was detected. The mean seedling mortality was 29%.

Darling Downs

A total of 17 fields across 14 farms were surveyed early season on the Darling Downs. Water stress was evident on several fields. The mean incidence of BRR was 47% of plants surveyed. BRR severity assessed based on the percentage of black necrosis covering tap roots was 10%, with a range of 0 to 70%. FW was detected in 11 out of 17 fields and remains a key disease for this region. The mean incidence of FW was 1.4%, with the lowest incidence being 0.5% and the highest incidence 14% (Figure 1). All isolations of this pathogen were determined to be VCG 01111. The mean incidence of *Rhizoctonia*-like rot detected was low at 2%, ranging from

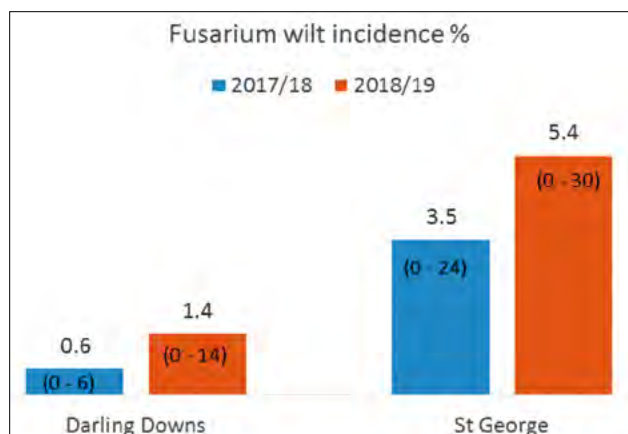


Figure 1: Mean Fusarium wilt incidence (%) recorded during the early season disease survey across the Darling Downs and St George regions, Qld, over two seasons. The range of disease incidence is in parentheses.

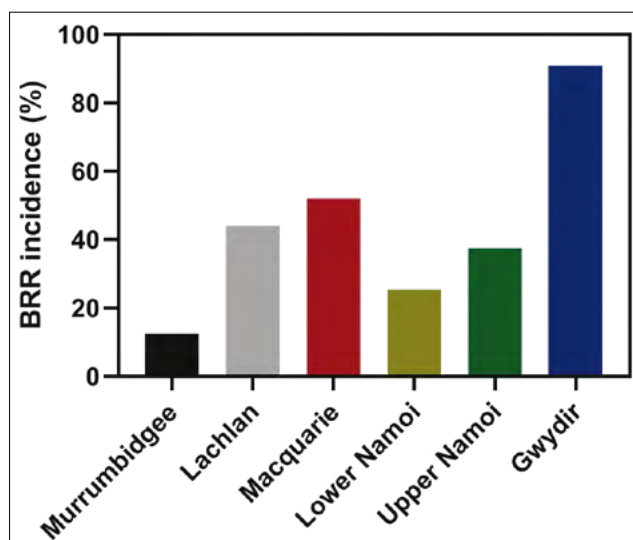


Figure 2: Mean BRR incidence (%) recorded during the early season disease survey across main growing valleys in NSW in 2018–19 season.

0–10%. Plants from only one field were detected to have *Pythium* infection, with a low incidence of 0.5%. Some fields suffered multiple disease issues e.g. a field with 10% *Rhizoctonia*-like rot, also had 100% of plants with evidence of a low infection of BRR, and a seedling mortality of 40%. The mean seedling mortality was 24%.

Border Rivers

A total of 14 fields across 10 farms were surveyed early season. The mean incidence of BRR was 15%, with a mean root necrosis of 19%, ranging from 0–76%. A low incidence of FW was observed early season, ranging from 0–0.5%. A low incidence of seedling disease was detected (2.3% *Rhizoctonia*-like rot, 0.1% *Pythium*). There was evidence of some soil compaction, patchy plant stands, volunteers and windblown sand blasted plants. The average seedling mortality was 24%.

Murrumbidgee

During the 2018–19 survey season, BRR and ALS were two diseases of concern in early and late growing season. BRR was detected on 70% of the surveyed fields, with an incidence from 1 to 99%. On average across the valley, the incidence of BRR was 12.5% (Figure 2). BRR severity was as little as 0.2% to 89%. Across the valley, the severity was 12% on average. ALS was detected on 80% of the surveyed fields. The ALS severity indicated by percentage necrosis of infected leaves was at trace levels on cotton seedlings. Though *Rhizoctonia*-like rot (Figure 3) also occurred frequently, with a mean incidence of 20%, the disease caused minor concern due to a low level of severity; less than 3% on average.

Lachlan

BRR and ALS were major diseases this season in the Lachlan. BRR was detected in 7 of 8 surveyed fields; the incidence was 1% up to 97%. On average the BRR incidence was 44% (Figure 2). BRR severity varied greatly from trace (0.1%) to up to 75%; across the Lachlan valley the disease severity was recorded at 24% on average. ALS on seedlings was detected across the 8 surveyed fields with the highest incidence of 30%, but the severity indicated by percentage necrosis of infected leaves was below 1% on average. *Rhizoctonia*-like rot occurred frequently in the Lachlan; the incidence was as low as 1% to up to 95%, and 25% on average across the 8 surveyed fields. The severity was a trace at 0.1% to 60%, and below 10% on average.

Macquarie

BRR and *Rhizoctonia*-like rot were more prevalent in the Macquarie. BRR was detected in all 10 surveyed fields; the incidence varied from 12 to 97%, and 52% on average (Figure 2). The disease severity was mostly below 20%, except for one field where the severity was up to 40%. *Rhizoctonia*-like rot was abundant across the 10 fields. The disease incidence was mostly above 80%; a couple of fields had an incidence up to 100%. Disease severity was relatively high on average, namely 35%. There were a couple of fields where disease severity was recorded below 10%; in contrast, the severity was recorded as high as 70% in another field. Though frequently occurred, *Rhizoctonia*-like rot caused minor concern. Symptoms were superficial, limited to the collar regions and sloughed off during the crop growth. ALS on seedlings was detected on 7 surveyed fields; the incidence was as low as 1.5% to up to 50%, and 8% on average. ALS severity indicated by percentage necrosis of infected leaves was minor with the average below 1%.



Figure 3: *Rhizoctonia*-like diseased cotton seedlings exhibiting irregular red brown lesions which frequently girdled the collars (red arrows).

Namoi

BRR, ALS and *Rhizoctonia*-like rot were prevalent across the 18 surveyed fields in the Namoi in early 2018–19 season. BRR was detected in all surveyed fields; the incidence was as low as 0.5% to up to 90%, and 30% on average (Figure 2). BRR severity was most below 10%; the highest severity percentage was recorded at 30% in one field. *Rhizoctonia*-like rot was abundant across the 18 fields. The disease incidence varied from 2% to 100%, and 52% on average. Disease severity was mostly below 20%. There were a couple of fields where disease severity was as high as 50%. ALS on seedlings was detected on all 18 surveyed fields; the incidence was as low as 1% up to 98%, and 23% on average. ALS severity was minor with the average below 2%.

Gwydir

BRR, ALS and *Rhizoctonia*-like rot were prevalent across the 13 surveyed fields in the Gwydir in early 2018–19 season. BRR was abundant in all of the surveyed fields; the incidence was most above 90% (Figure 2). The lowest BRR incidence was recorded at 22% in one field. However, the BRR disease severity was relatively mild; the severity was mostly below 15%. ALS on seedlings was relatively abundant and detected on all surveyed fields; the incidence was as low as 6% to up to 100%, and 59% on average. ALS severity was minor with the average below 1.5%. *Rhizoctonia*-like rot was prevalent. The disease incidence varied greatly from 0.5% to 98%, and 45% on average. The disease severity varied from 2% to 85%, but mostly below 20%.

All regions – reniform nematode

Soil samples were collected from all fields surveyed early season in NSW and Qld for assessment of plant-parasitic nematodes, in particular reniform nematode (*Rotylenchulus reniformis*). New farms in Emerald were confirmed to have reniform nematode. To date, this plant pest has only been detected in CQ.

Key findings late season

Central Queensland

Emerald

No FW or VW was detected in fields surveyed. Only a low incidence of boll rot, tightlock and seed rot was detected, driven by the dry conditions. Mealybugs were observed on one farm (Figure 4), colonising the terminal buds of plants, resulting in terminal death. Water stressed plants were common as many growers had limited or insufficient water to finish crop.



Figure 4: Mealybugs were observed late season in CQ.



Figure 5: Cotton bunchy top was evident in Theodore.

Theodore

FW was detected in the 2018–19 season at a slightly higher mean incidence (3.3%) (Figure 6) than the previous season (1.5%), with the highest incidence of FW detected in surveyed fields of 33%, compared to previous season's high of 12%. No VW was detected in Theodore. Boll rot, seed rot and tightlock were reduced this season compared to the 2017–18 season, given the dry conditions. CBT (Figure 5), caused by a virus vectored by aphids, was detected on two farms. The mean incidence of disease for the two fields was 3.5%. A small population of mealybugs was observed on one farm.

The presence of mealybugs and CBT highlights the need to ensure that ratoon or volunteer cotton and weed hosts are eliminated, particularly over winter. This will assist in breaking the green bridge thereby minimising the risk of CBT and mealybugs in the following cotton crop.

Darling Downs

FW was detected in 71% of fields surveyed, with a mean incidence of 3%, ranging from the lowest incidence of 0.33% to a high of 21%. (Figure 6). All isolates of *Fusarium oxysporum* f. sp. *vasinfectum* (Fov) recovered from discoloured stems belonged to VCG 01111. VW was detected on 3 out of 19 fields surveyed, and for one farm, it was a first detection. The disease incidence for the three fields was 0.5%, 7.3% and 71% respectively, with a mean incidence across all fields surveyed of 4.1% (Figure 6). Strain identification is still underway. There are fields on the Darling Downs with a very high incidence of either FW or VW, which is very concerning. There was a trace of ALS observed late season. Environmental conditions are the biggest factors in infection rates of boll rot fungi. Hence the dry, hot conditions resulted in a low incidence of boll rots.

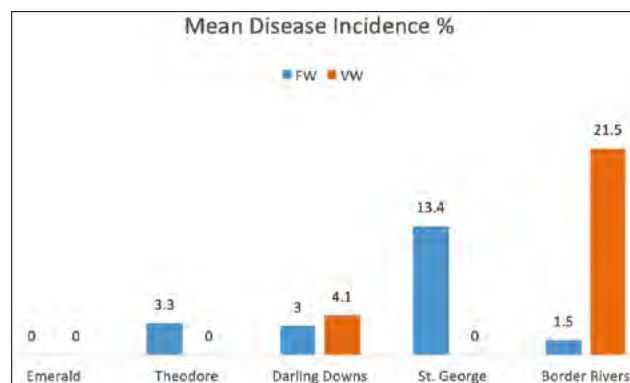


Figure 6: Mean Fusarium wilt (FW) and Verticillium wilt (VW) incidence (%) recorded during the late season disease survey across main growing valleys in Qld and Border Rivers in Qld/ NSW in 2018–19 season.

St George

FW was detected in 75% of fields surveyed, with a mean incidence of 13.4%, ranging from the lowest incidence of 0.5% to a high of 58% (Figure 6). All isolates of Fov recovered from discoloured stems belonged to VCG 01111. VW was detected on one field outside of the survey transect, and this was a first detection on farm. Strain identification is still underway. There are fields in St George that have a very high incidence of FW which is concerning. A trace of ALS and a low incidence of boll rots were observed. Mealybugs were observed on one field in St George.

A number of tall abnormal plants were observed scattered throughout several fields (Figure 7). The plants were taller with bunched growth towards the top, with flowers and small bolls. The cause of this phenomenon is not known. Suggested cause includes viruses (being investigated by Dr Murray Sharman) or Group B herbicide residue.



Figure 7: Abnormal tall plant (left), view from a distance of scattered abnormal tall plants within field (right)

Border Rivers

Both FW and VW were prevalent across the Border Rivers region in the 2018–19 late season survey. FW was detected in 40% of fields surveyed, with a mean incidence of 1.5%, ranging from the lowest incidence of 1.5% to a high of 9.5% (Figure 6). All isolates of Fov recovered from discoloured stems belonged to VCG 01111. VW was detected in 75% of fields surveyed, with a mean incidence of 21.5%, ranging from the lowest incidence of 1% to a high of 78.5% (Figure 6). The mean incidence of VW was higher this season (21.5%) compared to the previous season of 5%. Given the dry, hot conditions, this increase is concerning.

Murrumbidgee

ALS was detected in all of the surveyed fields in late season surveys. The ALS severity was up to 11.5% on average in the late season survey. Where ALS severely infected, the top canopy of cotton crops appeared purple red; defoliation and premature senescence was also observed in some fields, in which the severity was rated up to 28.5% on average. VW was not detected in the valley in the 2018–19 season (Figure 8). FW was detected on two fields with a low incidence, less than 1%. Boll rot was detected infrequently across the valley.

Lachlan

ALS remained prevalent across the surveyed fields in the Lachlan late into the 2018–19 season. The ALS severity was recorded from 1 to 19%, and below 10% on average across the valley. Though yield loss attributed to the ALS has not been established, most of the severely infested crops received one to two sprays, which increased production inputs. VW was detected again in the valley in a new field, with an incidence less than 2%. The pathogen was confirmed as a non-defoliating pathotype. Over the two seasons from 2017 to 2019, the total number of fields that have received positive detections of VW in southern NSW increased to six. This has allowed for the confirmation of the introduction and establishment of VW in southern region. FW was not detected in the Lachlan. Boll rot was detected infrequently across the valley.

Macquarie

ALS remained prevalent during the late season survey in the Macquarie in 2018–19 season. The ALS severity was recorded from 0.1 to 15%, and below 5% on average across the valley. VW was detected in one field, but the incidence was relatively high, at 40% (Figure 8). This could suggest that the pathogen has been well established in this field. Hence, management strategies such as selection of high V-rank cultivars, rotation with non-host crops, good farm hygiene practices are highly recommended for this field to diminish the pathogen inoculum as well as to minimise spread to adjacent fields. The pathogen was confirmed as a non-defoliating pathotype. FW (Figure 9) was also detected in three fields; the incidence was as low as 7% to up to 20%. *Fusarium oxysporum* was isolated from

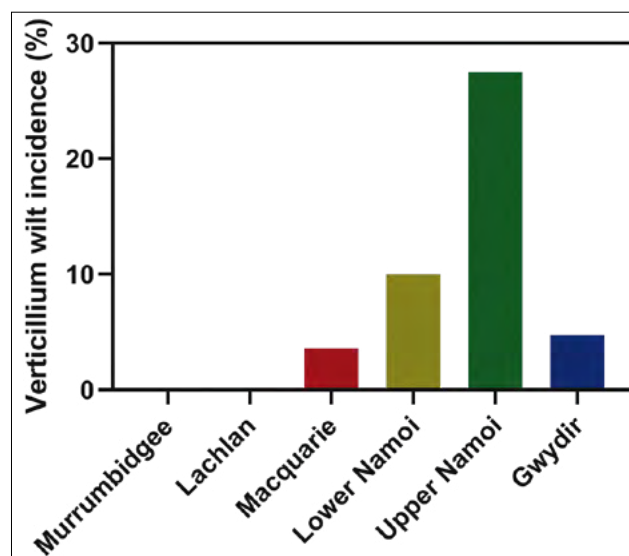


Figure 8: Mean Verticillium wilt incidence (%) recorded during the late season disease survey across main growing valleys in NSW in 2018–19 season.

these wilt cotton plants, and further identification of the pathogen is on its way. Other minor diseases, including boll rot and tightlock were frequently observed during the survey, but they were at low incidence.



Figure 9: A typical Fusarium infected cotton plant exhibiting top down die back symptoms of the main stem and branches.

Namoi

ALS remained prevalent during the late season survey in the Namoi in 2018–19 season. The ALS severity was recorded from 0.1 to 15%, and below 2% on average across the valley. VW was prevalent in the Namoi (Figure 10); the disease was detected in approximately 85% of the surveyed fields. Disease incidence varied from 1% to 64%, and 20% on average across the valley (Figure 8). Both the defoliating and non-defoliating pathotype of VW were confirmed. In some cases (20% of the total surveyed fields), both of the pathotypes were present in the same field. FW was not detected in 2018–19 season. Other minor diseases, including boll rot and tightlock were frequently observed during the survey, but they were at low incidence.

Gwydir

ALS was detected in all the surveyed fields in the Gwydir in late 2018–19 season. The ALS severity was recorded from 0.1 to 22%, but most below 2% on average across the valley. VW was frequently detected in the Gwydir; the disease was detected in approximately 40% of the surveyed fields. The incidence varied from 1% to 47%, and below 5% on average across the valley (Figure 8). Both of the pathotypes, defoliating and non-defoliating were detected in the valley. FW was also commonly detected in 2018–19 season; the disease was detected in more than 50% of the surveyed fields. The incidence was as low as 1% to up to 70%, and 7% on average across the valley. *Fusarium oxysporum* was isolated from these wilt cotton plants, and further identification of the pathogen is on its way. Around 30% of the total surveyed fields was detected, both with the VW and FW. This could pose a real challenge in managing crop residues, crop rotations and cultivar selections to minimise disease impacts. Boll rot was frequently observed during the survey, but they were at low incidence. ■■■



Figure 10: A relatively high Verticillium wilt pressure field, where the incidence was recorded up to 50%.

Common diseases of cotton

Tim Green, NSW DPI and CottonInfo

Acknowledgements: Susan Maas (CRDC); Stephen Allen (CSD); Karen Kirkby, Peter Lonergan, Duy Le, Aphrika Gregson (NSW DPI); Linda Smith, Linda Scheikowski, Sharna Holman, Murray Sharman (Qld DAF)

Alternaria leaf spot (ALS)

Pathogen: *Alternaria alternata* and other minor spp.

Symptoms

Cotton plants are prone to infection of *A. alternata* at all growing stages. Symptoms can be seen on cotyledons, young to mature leaves, squares and bolls. ALS symptoms start with pinhead necrotic lesions surrounded by a purple halo. Under favourable conditions, lesions continue to enlarge and coalesce to form irregular shapes. Severe infection may result in desiccated cotyledons and leaves.

Favoured by

Spores can only germinate when there is an adequate dew period – a period of 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.

- Plants are most susceptible at the seedling stage and late in the season when the crop begins to cut-out. Symptom development is favoured by any physiological or nutritional stress e.g. heavy fruit load or premature senescence.



Alternaria on seedlings. (Duy Le, NSW DPI)

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Alternaria on mature cotton. (Duy Le, NSW DPI)

Host range

A. alternata has a wide host range and is globally distributed. Around 100 plants species have been reported as hosts of *A. alternata*. However, some strains showing host specificity were also reported.

IDM tactics

- Don't plant susceptible varieties in fields with infected residues from a previous crop retained on the surface.
- Provide balanced crop nutrition (especially potassium).
- Manage crop to avoid extremely rank growth.
- Apply foliar fungicides according to label and refer to permit 82660.
- Incorporate crop residues as soon as possible after harvest.
- Control alternative weed hosts, volunteer and ratoon cotton plants.

Black root rot (BRR)

Pathogen: *Thielaviopsis basicola*

Symptoms

Affected crops may be slow growing or stunted, especially during the early part of the 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 opens the root up for infection by *Pythium* or *Rhizoctonia* spp. Plants that are badly affected early in the season may not continue to show symptoms later in the season as the dead cells of 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.
- Cotton following susceptible crops, including most legumes and cotton.

Host range

All varieties of cotton are susceptible. Most legumes are susceptible, including faba bean, soybean, cowpea, field pea, chickpea, mung bean, lablab and lucerne. *Datura* weeds (thornapple, castor oil) are also hosts.



Black root rot on seedlings. (Duy Le, NSW DPI)

Non-hosts include cereals, sunflower, brassicas such as canola and broccoli, onions and woolly pod vetch.

IDM tactics

- Choose more indeterminate varieties that have the capacity to 'catch up' later in the season.
- Use Bion® Plant Activator seed treatment. Bion is included as part of the Dynasty Complete™ seed treatment, which is available as a stand-alone treatment or paired with an insecticide seed treatment.
- Plant into well prepared, high, firm beds.
- Pre-irrigate/plant into moisture in preference to 'watering up' as this may cause a cold shock.
- Time sowing to avoid cool temperatures (>18°C) if possible. But sow early only if conditions are warm enough (minimum soil temperature of 16°C and rising). Temperature measurements should be taken in all fields.
- Replanting decisions should be made on the basis of 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.
- Rotation may not be a good practice for BRR, except for rice rotation, since BRR incidence and severity increase with number of cotton crops regardless of crop sequences or crop rotations.
- Rotate with biofumigation crops such as vetch or mustard between consecutive cotton crops or after a wheat fallow. The success of biofumigation depends upon the growth of the biofumigation crop and good incorporation (at least four weeks before planting cotton). Check biofumigant is not a host of other cotton diseases.
- Avoid legumes.
- Control weeds, cotton volunteers, and cotton ratoons.
- Flooding of fields for 30 days during summer reduces the population of *T. basicola* dramatically. This option will be limited by the topography of fields and the availability of water.

Boll rot, seed rot and tightlock

Boll rots are caused by a number of pathogens, including fungi and bacteria. Tightlock 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

Sclerotinia boll rot characteristically has black fungal structures (2 to 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 only infect the plant thorough dead or dying tissue (e.g. flower petals). The fungus then grows into healthy plant tissue such as the developing boll and down the fruiting branch towards the main stem.



Sclerotinia boll rot increasingly becomes a problem in characteristically wet seasons with spores able to be moved around the plant through rain-splash. (Linda Smith/Tony Cooke)

Fusarium boll rot

Not to be confused with Fusarium wilt, Fusarium boll rot causes similar boll rots to Phytophthora, with mould sometimes having a pink discolouration.

Diplodia boll rot

Diplodia boll rot starts as dark brown lesions which 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 cause by insect pests.



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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.

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 and pale cotton stainers) feed on the developing seeds through the boll wall. Small black spots 1-2 mm diameter on the surface of the boll indicates the feeding of sucking insects on developing seed within 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

- Boll rots are 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 low bolls enables infection for some boll rots. Low mature bolls and lodged plants are at higher risk of infection.
- Boll rots and tightlocks can also develop when bolls that are opening are exposed to wet weather.
- High numbers of sucking pests soon after flowering can increase the likelihood of seed rots.

Host range

There are a broad range of fungal and bacterial species involved in 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 the 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 which result in 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.
- *Sclerotinia* is most common in tall rank crops therefore avoid rank and dense crop canopies 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. Counts should not be confined to areas near the tail drain as this may give a misleading result.
- Thoroughly incorporate crop residues as soon as possible.
- Practice good farm hygiene and Come Clean. Go Clean.

Cotton bunchy top (CBT)

Cotton bunchy top (CBT) is a viral disease spread by the cotton aphid.

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.



CBT has a distinctive leaf mottling. (Stephen Allen, CSD)

After the plant is infected, subsequent growth is characterised by small leaves, short internodes and small bolls. This is usually limited to growth that occurred after the plant was infected; growth before infection usually appears normal.

When plants are affected at a very early stage (e.g. as seedlings) the growth of the whole plant is affected and has a compact, severely stunted appearance. Roots appear hairy and dark brown in comparison to the light yellow-brown colour of healthy roots and form small knots on the secondary root branches.

Symptoms are difficult to distinguish in perennial volunteer cotton & late crops (post cut-out) where there has been insufficient new growth to show symptoms. There is usually a period of 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 also harbour aphids which can then move to adjacent plants, spreading the disease.

Favoured by

Cotton bunchy top (CBT) virus can only survive in living plants. Fields at highest risk of CBT are those with 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. Disease spread is favoured by climatic conditions suitable for aphid reproduction, feeding and spread. The risk from CBT appears to be higher after wet winters and lower after dry winters. Mild winters 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 overwinter, increasing the likelihood of aphids moving into cotton early in the season.

Host range

CBT virus can infect many different host plants. However, the most critical alternative host plant is ratoon or volunteer cotton. They survive between seasons, retaining leaves through winter and supporting infected aphid populations from one season to the next. The importance of the 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.

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 experimental hosts.

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

- 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. If there is a break in the presence of host between cotton seasons, this will reduce the risk of CBT surviving on-farm through winter. Cotton volunteers, regrowth and ratoons are an important host of CBT. Good crop destruction and control of ratoons and volunteers is critical for controlling CBT. This also removes an important over winter 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.
 - Controlling volunteers or ratoons may force winged aphids to move to nearby cotton crops and spread CBT. To reduce this risk, control volunteers/ratoons before cotton emerges.

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 resistance and restrict control options.
- Sample young cotton regularly for aphids and assess aphid spread within the field.
- If aphid populations are unhealthy (many beneficials present, high mortality and little spread) then keep monitoring. If healthy then consider selective control so that beneficials can provide ongoing mortality.
- If a high influx of aphids is experienced consider a quick selective control to reduce the risk of CBT infection.
- Maintain the beneficial complex to help control aphids.

Fusarium wilt

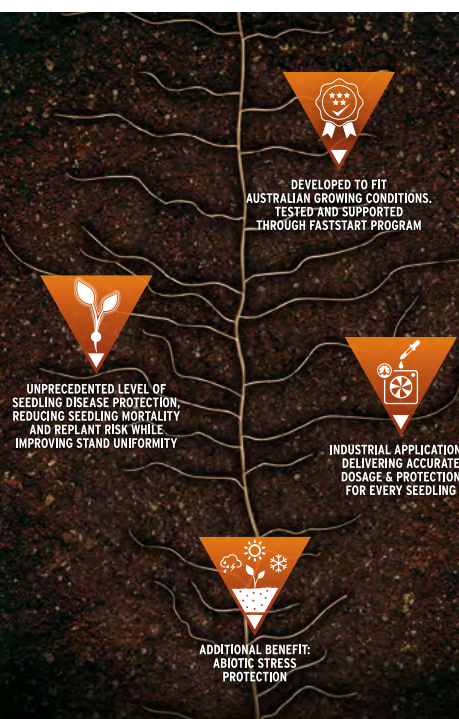
Pathogen: *Fusarium oxysporum* f. sp. *vasinfectum* (FOV)

Symptoms

External symptoms include stunted growth and dull and wilted leaves followed by yellowing or browning of the leaves and eventual death from the top of the plant. Some affected plants may reshoot from the base of the stem. External symptoms can appear in the crop at any stage. Most commonly they 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 but not always, near the tail drain or low-lying areas of the field.

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Fusarium wilt. (Linda Smith, Qld DAF)

Internal symptoms can be checked by cutting the stem. An affected plant will reveal continuous brown discolouration of the stem tissues running from the main root up into the stem. The discolouration is similar to that of 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 allowing the disease to spread.

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 this way! Ensure all farm staff and contractors practice good farm hygiene and Come Clean. Go Clean.
- Select varieties with a high F rank and use BION® Plant Activator. Bion is included as part of the Dynasty Complete™ seed treatment, which is available as a stand-alone treatment or paired with an insecticide seed treatment.
- 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 causes root damage and provides an entry point for the pathogen.
- Conduct regular field inspections for early detection and containment of isolated outbreaks. Send any suspected samples to Dr Linda Smith (Qld DAF) (see page 117 for a form and checklist on sending plant samples for diagnosis).
- Isolate affected areas from irrigation flows and traffic to avoid spreading the pathogen.
- Minimise tail water from affected fields.

- After harvest, root pull and retain crop residues on the surface for at least a month prior to incorporation. Raking and burning the whole field is NOT an option as raking is likely to spread the pathogen (if 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.

Reniform nematode

The pathogen

Reniform nematode (*Rotylenchulus reniformis*) is a plant parasitic nematode that feeds on the plant root using retractable, hollow, spear-like mouthparts causing plant stunting. It is distributed worldwide within tropical and subtropical regions. The first detection of reniform nematode in Australia, was in one field of cotton near Emerald in 2003. The first identification of reniform in Theodore was in 2012. The detections in Theodore were widespread and the impact was significant. Reniform nematodes are one of the most damaging nematode pests capable of attacking a wide range of crop plants as well as many weed species.

Symptoms

Feeding causes damage to the plant resulting in stunting and generally poor plant growth. The reniform nematode does not typically cause complete plant death, however they reduce the productivity of the crop. Populations can be quite uniform in their distribution across a field, making detection of early plant symptoms difficult.

Favoured by

The reniform nematode is largely distributed in tropical and subtropical regions 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 reniform nematode has a very wide host range including 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 of the Reniform nematode.
- Rotating with non-host crops such as wheat or sorghum to reduce base populations. Long fallows can help to also break the life cycle; however it is important to control all weeds, cotton volunteers and ratoons which may grow in the bare fields.
- Cotton stubble management – cotton stalks should be cut and soil tilled 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.
- Plant into good conditions including optimum soil temperature, no water stress and well-formed beds.
- Monitor crops for patches of stunted plants and submit root samples for testing if you are suspicious. Send any suspected samples to Dr Linda Smith (Qld DAF).

Assessment

Growers and consultants across the industry are asked to 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 in the soil or in plants. Affected roots may have small nodules/knots.

- Mark patches with GPS or on a map so that they can be monitored 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 in a clearly labelled plastic bag.
- Postage and handling – 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 117 for a form and checklist on sending plant samples for diagnosis).

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 attacking 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 favours infection by pathogens causing seedling disease. This includes 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.



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Host range

Seedling disease pathogens have a wide host range and can survive on the residues of many crops and weeds. There is some evidence that seedling diseases may be more severe after incorporation of legume residues.

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 (especially legume crop residues)

Verticillium wilt

Verticillium dahliae

Verticillium wilt is caused by the soil-borne fungal pathogen *Verticillium dahliae*. Recent research has found that in Australian cotton there are currently three strains of *V. dahliae*; two non-defoliating strains (VCGs 2A and 4B) and a defoliating strain (VCG 1A), however virulence varies greatly within some VCGs. For example some 'non-defoliating' VCG isolates cause defoliating symptoms.

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* needs to be diagnosed by a pathologist. In some instances there are fields with both Verticillium and Fusarium wilt present. Multiple stems should be sent if this is suspected.

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

Verticillium wilt is favoured by cooler temperatures. Varieties that are resistant at 25-27°C are susceptible at 20-22°C. Verticillium wilt is most severe during extended wet weather and or waterlogging and in late maturing crops. Extending the period of crop growth late in the season increases this risk.

The disease is also favoured by excessive use of nitrogen which results in late season growth and by potassium deficiency.

Host range

V. dahliae has a large host range causing vascular wilt on more than 250 plant species including volunteer cotton, ratoon cotton, soybeans, Noogoora and Bathurst burr, saffron thistle, thornapple, caustic weed, bladder ketmia, burr medic, black bindweed, pigweed, devils claw, turnip weed, mintweed, blackberry nightshade and others. There is some host specificity between strains. International literature and pot trials with Australian strains also suggests that mungbean, chickpea and faba beans may be hosts.



Verticillium wilt. (Stephen Allen, CSD)

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.
- Aim to ensure that crop destruction occurs soon after picking to reduce the build-up of inoculum.
- Rotate with non-host crops (i.e. sorghum and cereal crops).
- Avoid/control alternative hosts, including volunteer and ratoon cotton.
- Send any suspicious plant samples to your state pathologist for correct identification of pathogen. See page 117 for a form and checklist on sending plant samples for diagnosis, or visit <https://www.cottoninfo.com.au/sites/default/files/img/Diagnostic%20Form.pdf> for a copy of the form and checklist.
- 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.

III

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
<input type="checkbox"/> Poor emergence or seedling depth	<input type="checkbox"/> One field only	<input type="checkbox"/> All plants	<input type="checkbox"/> Irrigated
<input type="checkbox"/> Leaves: spots or dead areas	<input type="checkbox"/> In several fields	<input type="checkbox"/> Scattered single plants	<input type="checkbox"/> Dryland
<input type="checkbox"/> Leaves: discoloured	<input type="checkbox"/> In all fields	<input type="checkbox"/> Scattered patches of plants	<input type="checkbox"/> Seedling stage
<input type="checkbox"/> Leaves: mottled	<input type="checkbox"/> One variety only	<input type="checkbox"/> In a large patch (>5 m)	<input type="checkbox"/> Setting squares
<input type="checkbox"/> Leaves or shoots: distorted or curled	<input type="checkbox"/> Several varieties affected	<input type="checkbox"/> In a small patch (1-5 m)	<input type="checkbox"/> Early flowering
<input type="checkbox"/> Plants stunted	<input type="checkbox"/> Some rows more affected	<input type="checkbox"/> In a small patch (<1 m)	<input type="checkbox"/> Peak flowering
<input type="checkbox"/> Plants wilting	<input type="checkbox"/> On lighter soil types	<input type="checkbox"/> Plants dead	<input type="checkbox"/> First bolls open
<input type="checkbox"/> Premature plant death	<input type="checkbox"/> On heavier soil types	<input type="checkbox"/> Plants defoliating	<input type="checkbox"/> Defoliated
<input type="checkbox"/> Bolls: spots or dead areas	<input type="checkbox"/> In poorly drained area(s)	<input type="checkbox"/> One to a few plants only	<input type="checkbox"/> Ready to pick
<input type="checkbox"/> Roots: discoloured, bent, pruned, etc.	<input type="checkbox"/> 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 local 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.

Cotton disease control options

Sharna Holman, Qld DAF and CottonInfo

Registration of a pesticide is not a recommendation for the use of a specific pesticide in a particular situation. Growers must satisfy themselves that the pesticide they choose is the best one for the crop and disease. Growers and users must also carefully study the container label before using any pesticide, so that specific instructions relating to the rate, timing, application and safety are followed. This publication is presented as a guide to assist growers in planning their pesticide programs.

For potential disease implications of rotation crops with cotton please refer to the Australian Cotton Production Manual.

IMPORTANT – avoid spray drift

Spray Log Books

To assist in record keeping for pesticide applications, Spray Log Books can be purchased from:

- Qld DAF at Toowoomba (07) 4529 4200 or Dalby (07) 4669 0800.
- NSW DPI at Yanco 1800 138 351.

III

Best practice...

- Workers are trained and provided information for the safe use of pesticides.
- Develop a farm map to identify sensitive areas and potential hazards.
- Establish communication processes to manage safety and reduce risk – discuss application requirements with your consultant, spray applicator and neighbours.
- Give careful consideration to the selection and application of pesticides.
- Carefully follow all label directions – use the correct application equipment and techniques.
- Ensure chemicals are transported, handled and stored appropriately.
- Ensure unwanted chemicals and chemical containers are disposed of appropriately.
- Keep up-to-date, comprehensive records.
- Come Clean. Go Clean.

TABLE 29: Fungicides for use in cotton under permit

Active ingredient	Mode of Action	Comments
Azoxystrobin, Fludioxinil, Metalaxyl-M and Acibenzolar-S-methyl (Dynasty Complete seed treatment)	Groups 4, 11, 12	Seed treatment
Tebuconazole (430 g/L g a.i.)	Group 3	Permit Number – 82660: For control of alternaria leaf spot disease in upland and pima cotton varieties. For use in crops grown in the Southern Cotton Growing Valleys: Bourke, Gwydir, Lachlan, Macintyre, Macquarie, Murrumbidgee, Murray and Namoi Valleys only.

Cotton growth regulators and defoliants

Sharna Holman, Qld DAF and CottonInfo

Acknowledgements: Michael Bange, Sandra Williams, Greg Constable, Stuart Gordon, Rob Long, Geoff Naylor (CSIRO) and Rene van der Sluijs (Textile Technical Services)

Plant Growth Regulators

Cotton is very responsive to management and environmental changes. Excessive vegetative growth not only reduces the retention of fruit and delays crop maturity, but can also inhibit the efficacy of insecticide by poor penetration into the canopy. Mepiquat Chloride can help to manage crop growth. There are many factors that should be considered when making the decision to apply Mepiquat Chloride, the most critical being whether there are other sources of stress already controlling growth, and the rate and timing of the application.

Mepiquat Chloride reduces the production of Gibberellic acid (GA) in a plant by partially inhibiting one of the enzymes involved in the formation of GA. GA belongs to a group of plant hormones, Gibberellins, which are natural growth regulators in plants. They play an important role in stimulating plant cell wall loosening which allows stretching of the wall by internal pressure. This is known as cell expansion and is one mechanism allowing a plant to grow. In addition to GA, cell expansion is driven by a number of factors including water availability, humidity and temperature.

For more information refer to 2019 Australian Cotton Production Manual (ACPM).

Note: Some defoliant products containing Ethephon are labelled as a 'Growth Regulator'. Ethephon is used for preparing the crop for harvest and may cause significant fruit loss if used at inappropriate times.

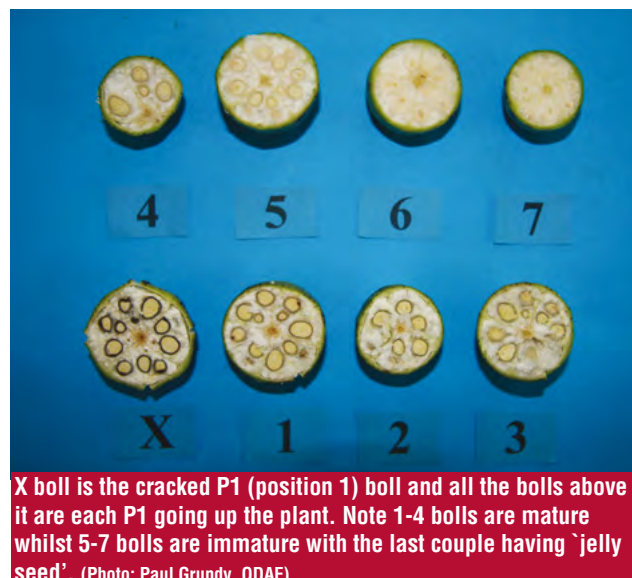
Defoliation

Defoliation induces leaf abscission which is the formation of a break in the cellular structure joining the leaf to the stem allowing the leaf to fall off. Leaf removal is critical for reducing the amount of leaf trash in machine harvesters. Boll opening is also accelerated by defoliation as removal of leaves exposes bolls to more direct sunlight, promoting increased temperatures for maturation, and drying and cracking of the boll walls.

The safe timing of defoliation is when the youngest boll expected to reach harvest is physiologically mature. This usually occurs when 60-65% of bolls are open. In addition to timing of harvest aids, it is important to consider product, rate and application issues.

There are a number of factors which improve the performance of defoliation products such as: ensuring defoliation practices occur before the onset of frost; aim to have soil moisture at refill at defoliation; and, avoiding the application of defoliants when there is a risk of rainfall shortly afterwards.

For more information on defoliation refer to 2019 ACPM.



Types of harvest aids

The categories of harvest-aid chemicals include herbicidal and hormonal defoliants, boll conditioners/openers and desiccants each with a different mode of action:

- Defoliants (Thidiazuron, Diuron, Dimethipin, Pyraflufen-ethyl) – all defoliants have a common mode of action to remove leaves. They increase the ethylene concentration in leaves by reducing the hormone auxin and/or enhancing ethylene production. Dimethipin alters the concentration of ethylene by reducing the amount of water in the leaf stimulating ethylene production. Pyraflufen-ethyl inhibits the enzyme protoporphyrinogen oxidase (PPO), causing the accumulation of protoporphyrins, resulting in cell membrane destruction, and triggering the production of ethylene by the plant. This change in ethylene concentration triggers separation in the abscission zone at the base of the petiole (leaf stalk). Chemical defoliant enters leaves through the stomates (minor route) or through the leaf cuticle (major route). Hormonal defoliants are applied to reduce auxin and/or enhance ethylene production, while herbicide defoliants injure or stress the plant into increasing ethylene production (similar to waterlogging or drought effects). If herbicide defoliants are applied at too higher rates the plant material may die before releasing enough ethylene to cause defoliation resulting instead in leaf desiccation (leaf death).
- Boll conditioning/openers (Ethephon, Cycanillide, Aminomethanane, Dihydrogen Tetraxosulfate) – these chemicals specifically enhance ethylene production by providing a chemical precursor for the production of ethylene, which leads to quicker separation of boll walls (carpels). It is important to note that the use of boll conditioning/opener products should only be considered if the bolls that will be forced open are mature; if these products are applied prior to boll maturation they may cause bolls to shed and reduce yield.
- Desiccants and herbicides (Sodium Chlorate, Magnesium Chlorate, Glyphosate, Diquat, Paraquat, Carfentrazone-Ethyl) – Desiccants are contact chemicals that cause disruption of leaf membrane integrity, leading to rapid loss of moisture, which produces a desiccated leaf. Desiccants should be avoided as they dry all plant parts (including stems) which can increase the trash content of harvested lint. Sometimes it is necessary to use desiccants if 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.

TABLE 30: Plant growth regulators and cotton defoliation products

Product type	Active ingredient
Plant growth regulator	Mepiquat Chloride
Defoliant	Pyraflufen-ethyl
	Thidiazuron
	Thidiazuron + diuron
Boll conditioner	Ethephon
	Ethephon + AMADS
Dessicant	Carfentrazone-ethyl
	Diquat
	Paraquat + diquat
	Sodium chlorate
Adjuvant	Paraffinic oil/non-ionic surfactant adjuvants
	Petroleum oil

- Wetting agents and spray adjuvants 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.

Many growers use combinations of defoliants with different modes of action and multiple applications to enhance defoliation. Multiple applications are becoming more common due to the indeterminate growth habit and rank of current varieties.

Registration of a chemical is not a recommendation for the use of a specific chemical in a particular situation. Growers must satisfy themselves that the chemical they choose is the best one for the crop and situation.

Growers and users must also carefully study the container label before using any chemical, so that specific instructions relating to the rate, timing, application and safety are noted. This publication is presented as a guide to assist growers in planning their agronomy programs.

If there is any omission from the list of chemicals, please notify the authors.

IMPORTANT – avoid spray drift


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

- Planning your crop layout to avoid sensitive areas, including homes, school bus stops, waterways, grazing land and non-target crops.
- Ensuring that all spray contractors have details of any sensitive areas near spray targets.
- Consulting with neighbours to minimise risks from spraying near property boundaries. Keep neighbours informed of your spraying intentions near property boundaries. Make it clear that you expect the same courtesy from them.
- Carefully following all label directions.
- Paying particular attention to wind speed and direction, air temperature and time of day before applying pesticides using buffer zones as a mechanism to reduce the impact of spray drift or overspray.
- Keeping records of chemical use and weather conditions at the time of spraying.

III



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Biosecurity – we all have a responsibility

Sharna Holman, Qld DAF and CottonInfo

Acknowledgements: Susan Maas (CRDC), Nicola Cottee (formerly Cotton Australia) and Brad Siebert (Plant Health Australia)

Biosecurity is the protection of your property and the entire industry from the entry, establishment and impact of exotic pests. As an exotic pest can affect everyone – farmers, agronomists and the community, 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. In addition to the possibility of pests entering via natural routes, rapid increases in overseas tourism, imports and exports make it all the more likely that incursions of exotic plant pests will occur.

Biosecurity – a legal responsibility

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.

Anyone going on to farms has a biosecurity responsibility

- **Come Clean. Go Clean.** – Vehicles, farm equipment and people can carry pest, especially attached to soil or plant debris. People can even carry aphids from farm to farm. 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 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 farm workers 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 department of primary industries. Early reporting improves the chance of effective control and eradication.
- **Come Clean. Go Clean.** – should be practiced on all farms regardless of whether pests or diseases are known to be present.
- **Communicate your requirements using clear signage** – to ensure only essential vehicles and equipment gain access to any growing area.
- **Available wash down facilities** – are provided for contractors and visitors to use with Bio-Cleanse or equivalent and a decent water supply to clean their equipment and tools prior to entry and exit.
- **Develop a farm biosecurity plan** – creating a biosecurity plan provides an opportunity to assess how pests, weeds and diseases could enter the farm and what systems are in place to manage or reduce these risks.

- **Visits to farms overseas should be declared on re-entry to Australia.** All clothes and footwear should be thoroughly washed before returning, or left behind. Fungal spores can even be carried in hair, so a shampoo is worthwhile.
- **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.

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 Industry 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. Refer to links.

Further information on cotton industry biosecurity contact Cotton Australia on (02) 9669 5222 or go to www.cottonaustralia.com.au/cotton-growers/biosecurity

To learn more about on-farm biosecurity for cotton growers, download a copy of the Cotton Industry Farm Biosecurity Manual from the biosecurity section of PHA's website: www.phau.com.au

For more information on the NSW's General Biosecurity Duty: www.dpi.nsw.gov.au/biosecurity/overview/biosecurity-legislation/general-biosecurity-duty

For more information on Qld's General Biosecurity Obligation: www.daf.qld.gov.au/biosecurity/about-biosecurity/biosecurity-act-2014/information-and-resources-about-the-act/overview-and-foundation-principles/general-biosecurity-obligation



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- Halox 520
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Come Clean. Go Clean.

With the removal of Farm Cleanse, there are replacements available for growers and agronomists to use to ensure vehicles, machinery and equipment coming on farm are free of mud and trash.

There are two different types of products available: agricultural detergents/degreasers and agricultural decontaminants. Agricultural detergents are used to provide optimum soil removal. While decontamination products contain actives which certain organisms and bacteria can be susceptible to. Decontaminant products also need to be applied to a surface that has all soil and trash removed to be effective.

Further Come Clean Go Clean steps for cleaning down vehicles can be found on page 125. It is important that users follow label directions for rates and use patterns.

For more information on Come Clean. Go Clean. including available wash down products please refer to www.cottoninfo.com.au

III

TABLE 31: Agricultural detergents available for assisting with soil removal from machinery and vehicles

Product name	Registrant
Bio-Cleanse	Queensland Cleaning Solutions
Fleetmaster Harvest Kleen	Minehan Agencies Pty Ltd

TABLE 32: Agricultural decontaminants

Active ingredient	Product name	Registrant
Benzalkonium chloride	Bactex CF	Whiteley Corporation
	Path-X	Nutri-Tech Solutions
	Sporekill	Nufarm
Didecyl dimethyl ammonium chloride	Steri-Max	Sipcam
	Virkon S	Lienert Australia
	Broadspectrum	
Sodium dodecyl benzene sulfonate/Potassium Peroxomonosulfate triple salt/ sodium chloride	F10SC Veterinary Disinfectant	Health and Hygiene Pty Ltd
	Microtech 7000 General purpose	Chemetall (Australasia) Pty Ltd
	Virkon S Tablets	Lienert Australia
Potassium peroxymonosulfate/ Sodium chloride	Virugard	Farm Care
Sodium dodecylbenzene sulphonate	Viraban	Bayer
	ViralFX	Spick N Clean Products

Come Clean. Go Clean.

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

A GUIDE TO EFFECTIVE WASH DOWN OF VEHICLES AND MACHINERY

1 WASH DOWN

- Use compressed air or high pressure water to remove caked on trash and mud
- Get into crevices where mud or trash might be trapped
- Clean out the inside of the car, particularly foot pedals and mats regularly in contact with dirty footwear

WHERE

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



2 CLEAN

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

*unless otherwise directed by product label



REMEMBER

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

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



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

Exotic pests and diseases of greatest threat to Australian cotton

A risk assessment carried out during the development of the Cotton Industry Biosecurity Plan identified 15 high priority pests that currently do not exist in Australia, that could establish in our farms and threaten production. It is important that people working on-farm are aware of industry high priority pests as well as what to do if they see any unusual plant symptoms or pests to improve the chance of effective control and eradication.

Cotton boll weevil

Anthonomus grandis

Cotton boll weevil is specific to cotton and causes large yield losses due to damage to developing bolls and subsequent reduction in lint production. 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. (Source: Alton N. Sparks, Jr., University of Georgia, Bugwood.org)

Brown marmorated stink bug

Halyomorpha halys

Brown marmorated stink bug (BMSB) is a typical stink bug with a shield shaped body. Stink bugs emit a pungent odour when disturbed. There



Brown marmorated stink bug. (Source: Steven Valley, Oregon Department of Agriculture, Bugwood.org)

are a number of Australian native stink bugs which are similar to BMSB. However, the distinct features of adult BMSB are the white bands on the antennae, sides of the abdomen and on the legs. BMSB can damage very large bolls.

Cotton stainer; red bugs

Dysdercus spp

These often colourful bugs tend to form groups, which help them find mates. These bugs look like and cause damage similar to the already endemic pale cotton stainers (*Dysdercus sidae*). Many *Dysdercus* species transfer microorganisms that increase staining of the cotton bolls that they prefer to feed on.



Adults and nymphs of the cotton stainer, *Dysdercus suturellus*. (Photograph by Lyle J. Buss, University of Florida. http://entnemdept.ufl.edu/creatures/field/bugs/cotton_stainer.htm)

Bt resistant Cotton bollworm

Helicoverpa armigera (carrying Bt resistance alleles)

The introduction of Bt cotton, has dramatically reduced the need to control the major insect pests, *Helicoverpa*. There are also exotic, Bt tolerant, strains of endemic pests such as *H. Armigera* which carry resistance alleles (e.g. dominant resistance to Cry1Ac in China) that would have a significant effect on Australia's cotton industry if they were to become established in Australia. With the movement of *H. Armigera* into South America, there is also some concern that *Helicoverpa Zea* (American cotton boll worm) may hybridise with *H. Armigera*.

False Codling moth

Thaumototibia 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.

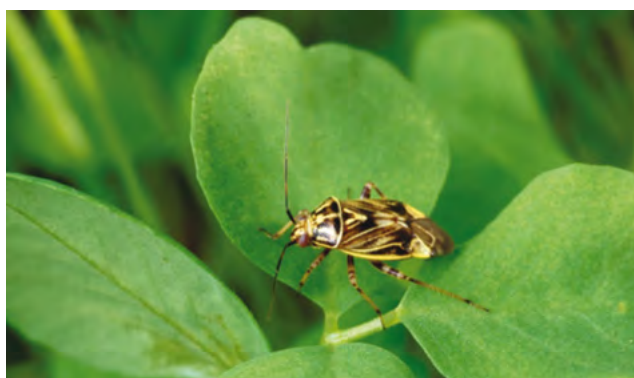


False codling moth larvae (left) and female moth (right). (Source: Marja van der Straten, NVWA Plant Protection Service www.bugwood.org (left) and <http://idtools.org> (right))

Tarnished plant bug and Western plant bug

Lygus lineolaris and *Lygus hesperus*

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



Tarnished plant bug. (Source: Scott Bauer, USDA Agricultural Research Service, Bugwood.org)

Whitefly

Bemisia tabaci (exotic biotypes)

Whitefly feeding results in a sticky residue, sooty moulds, reduced boll size and poor lint quality. Although the B-type whitefly is present in Australia there is a risk of other B-type strains and other biotypes, e.g. Q-type, entering the country with different insecticide resistance profiles. Whiteflies are also vectors of damaging exotic viruses such as cotton leaf curl disease.



Bemisia tabaci B-type. (Neil Forester)

Cotton aphid

Aphis gossypii – exotic strains

Aphids damage cotton by feeding on young leaves and bolls which can reduce yield. They produce a sticky residue that can cover leaves resulting in reduced photosynthesis and contamination of lint as bolls open, reducing the crop's value. This species may also carry exotic diseases 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.



If a new aphid strain enters the country it may have a different insecticide resistance profile, making control more difficult, or may carry an exotic plant disease. (Photo: L. Wilson)

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 a whitefly vector. 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 are seen on leaves and 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)

Fusarium wilt

Fusarium oxysporum f. sp. *vasinfectum* – exotic strains

Fusarium wilt is a fungal disease. Strains of Fusarium were identified in Australia in 1993 however the introduction of new strains (races) would increase the difficulty of management as new resistant cotton varieties would be required.

External symptoms can appear in the crop at any stage but most commonly appear in either the seedling phase or after flowering when bolls are filling. Leaves appear dull and wilted before yellowing or browning progresses to eventual death from the top of the plant. Seedlings may either wilt and die or survive, but often with stunted growth. Adult plants may wilt and die, especially under conditions of stress. Some affected plants may re-shoot from the base of the stem. Lengthwise cutting of the stem

from affected plants will show continuous brown discolouration of the tissue. The internal discolouration is similar to that of *Verticillium* wilt but usually appears as continuous browning rather than flecks. Sometimes the discolouration is visible in only one side of the stem. External symptoms do not always reflect the extent of discolouration in the stem.



Fusarium wilt causing vascular discolouration and root knots caused by nematodes. (Chris Anderson, NSW DPI)

Texas root rot

Phymatotrichopsis omnivore

Texas root rot is an extremely damaging fungal disease with a wide host range. It causes sudden death of affected plants, 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, leaves wilt and die; dead leaves usually remain on plant. At this stage, roots are dead and surface is covered with 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 leaf roll 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 was not detected from Australian cotton affected by cotton bunchy top disease.

Cotton blue disease affected leaves tend to be smaller, thick, more brittle and leathery and have an intense green to bluish colour 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 shortening of the branch internodes and produce many branches, giving a bunchy zig-zag stem habit. Symptoms are more obvious in plants infected at an early age and stunting is more pronounced. Infected plants also produce smaller bolls and boll shed may occur. Single infected plants can be overlooked if overgrown by nearby healthy plants.



Blue disease. (Murray Sharman Qld DAF)

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. The disease is seed borne allowing easy dispersal and introduction of new races into new areas. Bacterial blight is spread by high temperature, humidity and rainfall.

The initial symptoms include the undersides of leaves having angular water soaked lesions. Lesions dry and darken with age then leaves are shed. Black lesions spread along stem. Bolls often infected at base or tip. Lesions dry out and prevent the boll opening. The pathogen is capable of symptomless transfer and therefore could be undetected through quarantine.



Bacterial blight.

Verticillium wilt

Verticillium dahliae – exotic strains

Recently it was identified that there are at least three strains of *V. dahlia* in Australia including a defoliating strain. Exotic strains would still impact Australian cotton, and so this remains a biosecurity priority.

Getting the best out of your spray application

Susan Maas, CRDC

Acknowledgements: Mary O'Brien (Mary O'Brien Rural Enterprises), Bill Gordon (Bill Gordon Consulting Pty Ltd), Phil Hurst (Aerial Application Association of Australia) and Nicola Cottee (formerly Cotton Australia). Adapted from earlier versions by Andrew Hewitt (Centre for Pesticide Application and Safety, University of Queensland); Peter Hughes (formerly Qld DAF); Tracey Leven (formerly CRDC) Graham Betts (ASK GB)

Top 10 tips for agronomists this spray season

1. Run through a pre-season spray plan with your growers (https://grdc.com.au/_data/assets/pdf_file/0018/234162/5grdcsm5sprayplans.pdf).
2. Highlight to growers the spray drift risk factors when making chemical recommendations and timeframes for pest control and include advice on water quality and adjuvant and tank mix considerations.
3. Have a conversation with your grower if you suspect that spray practices can be improved.
4. Recommend a coarser nozzle to reduce spray drift risk and recommend higher water rates to improve efficacy for pest control.
5. Check that your grower's spray rig is fit-for-purpose to deliver your spray recommendations and discuss sprayer set up and operation (e.g. nozzles for spray quality, relationship between droplet size and velocity).
6. Understand the relationship between translocation and coverage.
7. Ensure growers understand the importance of paying attention to environmental conditions and stop spraying if conditions become unfavourable.
8. Ensure growers understand the importance of not spraying under inversion conditions, which may include limiting night-time spraying.
9. Follow up on recommendations to assess efficacy and efficiency
10. Understand that spraying with a slightly higher Delta T is acceptable if weeds are not stressed and adjustment to spray droplet size and water rate have been made.

Best practices for spray application

When using pesticides, best practice means not only doing the best job you possibly can, but also being able to demonstrate what you have done and how it has impacted others.

Movement of spray beyond the target area is undesirable as it represents wastage of product and exposure of non-target sensitive areas to potentially damaging materials. 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.

Planning

The development of a comprehensive Pesticide Application Management Plan (PAMP) is an important part of the Best Management Practice (*myBMP*) program for cotton. The PAMP for farming enterprises should be completed prior to the season and should cover:

- Farm layout;
- Record keeping;
- Weather monitoring;
- Identification of sensitive areas, potential hazards and awareness zones;
- 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 requirements

Always read and follow the label when handling and applying chemicals. Label conditions may specify spray quality, spray conditions including mandatory wind speed range, and no spray zones/buffers. 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, which require a hazard analysis to be completed, in addition to maintaining an inventory of the hazardous chemicals you use and store and current copies of the Safety Data Sheets for each of those chemicals.

Users are not absolved from compliance with the directions on the label or the conditions of the permit by reason of any statement made or not made in this publication.

Label Instructions

Many product labels now include a range of mandatory statements. Some examples include:

Mandatory spray qualities

Labels typically require the use of a coarse spray quality or larger, or a medium spray quality or larger according to the ASABE¹ or BCPC² classification systems. Ensure nozzles are selected from charts that refer to either of these standards and equipment is setup and used appropriately to achieve the required spray quality. Make sure you consult a current nozzle chart to check the spray quality classification of the nozzle.

Mandatory wind speed range

Labels state that the wind speed must be above 3 km/h and less than either 15 km/h or 20 km/h (depending on the product) as measured at the site of application.

No spray zones

A NO SPRAY ZONE is the downwind distance between the sprayed area and a sensitive area. The product must not be applied if a sensitive area is within the downwind NO SPRAY ZONE. A sensitive area may be a residence, public area, water body, pasture, terrestrial vegetation or another susceptible crop. A label may include several NO SPRAY ZONE tables. The distance required for the NO SPRAY ZONE may differ for the various types of sensitive areas.

Always check the label to see if a no spray zone is required, and how wide the no spray zone has to be for the product and the specific tank mix you wish to use. NO SPRAY ZONES for aerial applications can be larger than those required for ground application.

Record keeping

Record keeping requirements are included on the label or permit conditions for many products. It is a legal requirement to maintain those records, in addition to any state based requirement for record keeping.

Communication and neighbour notification

Prior to spray application and product selection, check the proximity of susceptible crops and sensitive areas such as houses, schools, waterways and riverbanks. It is good practice to notify neighbours and staff of your spray intentions, regardless of label requirements. By doing this, sensitive crops or areas that you may not have been aware of can be accounted for.

Cotton is extremely sensitive to phenoxy via off-target application. **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. Refer to the Cotton Australia website for more details.**

Don't forget apiarists as neighbours. BeeConnected can help identify nearby location of hives and facilitate communication between spray applicators and beekeepers (www.beeconnected.org.au).

Monitoring and recording weather conditions

Weather conditions need to be checked regularly during spray applications (this means continual visual observations and actual measurement at least every load) and recorded as per label requirements. Growers can also subscribe to 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 times that may be suitable for spraying. You can access the websites at either Spraywisecisions.com.au or Syngenta.com.au for more information.

Labels contain a legal requirement to measure weather parameters at the site of application. This can be done with handheld equipment (e.g. Kestrel 3000, 3500, 4000 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.

myBMP resources: Fact sheet on weather monitoring equipment.

Spray Log Books

To assist in record keeping for pesticide applications, Spray Log Books can be purchased from:

- Qld DAF at Toowoomba (07) 4529 4200 or Dalby (07) 4669 0800.
- NSW DPI at Yanco 1800 138 351 (SMARTtrain spray record book).
- Other websites, including Spraywise, have record forms or you can download an app from Farming with apps (www.farmingwithapps.com/)

Temperature and humidity

Higher ambient air temperatures and lower relative humidity conditions increase evaporation rates. Higher evaporation rates will decrease droplet size and increase the risk of drift for water-based sprays. Water-based

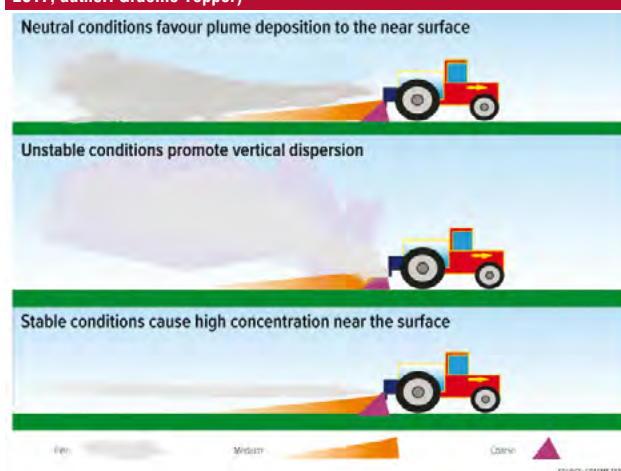
sprays should not be applied under conditions of high temperature and low relative humidity (RH). Spraying is best conducted when the delta T (the difference between the wet bulb and dry bulb) is in the range 2-10°C. This may be extended to 12°C where targets are not stressed and a coarse spray quality or larger is used. Refer to Fact Sheet on Tips to Reduce Spray Drift for a Delta T Chart in myBMP resources.

When using coarse sprays at high water volume rates, evaporation may be less significant, which may allow some applications to continue into marginal delta T conditions (where soil moisture exists, and the targets are not in a stressed condition). Never start a spraying operation when the Delta T is below 2 or above 10-12.

Further information: www.grdc.com.au/GRDC-FS-SprayPracticalTips

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

(SOURCE: GRDC Weather Essentials for Pesticide Application booklet, 2017; author: Graeme Tepper)



Surface temperature inversions

Labels state that spraying must not occur during a surface temperature inversion. There is a high risk of surface temperature inversions being present at night. The APVMA suggest that applicators should anticipate that a surface temperature inversion will be present every night between sunset and shortly after sunrise, unless there is heavy low level cloud, it is raining or the wind speed remains above 11 km/h for the entire evening.

For more information refer to the GRDC factsheets on Surface Temperature Inversions (<https://grdc.com.au/GRDC-FS-SprayInversions>) or refer to 24 hour spray diagram on page 132.

Vegetative plantings for spray drift barriers

Effective vegetative barriers can reduce drift by up to 90%. A good vegetative barrier will be comprised of a mixture of tree and shrub species with foliage all the way to the ground. The planting arrangement and density should allow for air to partly flow through the barrier. Dense vegetative barriers (without airflow) act like impermeable walls, directing wind containing the spray drift up and over the top of the barrier and increasing how far drift may travel. Do not locate vegetative barriers where airflow will be obstructed by adjacent objects such as turkey's nests, water storages or large banks.

The minimum height for a vegetative barrier should be at least 1.5 times the release height of the spray, when the barrier has a porosity of around 50% (visually this means you can see 50% light and 50% dark when you look through the vegetation). As the porosity reduces, the height of the vegetative barrier needs to be increased. For example, at 40% the height should be 2 times the release height for the spray. Trees and shrubs

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with long thin or needle like leaves, or hairy leaf surfaces are the most effective at trapping airborne droplets. Many trees and shrubs are effective at trapping droplets from ground applied sprays from early stages in their development, so make sure the species chosen is hardy, and drought tolerant with thick cuticles to help them survive small doses of pesticide.

Most guidelines suggest that the optimum width of the barrier is 20 m with a 10 m maintenance strip on either side. It is important that remnant native vegetation is protected from negative impacts such as spray drift. This vegetation should be identified as sensitive areas along with riparian areas and waterways.

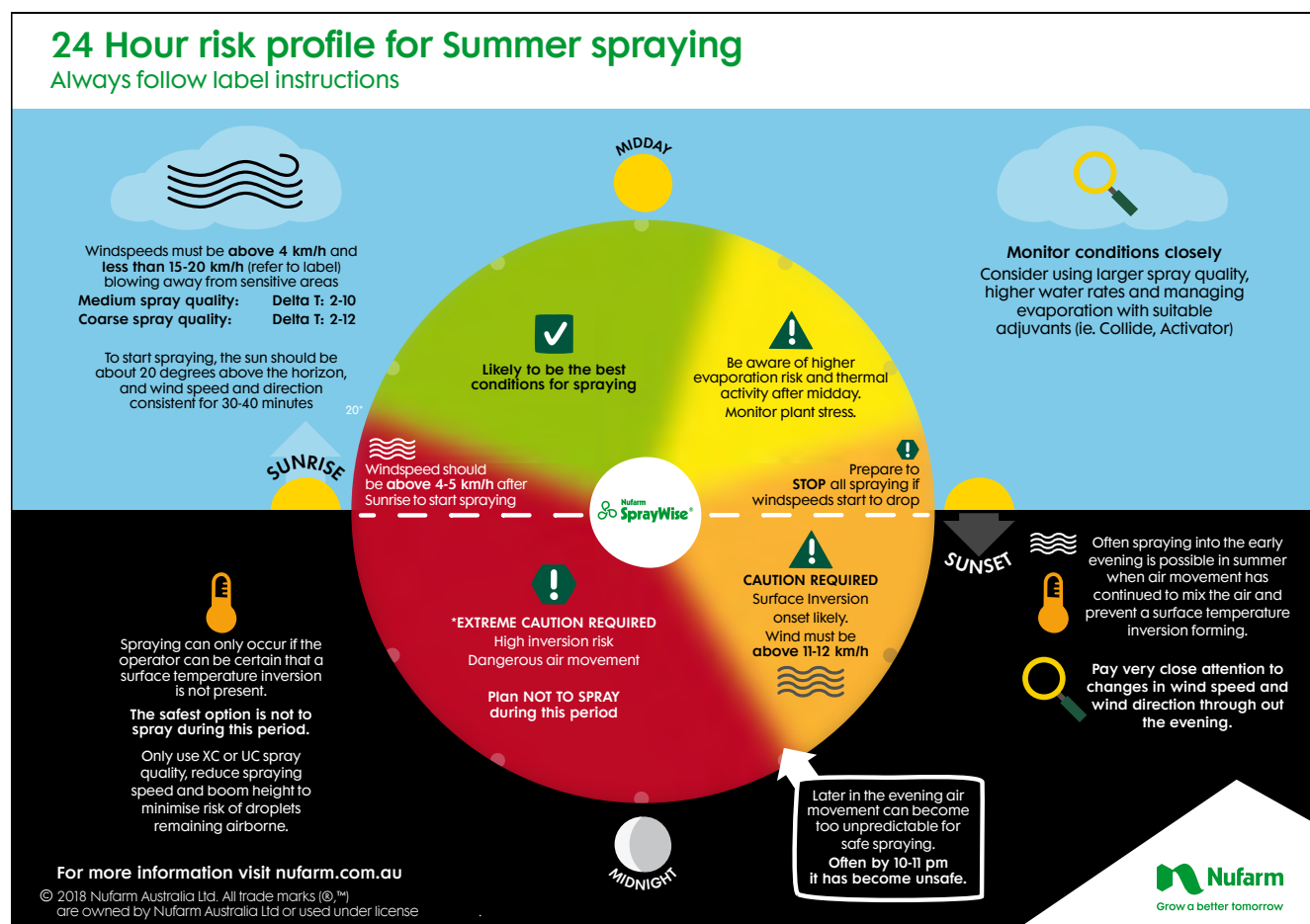
CottonInfo NRM/Pesticide Input Efficiency fact sheet – Using vegetative barriers to minimise spray drift on cotton farms <http://www.cottoninfo.com.au/publications/nrmpesticide-input-efficiency-using-vegetative-barriers-minimise-spray-driftcotton>

Summary of factors that influence spray drift and best practice

Spray application needs to maximise efficacy against the target pest, while minimising any off-target movement or effect. Application technique needs to be matched to the target and weather conditions. Achieving the best outcome from spray application requires the careful consideration of many factors:

- Setting appropriate spray release height;
- Avoid excessive travel speed for ground rigs;
- Pressure at the nozzle;
- Suitable water volumes and quality;
- Nozzle selection; and,
- Maintenance and hygiene.

These factors are expanded in the Australian Cotton Production Manual.



Ground application

Considerations for selecting a contract spray applicator

It is important to ensure that any spray contractor has the appropriate license as required in your state. You can search to see if a ground or aerial contractor is licensed in NSW at <https://apps.epa.nsw.gov.au/prdlapp/plpr.aspx> and in QLD at <https://www.business.qld.gov.au/industries/farms-fishing-forestry/agriculture/land-management/chemical-controls/licence-search>.

Operators should also be trained and accredited. An example of an Advanced Spray Training courses run by Craig Day, an experienced spray specialist from Spray Safe and Save, are being offered to NSW grain and cotton growers, farm staff, contractors and advisors, fully funded through the AgSkilled program. They consist of two parts: a one-day workshop; plus a workplace visit later that week. The course meets the requirements for NSW chemical user accreditation. Register your interest: contact Cath on 02 6345 5818 or 0437 455 818 or email craig.day@bigpond.com

Calculating banded sprays

Banded sprays present an opportunity to place the recommended rate of the product onto an area smaller than the whole field. This way we use less chemical over the whole field, but still apply the equivalent rate per hectare to the target. There are often big differences between the consultant's recommendation, the applicator's instincts and what the machine can do with the nozzles available.

Commonly asked questions are:

- What is the actual application rate?
- How much chemical to put in the tank?
- How many paddock hectares can be treated with each tank load?
- What rate to put in the spray controller? and,
- What nozzles to use to achieve required application rate?

To work out the true application rate we need to know the sprayed width, or average sprayed width for each nozzle. This allows us to calculate the litres per sprayed ha. Label rates are always given as L/sprayed ha. Advisors should always give recommendations as L/sprayed ha. To apply the correct L/sprayed ha there are two main things to work out:

- **How much chemical to put in the tank**, which is based on L/sprayed ha.
- **What to put into a controller**, which is based on paddock ha per tank.

Calculations

Application rate

You need to know:

Band width in metres: **e.g. 0.7 m band** ÷ 1 m row spacing = band width (m) ÷ row spacing (m).

Sprayed width per nozzle (m): = **band width (m) ÷ number nozzles per band** (e.g. 3 nozzles per 70% band of a 1 m row = 0.7 m ÷ 3 = 0.23 m)

Calculate:

$$\text{The application rate} = \frac{\text{L/sprayed ha} \times \text{L/min/nozzle} \times 600}{\text{speed (km/h)} \times \text{sprayed width per nozzle (m)}}$$

L/sprayed ha applies to each band (row), whether you spray 1 band (row), or many rows, whether it is a solid plant, single skip or double skip.

How much chemical per tank

You need to know:

Number of sprayed ha per tank = **Tank size (L) ÷ L/sprayed ha.**

Calculate:

$$\text{Amount of chemical to add per tank} = \text{Sprayed ha per tank} \times \text{chemical rate/ha.}$$

Paddock hectares per tank

Calculate:

$$\text{Paddock ha per tank (solid plant):} = \frac{\text{Sprayed ha per tank}}{\text{band width (m)}}$$

For skip row configuration, you need to calculate an adjusted band width:

Adjusted band width (m) = **band width (m) x width of boom ÷ row width (m) ÷ number of planted rows under the boom**

Calculate:

$$\text{Paddock ha per tank (skip)} = \frac{\text{Sprayed ha per tank} \div \text{the band width (m)} \times \text{width of boom} \div \text{row width (m)} \div \text{number of planted rows under the boom.}}$$

Rate to put in the Controller

Calculate:

$$\text{Rate to put in the Controller:} = \frac{\text{Tank Size (L)}}{\text{Paddock ha per tank.}}$$

*This works if you don't want to change the section widths in the controller.

Nozzle selection

To select the correct spray nozzle, you need to calculate the required flow rate of each nozzle (L/min). This is simple if all nozzles are the same size, as the flow rate will be the same for each nozzle.

You need to know:

The average sprayed width per nozzle:

e.g. For 5 nozzles per 1 m row at 100% band: **1 m ÷ 5 = 0.2 m**

For 4 nozzles per 1 m row and a 70% band: **0.7 m ÷ 4 = 0.17 m**

Calculate:

$$\text{Required flow rate per nozzle} \\ \text{L/min/nozzle} = \frac{\text{L/sprayed ha} \div 600 \times \text{speed (km/h)} \times \text{average sprayed width per nozzle (m)}}{}$$

Always remember to check the spray quality produced to ensure it is consistent with what is required by the product label.

Useful resources:

• The myBMP Pesticide application module, www.mybmp.com.au

• NuFarm Australia Ltd: 03 9282 1000, www.nufarm.com.au

• Cotton Pest Management Guide, www.cottoninfo.com.au

• GRDC fact sheets on:

- Spray Mixing Requirements
- Spray Water Quality
- Pre-season check and Controller Settings

* Information on weather:

- Weather essentials for pesticide application, Graeme Tepper, GRDC.
- GRDC Fact Sheet on Weather Monitoring Equipment

• Information on weather forecasting tools:

- www.spraywisedecisions.com.au
- Agricast

• Information on pesticide application:

- Spraywise Broadacre Application Handbook, Dr Jorg Kitt, Nufarm Australia

• Information on nozzle selection tools:

- Teejet Nozzle Selection App
- Hardi Nozzle App



For more information on best practice for aerial and ground spray application go to www.myBMP.com.au.
(Photo: Cotton Australia – Jack Hawkins)

Web links:

<http://agriculture.vic.gov.au/agriculture/farm-management/chemical-use/agricultural-chemical-use/spraying-spray-drift-and-off-target-damage/calibration-and-preparation-of-boom-sprayers>

https://grdc.com.au/data/assets/pdf_file/0031/234778/8grdcsm8callibration-of-the-spray-system.pdf.pdf

[https://grdc.com.au/data/assets/pdf_file/0022/244336/Nozzle-selection-for-boom-band-and-shielded-spraying-the-back-pocket-guide.pdf?utm_source=website&utm_medium=download_link&utm_campaign=pdf_download&utm_term=National&utm_content=Nozzle Selection for Boom, Band and Shielded Spraying: The Back Pocket Guide](https://grdc.com.au/data/assets/pdf_file/0022/244336/Nozzle-selection-for-boom-band-and-shielded-spraying-the-back-pocket-guide.pdf?utm_source=website&utm_medium=download_link&utm_campaign=pdf_download&utm_term=National&utm_content=Nozzle%20Selection%20for%20Boom,%20Band%20and%20Shielded%20Spraying%3A%20The%20Back%20Pocket%20Guide)

Aerial Application

Aircraft are extensively used for pesticide application in agriculture. They have the advantage of being able to cover large areas quickly and in conditions that may not suit ground application e.g. dense crop cover or wet ground. Aerial operators are professional spray applicators that understand the parameters required for getting the best out of a spray job. It is important to discuss the requirements of a spray application with the aerial operator. Communication about the target, timeliness, coverage required, and sensitive crops nearby will assist the operator 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** – any information to assist the aerial operator in understanding the target should be provided. For example, an insecticide application may vary depending on where the pest is present in the canopy of the crop.
- **Water Rates** – aircraft can be more efficient by using lower water rates, but it is important to understand the potential impacts on efficacy. It is critical that the correct coverage is achieved for the given application, which is usually specified on the product label. Minimum water rates should be adhered to and in some cases will need to be increased e.g. weather parameters, or to provide sufficient volume to carry all of the products in the tank.
- **Droplet Size** – aircraft are good at producing small droplets which are generally good for efficacy but may increase the risk of off-target movement. Some product labels specify the need to achieve a certain number of droplets per square cm on the target. Discuss this with your aerial operator because they are well positioned to select the correct droplet size to achieve these parameters.

- **Swath Width** – The swath width of a spray plane 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. It is good to 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 AAAA membership, Spraysafe or AIMS accreditations to ensure that they are getting the most professional service.

The Aerial Application Association of Australia (AAAA) has produced some useful documents to provide growers and agronomists with comprehensive information about aerial spraying and to assist with working more effectively with your aerial operator. These guides can be accessed at the AAAA website www.aaaa.org.au.

Chapter references:

1. American Society of Agricultural and Biological Engineers.
2. British Crop Production Council.

Further information:

2019 Australian Cotton Production Manual

GRDC Spray application manual <https://grdc.com.au/spray-drift-manual>

Mary O'Brien Rural Spray Drift resources www.maryobrienrural.com.au/resources/

SPRAYpak – Cotton Grower's Spray Application Handbook, 2nd edition, available from <https://www.cottoninfo.com.au/publications/spraypak>

Spraywise – Broadacre Application Guide – Available through Croplands Distributors.

Nozzle selection for boom, band and shielded spraying. The Back Pocket Guide published by GRDC <https://grdc.com.au/resources-and-publications/all-publications/publications/2017/07/nozzle-selection-for-boom,-band-and-shielded-spraying>

For more information about using vegetative barriers to minimise spray drift on cotton farms, see factsheet: www.cottoninfo.com.au/publications/nrmpesticideinput-efficiency-using-vegetative-barriers-minimise-spray-drift-cotton

<https://aaaa.org.au/>

Additional resources can be found at www.myBMP.com.au

III

***Rinse them out
Round them up
Run them in***

drummuster provides Australian agricultural and veterinary chemical users with a recycling pathway for eligible empty agvet chemical containers.

drumMUSTER is a national product stewardship program that is supported by agvet chemical manufacturers, industry stakeholders including member and farming associations as well as state and local governments.

Recycle your empty eligible agvet containers. Visit the ***drumMUSTER*** website to find the nearest collection site to you. Remember, every container counts.



drummuster.org.au

Connect with us



drumchem16

drum_MUSTER



drumMUSTER
rinse them out, round them up and run them in.

info@drummuster.org.au
1800 008 707

Use of pesticides

Product registration (APVMA tools and resources)

Fiona Anderson, Crop Consultants Australia

Acknowledgements: Carly Ambler (APVMA)

Role of the APVMA

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 ensure the health and safety of people, animals, crops, trade and the environment are protected.

Before agvet chemical products can be legally sold, supplied, marketed or bought in Australia, they must be registered by the APVMA. The APVMA's 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.

As part of the registration process, the APVMA approves product labels which include information that identifies the product and explains 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.

Find APVMA registered chemicals

Search the APVMA Public Chemicals Registration Information System (PubCRIS) database to find agvet chemical products, active constituents and labels approved and registered for use in Australia at:

<https://portal.apvma.gov.au/pubcris>

Guidance for using PubCRIS is available at:

<https://apvma.gov.au/node/45>

Looking for permit information?

Search the APVMA permit database to find minor use and emergency use permits issued by the APVMA at: <https://portal.apvma.gov.au/permits>

Tailored guidance for common APVMA applications

The APVMA is improving its applicant guidance material, tailoring it to the information applicants need to lodge the right application, with the right data and supporting evidence to meet APVMA criteria.

Guidance for applications to vary a product pack size and to vary product manufacture sites is available now, with more guidance for other common application types to be made available soon.

Access tailored guidance for applicants at:

<https://apvma.gov.au/node/27441>

Note: Product Expiry Dates are updated during the renewal period in July each year. Active Constituent Approvals do not have expiry dates.

Search products

SEARCH 

Product, ID, registrant, pest, host, or active. Searches on phrases should be enclosed in double quotation marks e.g. "adif clothing"

Advanced search ▲

Search terms include

Filter on

Registration



Product number



Product name



Registrant



Active constituent



Other constituent



Host



Pest

Reset 

Search 

The APVMA PubCRIS and permit search databases have a responsive design, making it easy to access and use on a mobile and other portable devices.

Chemical reviews

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. Changes that may be necessary include modifying the way chemicals are used or if risks cannot be managed, removing chemicals from the market.

A list of products currently under review is available at:

<https://apvma.gov.au/chemicals-and-products/chemical-review/listing>

Legal responsibilities

Labels are a legal document. All agricultural chemical applications **MUST** accord with the currently registered label for that particular agricultural chemical, crop, pest and region. State regulations detail additional requirements associated with the use of agricultural chemicals including record keeping, and training and licensing requirements for applications.

New South Wales

Jenene Kidston, NSW DPI

The *Pesticides Act 1999* is the primary legislative instrument controlling the use of pesticides in NSW and is administered by the Environment Protection Authority (EPA). The underlying principle of the Pesticides Act is that pesticides must only be used for the purpose described on the product label and all the

instructions on the label must be followed. Consequently, all label directions must be read by or explained to the user prior to each use of the pesticide.

All pesticide users should take reasonable care to protect their own health and the health of others when using a pesticide. They should also make every reasonable attempt to prevent damage occurring from the use of a pesticide, such as off-target drift onto sensitive areas or harm to endangered and protected species.

The Pesticides Regulation 2017 contains licensing and training provisions and requires all commercial pesticide users, i.e. all farmers and spray contractors, to keep records of their pesticide application.

While no set form is required for records they must include the following:

- Full product name;
- Description of the crop or situation;
- Rate of application and quantity applied;
- Description of the equipment used;
- Address of the property, identification of the area treated and order of paddocks treated;
- Date and time of the application (including start and finish);
- Name, address, and contact details of the applicator and of the employer or owner if an employee or contractor is the applicator;
- Estimated wind speed and direction (including any significant changes during application);
- Other weather conditions specified on label as being relevant (e.g. temperature, rainfall, relative humidity); and,
- There are some products with additional record keeping requirements determined on the label (so are national requirements) e.g. the new 2,4-D label requires that nozzle records are also kept.

An example form that captures all the information required by the Pesticides Regulation 2017 is provided on page 140. Notes on how to fill it in, can be downloaded from the NSW DPI website (<https://www.dpi.nsw.gov.au/agriculture/chemicals/farm-chemical-management/records>). A self-carbonating record book is available for purchase through the Qld DAF Dalby and Toowoomba offices and through the NSW DPI SMARTtrain National Support Centre at Yanco.

The record must be made as soon as practicable after the use of the pesticide concerned and, in any event, no later than 48 hours after the pesticide is used. A copy of the record must be kept for at least three years.

For further information about NSW Pesticides Regulation 2017 please refer to the following website:

<https://legislation.nsw.gov.au/#/view/regulation/2017/448/part4/sec36>

All fee-for-service pesticide users (aerial & ground application) are also required to be licensed. you can search to see if a ground or aerial contractor is licensed in NSW at <https://apps.epa.nsw.gov.au/prdlapp/plpr.aspx>

The Pesticides Regulation 2017 also requires all commercial pesticide users to be trained in pesticide application and hold a prescribed qualification. Only domestic use, such as home gardens, is excluded, provided the pesticide is a specific domestic/home garden product and used in quantities allowed through the domestic like use exemption.

The minimum level of competency in pesticide use required under the Pesticides Regulation 2017 is Australian Qualifications Framework Level 2 (AQF2). This is for people applying pesticides under supervision (AHCCHM201) where the supervisor must be AQF3 certified.

If you are working as an unsupervised operator or independent business person, you need training in Australian Qualifications Framework Level 3 (AQF3)(AHCCHM 303 and 304).

Further detail is available at <https://www.epa.nsw.gov.au/your-environment/pesticides/compulsory-training-pesticides>

More info about training providers can be found at <https://www.epa.nsw.gov.au/your-environment/pesticides/compulsory-training-pesticides/pesticide-trainers-courses>

Growers are recommended to undertake the SMARTtrain course, Chemical Application, or the standard ChemCert course, both of which cover the higher AQF3 competencies.

An important change in the 2017 regulation for cotton growers is: cotton growers who are accredited under a QA program (*myBMP* accreditation), that includes chemical recording and management records are no longer obliged to retrain every 5 years.

Further information available at:

<https://www.epa.nsw.gov.au/your-environment/pesticides/compulsory-training-pesticides>

The EPA can be contacted on <https://www.epa.nsw.gov.au/> phone 131 555 or info@epa.nsw.gov.au or your regional EPA office.

For additional information on legal responsibilities in applying pesticides in NSW, refer to Primefact 1464, http://www.dpi.nsw.gov.au/data/assets/pdf_file/0009/186390/legal-responsibilities-in-applying-pesticides-F.pdf

Queensland

Bartley Bauer, Qld DAF

In Queensland, the *Chemical Usage (Agricultural and Veterinary) Control Act 1988* (Chem Usage Act) sets legal requirements on how agricultural chemicals must be used. All chemical users are required to:

- Use agricultural chemical products which are currently registered with the Australian Pesticides and Veterinary Medicines Authority (APVMA);
- Use the products for the crop or situations specified on the approved label instructions or under the conditions of a permit granted by the APVMA; and,
- Apply agricultural chemical products according to all other label instructions, including any use instructions or restraints that may be listed, including those which specify droplet size, wind speed and direction, mandatory downwind no spray zones and other off-target spray drift reduction, risk management practices.

There are significant penalties that apply to anyone found to have breached the Chem Usage Act for failing to follow label instructions.

Under the *Agricultural Chemicals Distribution Control Act 1966* (ACDC Act) aerial distribution contractors and ground distribution contractors must be licensed. Pilots and ground spray operators working for these contractors must also be licensed. The ACDC Act makes provision for the licensing which applies to unmanned aerial vehicles (UAVs) or “drones” for the application of pesticides in Queensland. An aerial distribution contractor licence and pilot chemical rating licence are required for agricultural chemical spraying with a UAV. Exemptions which may apply to Commonwealth Civil Aviation Safety Authority (CASA) authorisations, for certain types of UAVs used on privately-owned land, do not apply for State chemical applicator licensing purposes.

In most instances, cotton growers applying agricultural chemicals with ground equipment on their own land do not need to hold a licence. However, growers are strongly encouraged to complete chemical application training to improve their skills and knowledge in application technology, handling, storing and transporting chemicals. Queensland growers are strongly encouraged to keep records of all their chemical applications along the same lines as NSW growers. Growers must keep records of chemical treatment activities where specified on the label instructions or under the conditions of a permit. Workplace health and safety also requires spray records to be maintained.

Aerial and ground distribution contractors are required to make records of all their spraying activities and keep these for a minimum of 2 years.

Record keeping for agricultural chemicals and training requirements for users of S7 and restricted chemical products are expected to be implemented in the near future, in accordance with a national agreement.

For additional advice on legal responsibilities in applying pesticides in Qld, contact Biosecurity Queensland on 13 25 23.

Other States

Please refer to your relevant state department for information on legal responsibilities for use of pesticides:

NT – <https://nt.gov.au/industry/agriculture/farm-management/using-chemicals-responsibly>

VIC – <http://agriculture.vic.gov.au/agriculture/farm-management/chemical-use/publications/a-guide-to-using-agricultural-chemicals-in-victoria>

WA – <https://www.agric.wa.gov.au/pests-weeds-diseases/control-methods/chemicals>

Safe storage, handling, use & disposal of chemicals

Phil Tucker, *drumMUSTER/Chemclear*

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, and most of those that are not, pose some risk to the health of those who use them or are exposed to them. Workplace health and safety regulations exist in both NSW and Qld to protect workers from the short and long term health effects from exposure to hazardous chemicals. *myBMP* provides guidance and resources to meet your requirements for handling, storage and application of chemicals and petrochemicals. The templates provided also help to document the farm specific procedures in place to minimise as well as respond in the event of an injury, fire, or spill. It is important that these procedures are communicated to all staff.

Recycle chemical containers

Empty chemical containers present a risk to people and the environment. All containers should be triple rinsed or pressure washed during mixing, with contents added to the spray tank, and securely stored. Recycling is now possible for properly rinsed metal and plastic containers used for farm chemicals. *drumMUSTER* is the national program for the collection and recycling of non-returnable crop production and animal health product chemical containers.

The containers when presented at a *drumMUSTER* receipt site MUST BE: Free of chemical residue with the lids removed. Some stains are acceptable but physical chemical residue is not. Dirt, dust and mould are not reasons for rejection. Inspection of containers at *drumMUSTER* collection points is necessary to ensure that containers can be safely recycled. There must be no product residue on the inside or the outside

of the container, including the thread and cap. Visible residues could be powder, flake, coloured/dark fluid or clear fluid.

Always follow these procedures to ensure your drums are suitable for delivery to a collection centre:

- 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 into the spray tank. Dispose of rinsate in spray tank appropriately.
- Inspect the container, particularly the thread and screw neck to ensure all chemical residues have been removed.
- Metal containers should be punctured using a steel rod or crowbar, this should be done by passing it through the neck/pouring opening and out the base of the container. This also allows the containers to vent and remove any residual odour.
- Allow the containers to drain completely and air dry them (this may take a number of days) to ensure they do not retain any rinse water.
- Store cleaned containers preferably in a sheltered place with caps removed, where they will remain clean and dry until they can be delivered to a *drumMUSTER* collection centre.

If your container is rejected, the inspector will request that your container is taken home, properly cleaned and returned for recycling in your next delivery.

As more resellers turn to using Intermediate Bulk Containers (IBCs), many are still unsure about the right way to return IBCs once they've been used. IBCs do not fall into the schedule of containers recycled by the *drumMUSTER* program. However, Agsafe has prepared a quick and easy guide that may assist users on how to send IBCs back for recycling or reuse. <http://www.drummuster.org.au/container-recycling/the-abcs-for-your-ibcs/>

For information on the <i>drumMUSTER</i> program phone 1800 008 707 or contact your local representative:		
Northern NSW	Southern NSW	Queensland
Phil Tucker	Tanya Ginns	Colin Hoey
0427 925 274	0428 556 924	0428 964 576

Safely dispose of unwanted chemicals

Unwanted rural chemicals may result from; discontinued use of a chemicals because of changes in cropping or animal practices, development of newer, more effective or safe chemicals, changes in a chemical's registration through the APVMA and/or banning from use, unknown product, sale of property, inherited product and deceased estates. Any unwanted or unknown chemicals held on farm are potential hazards to people, the environment and the community, so they must be disposed of responsibly and lawfully.

ChemClear is an industry stewardship program which is funded to collect currently registered agricultural and veterinary chemicals at the end of their life cycle, or, when they become surplus. The program is targeted to meet disposal requirements of ag and vet chemical users, and, whilst doing so diverts potential hazardous chemicals from being dumped in landfills, creeks or being inappropriately disposed of in the community.

There are six simple steps in using the program:

1. Take an inventory of any unwanted rural chemicals. The inventory should include all identifiable features of the container including label, manufacturer, expiry date, size of container and the remaining quantity of chemical left in the container. NB 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 <http://www.chemclear.org.au/>
3. Continue to store your registered chemicals safely and securely.
4. ChemClear will contact you direct to advise the location for retrieval.
5. Prepare chemicals for delivery to collection site.
6. Deliver chemicals ensuring that transportation is safe. Never place chemicals in the boot of a car or back of a station wagon. Refer to ChemClear website for information about safe transportation.

The cost to use the ChemClear service depends on the chemical to be collected. Group 1 chemicals are collected free of charge under the program. These chemicals are currently registered, or within 2 years of expiry or deregistration, and ag and vet chemicals manufactured by companies supporting the Industry Waste Reduction Stewardship initiative, that is, those containers displaying the drumMUSTER logo. Group 2 chemicals are those chemicals that are no longer registered do not display the drumMUSTER logo, unknown, unlabelled, out of date, or mixed ag and vet chemicals. The ChemClear program covers the transport costs, however a fee applies for the disposal of Group 2 chemicals. 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 subsidize Group 2 disposal.

Agsafe contact details:

Agsafe Limited

P: 02 6206 6888

Level 1, 40 Macquarie Street Barton ACT 2600

GPO Box 816 Canberra City ACT 2601

W: <http://www.agSAFE.org.au>

<http://www.drummuster.org.au>

<http://www.chemclear.org.au>



drumMUSTER

Spray Drift (2,4-D review)

Sally Ceeney (Cotton Australia)

Each season, Cotton Australia runs a campaign to help protect Australia's cotton crops from the effects of spray drift that includes educating users of Group I herbicides such as 2,4-D. Cotton Australia consider that the currently approved 2,4-D labels do not provide adequate instructions to effectively mitigate risk associated with spray drift. The APVMA are working closely with grower groups, state and territory authorities, and other stakeholders to develop new label instructions to reduce the likelihood of off-target damage due to spray drift.

As of 3 October 2018, the new 2,4-D label instructions (<https://apvma.gov.au/node/32941>) came into effect and old labels have been suspended. Users of 2,4-D must comply with the new label instructions, even if they are using products with the old labels.

The APVMA has issued permit PER 87174 "The New Instructions" to allow persons to possess, have custody of, supply, and/or use 2,4-D products currently on farm and in retail outlets. Supply at the point of retail sale must occur with the new instructions being provided with each container supplied. A copy of the permit can be found via <http://permits.apvma.gov.au/PER87174.PDF>

These changes affect about 220 products, and the new instructions for use include:

- A requirement not to spray in inversion conditions and additional information on recognising inversion conditions;
- Downwind mandatory no-spray zones for both aquatic and terrestrial off-target vegetation (including sensitive crops, gardens, landscaping vegetation, protected native vegetation or protected animal habitat);
- A requirement to use nozzles producing droplets no smaller than the VERY COARSE spray quality category;
- Mandatory record keeping requirements; and,
- Advisory statements about spray application over summer.

The new requirements do not change or restrict other aspects of the currently approved use patterns and should not affect availability of the product.

Products containing 2,4-D continue to be under review (reconsideration) by the APVMA (<https://apvma.gov.au/node/12351>).

For more information regarding the APVMA spray drift review, please refer to <https://apvma.gov.au/node/10796>

III

Pesticide Application Record Sheet



Industry &
Investment

Location, Applicator, Date of Application

Property/Holding: (residential address)					Date:										
Applicator's Full Name:				Owner (if not applicator):											
Address:				Address:											
			Phone:												
Mobile:		Fax:		Email:		Mobile:									
Sensitive Areas (including distances, buffers):				Comments (including risk control measures for sensitive areas):											
<table border="1" style="margin-left: auto; margin-right: auto;"> <tr> <td></td> <td>N</td> <td></td> </tr> <tr> <td>W</td> <td>Treated Area</td> <td>E</td> </tr> <tr> <td></td> <td>S</td> <td></td> </tr> </table>					N		W	Treated Area	E		S				
	N														
W	Treated Area	E													
	S														

Host/Pest

Paddock Number/Name:		Paddock Area:		Order of Paddocks Sprayed:	
Crop/Situation:				Type of Animals:	
Crop/Pasture Variety:				Age/Growth Stage:	
Growth Stage:				Mob/Paddock/Shed:	
Pest/Disease/Weed:				Animals — Number Treated:	
				Pest Density/Incidence: Heavy <input type="checkbox"/> Medium <input type="checkbox"/> Light <input type="checkbox"/>	

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 <input type="checkbox"/> Overcast <input type="checkbox"/> Light Cloud <input type="checkbox"/> Clear Sky <input type="checkbox"/>					
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.

Pesticides and the environment

Stacey Vogel, CottonInfo

Acknowledgement: Vesna Gagic (CSIRO)

The cotton industry's guidelines for minimising risk to the environment are another component of *myBMP*.

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, crustacea and the environment'.

Protecting the aquatic environment

The risk to aquatic organisms can be managed by:

- Preventing drift into surface waters during application;
- Locating mixing/loading and decontaminating facilities away from surface waters and providing such facilities with bunding and sumps to prevent movement of either concentrate or rinsate into surface waters;
- Installing valves which prevent back-flow when filling spray tanks from surface waters and in suction lines for chemigation systems which draw directly from surface waters;
- Avoiding aerial application of spray on fields during irrigation;
- Building sufficient on-farm storage capacity (including provision for storm run-off) to contain pesticide contaminated tail water from irrigation;
- Spraying in an upstream direction, when it is necessary to spray near surface waters, to reduce the maximum concentration at any one point in the watercourse;
- Using only registered products to control aquatic weeds, e.g. Roundup Bioactive® rather than Roundup®; and,
- Avoiding disposal of used containers in surface waters and on flood plains and river catchments.

Protecting birds

Organophosphate and carbamate insecticides can be particularly toxic to birds, especially in granular formulations. Insecticidal seed dressings can pose similar risks. Just a few seeds and granules can be lethal. Spillages can be very hazardous as birds can easily ingest a toxic dose from a small area.

Risks to birds from granular products can be managed by:

- Ensuring complete incorporation beneath the soil, particularly at row ends where spillage may occur; and,
- Immediate clean up of spillage, however small.

Bait materials for control of rodents (not registered in cotton, but relevant to crops grown in rotation with cotton) 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. The risks to birds from baits can be managed by:

- Ensuring even bait distribution, with no locally high concentrations;
- Not baiting over bare ground or in more open situations, such as near crop perimeters, where birds may see the baits;
- Not baiting near bird habitat such as remnant native vegetation;

- Use of bait stations which prevent access by birds, particularly near bird habitat;
- Only baiting where pest pressure is high;
- Baiting late in the evening when birds have finished feeding; and,
- Prompt collection and burial of rodent carcasses where these occur 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 sufficiently affected to make them more vulnerable to predation. Contaminated seed and insects collected from sprayed fields by parent birds can also be lethal to young chicks still in the nest. Risks to feeding and nesting birds can be managed by:

- Minimising drift into remnant vegetation, wildlife corridors, nesting sites, or other bird habitats; and,
- Actively discouraging birds from feeding in crops which 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. Reduce potential food and habitat loss through:

- Protecting sensitive areas such as remnant vegetation, riparian areas and waterways from spray drift;
- Where possible use target specific pesticides as opposed to broad-spectrum pesticides which 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;
- Spraying late in the day when birds have finished feeding; and,
- Using only low toxicity chemicals when large concentrations of birds are nesting nearby. 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.



Whistling ducks on "Taraba" Toobeah. (Photo: Anne Palfreyman)

Protecting 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.

The risk to remnant vegetation can be managed by:

- Preventing drift by implementing best practices for spray application;
- Installing natural or artificial barriers to intercept spray drift;
- Adhering to product label NO SPRAY ZONE instructions;
- Selecting target specific herbicides as opposed to broad-spectrum herbicides;
- Select non-soil active herbicides when remnant vegetation is nearby; and,
- Using an Integrated Weed Management approach when managing environmental weeds.

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Top arrow – vegetative barrier.
Bottom arrow – Remnant vegetation.

IMPORTANT: USE OF PESTICIDES

Pesticides must only be used for the purpose for which they are registered and must not be used in any other situation or in any manner contrary to the directions on the label. Some chemical products have more than one retail name. All retail products containing the same chemical may not be registered for use on the same crops. Registration and enforcement of label directions may also vary between states. Check carefully that the label on the retail product carries information on the crop to be sprayed.

This publication is only a guide to the use of pesticides. The correct choice of chemical, selection of rate, and method of application is the responsibility of the user. Pesticides may contaminate the environment. When spraying, care must be taken to avoid spray drift on to adjoining land or waterways.

Pesticide residues may accumulate in animals treated with any pesticides or fed any crop product, including crop residues, which have been sprayed with pesticides. In the absence of any specified grazing withholding period(s), grazing of any treated crop is at the owner's risk. Withholding periods for stock treated with any pesticides or fed on any pesticide treated plant matter must also be observed. Animals which test positive for chemical residues (i.e. with readings which exceed maximum residue limits for certain chemicals) at slaughter will be rejected. Pesticide residues may also contaminate grains, oils and other plant products for human use and consumption. Growers should observe harvest withholding periods on the pesticide label and should not assume that in the absence of a withholding period or after the expiry of a withholding period that the plant products will be free of pesticide residues.

Some of the chemical use patterns quoted in this publication are approved under Permits issued by the Australian Pesticides and Veterinary Medicines Authority (APVMA) at the time the publication was prepared. Persons wishing to use a chemical in a manner approved under Permit should obtain a copy of the relevant Permit from the APVMA and must read all the details, conditions and limitations relevant to that Permit, and must comply with the details, conditions and limitations prior to use.

Pesticides and bees

Stacey Vogel, CottonInfo

Acknowledgement: Vesna Gagic (CSIRO), Trevor Weatherhead (Australian Honey Bee Industry Council), Nicola Cottee (formerly Cotton Australia) and Katie Aspin (Croplife)

Protecting bees

Although cotton is commonly regarded as being largely self-fertile and self-pollinating, bees are helpful to the productivity of a range of agricultural crops. As well as managed honeybees and native bees, there are many wild insect pollinators on and around farms. Because they do not have such obvious hives, they are less easily seen, but they also provide an important service to agriculture. Native stingless bees are resistant to diseases and parasites common in honeybees (including varroa mite) and therefore provide an “insurance policy” for pollination (Tim Herd 2017, The Australian Native Bee Book). Current research suggests that pollination may contribute to reducing losses in cotton at high pressure from some pests. Remnant vegetation and other bushland on the farm should be thought of as pollinator habitat and protected accordingly.

The cotton growing environment can be high-risk environment for bees. Bees are particularly susceptible to many of the insecticides used on cotton farms, such as abamectin, fipronil, indoxacarb and pyrethroids. If bees or the hives are contaminated by insecticides, individual bees may be killed, or whole hives can be destroyed or their productivity diminished. Insecticides that are particularly toxic to bees are identified as such with the following special statement on the label such as:

Dangerous to bees. DO NOT spray any plants in flower while bees are foraging.

The IRMS highlights insecticides with label warning about bee safety. The relative toxicities of cotton insecticides to honeybees are listed in Table 3 on pages 10–11.

Table 3 ranks the acute toxicities of products to bees based on LD50 information. The residual toxicity of insecticides, that is, the amount of time the product remains toxic to bees after the time of application, should

also be considered when information is available. This information must be sourced from the current product label. Recommendations may vary between different formulations containing the same active ingredient. Many insecticides are safe to bees once the spray deposits have dried on the crop. The label will state this explicitly if it applies, otherwise it will provide information about the residual activity on bees and what action must be taken to avoid impacting bees. Refer to the APVMA Pubcris database to search for more information about individual insecticides (<https://portal.apvma.gov.au/pubcris>).

ALWAYS READ AND FOLLOW LABEL INSTRUCTIONS.

Bee field activity is temperature and food related. Bees become more active at temperatures above 12–13 degrees with maximum flight activity reached at 18 degrees. At temperatures above 35 degrees, water gathering bees are deployed by the hive. With water gatherers, the main flight activity occurs when temperatures are above the mid thirties. Honeybees forage within a 2–4 km radius of their hive. Although honeybees prefer to forage near their hive, they will fly many km (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 forage in cotton crops before, during and after flowering. As well as bees foraging in cotton crops, damage



The cotton growing environment is a high-risk environment for bees. (Photo: Lance Pendergast, Qld DAF)

Further information about protecting bees or to contact the owner of bee hives

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Protect bees when using Fipronil Refer to 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.”

may occur to bees when pesticides drift over hives or over neighbouring vegetation being foraged by bees e.g. coolibah, black box and river red gum.

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 the cotton growing areas. Flowering occurs in response to good spring rains. In northern NSW trees begin to flower mid- late December finishing about the end of January. Flowering times vary by a few weeks in both the southern and central Qld areas. When heavy flowering is expected beekeepers may move large numbers of hives into cotton growing areas for honey production.

With good communication and good will, it is possible for apiarists and cotton growers to work together to minimise risks to bees, as both the honey industry and cotton industry are important to regional development.

The pesticide risk to bees can be reduced by:

- Following the registered label directions;
- Register on BeeConnected and map your cotton fields in SataCrop;
- Notifying apiarists when beehives are in the vicinity of crops to be sprayed, to allow removal of the hives before spraying. Beekeepers require as much notice possible, preferably 48 hours, to move an apiary;
- Informing contract pesticide applicators operating on the property, of the locations of apiaries;
- Paying particular attention to windspeed and direction, air temperature and time of day before applying pesticides;
- Using buffer zones as a mechanism to reduce the impact of spray drift or overspray on to non-target crops and native vegetation used by foraging bees;
- Avoiding drift and contamination of surface waters where bees may drink (see advice on risk management for aquatic organisms);
- Only apply pesticides when they are necessary using an IPM framework; and,
- Favour pesticides that have lower toxicity to bees and other beneficial insects.

Where possible, use EC or granular formulations in preference to wettable powders which are particularly hazardous to bees. Micro-encapsulated formulations such as that used for lambda-cyhalothrin are particularly hazardous to bees because of their persistence in the environment and because bees transport the micro-capsules back to the hive along with the pollen. Growers should also be aware of stewardship guidelines provided in CropLife Australia's Seed Treatment Stewardship Strategy. This outlines measures to reduce risks from dust generated during handling and planting of treated seed, as well as providing farmers with guidance on minimising off-target movement of crop protection products to protect important pollinators.

For more information refer to <https://www.croplife.org.au/resources/programs/seed-treatment-stewardship-strategy/>



For more information and to participate in the BeeConnected service go to: www.beeconnected.org.au/

BeeConnected app

Communication between growers and bee keepers is critical in reducing the risk of unintended exposure of bees to any 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 through a Google Maps-based platform with GPS capability. Beekeepers can use the same functions to log the present or future locations of their beehives. When a beehive is logged nearby to a farmer's property, both users are sent automated notifications and are able to 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. Even with this system, it is important to keep an eye out for bees near your property, because some apiaries might not be logged in the system.

For more information and to participate in this great service go to: www.beeconnected.org.au/

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180+ short videos on the latest RD&E
with **1.1 million+** views
all found on one channel:
www.youtube.com.au/cottoninfoaust



Re-entry periods after spraying

Fiona Anderson, Crop Consultants Australia

Acknowledgements: Sharna Holman (Qld DAF and CottonInfo), Susan Maas (CRDC)

The re-entry period is the period in which a treated field must not be re-entered by unprotected persons after the application of a chemical on a crop. This should be considered as part of the risk assessment. Workers including chippers must be advised on the correct time lapse and when it is safe to enter the crop again without protective workwear. It is important to observe the re-entry period when contact between foliage and skin is unavoidable. Herbicides are not included in the tables below as they are generally not as toxic.

Always check the label for the re-entry period

Older products often don't have a re-entry period stated. In this case it is recommended that entry is not allowed for a minimum of 24 hours after treatment. This should particularly be observed for products that have a signal heading of Caution, Poison or Dangerous Poison. Newer products will usually have a re-entry period stated but if not, it is generally accepted as being allowed to re-enter treated areas after the spray has dried. Caution should be exercised when entering wet crops where chemicals have previously been applied, irrespective of the time lapse between application and re-entry.

Re-entry periods should be considered in conjunction with the Personal Protective Equipment (PPE) required. This gives a guide as to the risk associated with re-entry. In the case that the field needs to be entered prior to the stated re-entry period, limit duration of entry and wear the PPE as stated on the label. Even after the re-entry period has been observed, some PPE may be necessary. Appropriate PPE should be indicated by the risk assessment.

Re-entry periods and the PPE to be worn are found in the General Instructions section of the label, which follows the Directions for Use table. All information will be found under the heading 'Re-entry Period'.

Re-entry periods may vary with formulation and product. The examples given in the table below may not be the same for all products with the active ingredient. Older labels for the same product may have different or no re-entry restrictions. Check the label of the product you are using and follow the directions.

Re-entry periods may change or be added to labels as chemicals are re-evaluated. Always read the label before using.

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TABLE 33: Common insecticides with label re-entry periods

Active ingredient	Re-entry period
Abamectin	Under field conditions the spray should be allowed to dry on the foliage before re-entry into treated areas.
Acetamiprid	Do not allow entry into treated areas until the spray deposits have dried.
Afidopyropen	Do not enter treated crops until spray has dried.
Alpha-cypermethrin	Do not allow entry into treated areas for 24 hours after application.
Amitraz	Do not allow entry into treated areas until the spray deposits have dried.
Amorphous silica	Do not allow entry into the treated area until the spray has dried.
Bifenthrin	Do not re-enter treated field/crop until spray deposits have dried.
Chlorantraniliprole/Thiamethoxam	Do not allow entry into treated areas until spray has dried.
Chlorfenapyr	Do not allow entry into treated areas for 12 hours after treatment.
Chlorpyrifos	Do not allow entry into treated areas until spray deposits have dried.
Cyantraniliprole	Do not allow entry into treated areas until the product has dried.
Deltamethrin	Do not allow entry into treated areas until the spray deposits have dried.
Diafenthiuron	Do not allow entry into treated areas for 24 hours after treatment.
Dimethoate	Do not enter treated areas until spray has dried unless wearing PPE as per label.
Dinotefuran	Do not allow entry into treated areas until the spray has dried, unless wearing PPE as per label.
Emamectin benzoate	Do not allow entry into treated areas for 12 hours after treatment.
Etoazole	Do not allow entry into treated areas until spray has dried.
Fipronil	Do not allow entry into treated areas until spray has dried.
Gamma-cyhalothrin	Do not allow entry into treated areas until spray has dried.
Helicoverpa NPV	Do not allow entry into treated areas until spray has dried.
Indoxacarb	Do not allow entry into treated areas until spray has dried.
Lambda-cyhalothrin	Do not allow entry into treated areas until the spray has dried.
Magnet®	Do not allow entry into treated rows until at least 24 hours after treatment. Do not allow entry into treated rows up to 72 hours after application when deposits are still moist from dew, light rain or high humidity.
Methomyl	Do not allow entry into treated areas for at least 24 hours after treatment.
Profenofos	Do not enter treated areas without protective clothing for 34 days after spraying.
Pymetrozine	Do not allow entry into treated areas until spray has dried.
Pyriproxyfen	Do not allow entry into treated areas for at least 24 hours after treatment.
Spinetoram	Do not allow entry into treated areas until the spray has dried, unless wearing PPE as per label.
Spirotetramat	Do not allow entry into treated areas until the spray has dried.
Thiamethoxam	Do not allow entry into the treated areas until spray has dried.
Thiodicarb	Do not allow entry into treated areas for 1 day after treatment.

Withholding periods

Fiona Anderson, Crop Consultants Australia

Acknowledgements: Sharna Holman (Qld DAF and CottonInfo), Susan Maas (CRDC)

Withholding periods (WHP) is the minimum time period from when a pesticide is applied to when the treated area is allowed to be grazed, cut for fodder or harvested. Some pesticide labels prohibit grazing by livestock or cutting fodder for livestock. Where a product has a no grazing WHP, crops treated with the product should not be grazed prior to harvest. Stock that graze the stubble or are fed by-products of the treated crop may develop detectable residues of the chemical. Growers should read the label and contact the chemical manufacturer for advice on managing chemical residues in stock. Crop residues **MUST NOT** be fed to stock if any product that specifically prohibits grazing or cutting for stock food has been applied to that crop.

Pesticide users must comply with these instructions or they may be prosecuted under offence provisions of relevant state or territory legislation for use of a pesticide in disregard of a label. ■■■

TABLE 34: Withholding period after application for common chemicals

Active ingredient	Crops not to be harvested for:	No grazing or cutting as stock fodder for:
Insecticides/miticides		
Abamectin	20 days	20 days
Acetamiprid	10 days	Do not graze or cut for stock fodder.
Afidopyropen	7 days	Not stated.
Alpha-cypermethrin	14 days	Not stated.
Amitraz	21 days	Not stated.
Amorphous silica	0 days	0 days
<i>Bacillus thuringiensis</i>	0 days	0 days
Bifenthrin	14 days	Do not allow livestock to graze crops, stubble or gin trash.
Beta-cypermethrin	14 days	Not stated.
Chlorantraniliprole	28 days	Do not allow livestock to graze crops, stubble or gin trash.
Chlorantraniliprole/Thiamethoxam	28 days	Do not allow livestock to graze crops, stubble or gin trash.
Chlorfenapyr	28 days	Do not allow livestock to graze crops, stubble or trash.
Chlorpyrifos	28 days	28 days
Chlorpyrifos-methyl	28 days	Do not all livestock to graze crops, stubble or trash.
Clothianidin	5 days	Do not graze or cut for stockfeed. Do not feed cotton trash to livestock.
Cyantraniliprole	14 days	Do not graze or cut for fodder. Do not allow livestock to graze crops, stubble or gin trash.
Cypermethrin	14 days	Not stated.
Deltamethrin	7 days	Not stated.
Dicofol	7 days	Do not graze or cut for stock fodder.
Diafenthiuron	14 days	Do not feed treated cotton fodder or cotton trash to livestock.
Dimethoate	14 days	Do not feed cotton fodder, stubble or trash to livestock.

TABLE 34: Withholding period after application for common chemicals (continued)

Active ingredient	Crops not to be harvested for:	No grazing or cutting as stock fodder for:
Insecticides/miticides		
Dinotefuran	14 days	Do not graze treated cotton crops or cut for stockfeed. Do not feed cotton trash to livestock.
Emamectin benzoate	28 days	Do not graze or cut for stock fodder. Do not feed trash to animals including poultry.
Esfenvalerate	7 days	Not stated.
Etoxazole	21 days	Do not graze treated crops or feed cotton trash to livestock.
Fipronil	28 days	Do not graze or cut for stock fodder.
Gamma-cyhalothrin	21 days	See label for the Export Slaughter Interval (ESI).
Helicoverpa NPV	0 days	0 days.
Imidacloprid	13 weeks	Do not allow livestock, including poultry, to graze crops, stubble or gin trash.
Indoxacarb	28 days	Do not allow livestock to graze crops, stubble or gin trash.
Lambda-cyhalothrin	21 days	Not stated.
Magnet®	WHP varies with insecticide mix – see label.	WHP varies with insecticide mix – see label.
Methidathion	3 days	Not stated.
Methomyl	0 days	Do not graze or feed crop to animals.
Paraffinic oil	1 day	
Pirimicarb	21 days	21 days
Phorate	10 weeks	10 weeks
Profenofos	28 days	Not stated.
Propargite	28 days	Do not feed cotton trash, stubble or failed crops.
Pymetrozine	28 days	Do not graze crop, stubble or gin trash.
Pyriproxyfen	28 days	Do not graze or cut for stock fodder. Do not feed treated cotton trash to livestock.
Spinetoram	28 days	Do not graze or cut treated cotton crops, stubble or gin trash.
Spirotetramat	21 days	Do not feed cotton fodder, stubble or trash to livestock.
Sulfoxaflor	14 days	Do not feed cotton trash to animals.
Thiamethoxam	28 days	Do not allow livestock to graze crops, cotton stubble or gin trash.
Thiodicarb	21 days	21 days
Growth regulator and defoliant chemicals		
Ethephon	14 days	Do not feed cotton stubble or gin trash to livestock.
Mepiquat	28 days	Do not graze or cut for stockfeed.
Paraquat + diquat	7 days	1 day (livestock) 7 days (horses).
Pyraflufen-ethyl	7 days	Do not feed, graze or cut for stockfeed for 7 days.
Sodium chlorate	0 days	Do not graze treated areas or feed cotton trash to livestock.
Thidiazuron	0 days	Do not graze or feed cotton trash to livestock.

The WHP given may not be the same for all products with that active ingredient. Always check the label.

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Regional Extension Officers

Regional Extension Officers provide cotton research outcomes and information directly to growers, agronomists, consultants and agribusinesses in each region. Contact your local Regional Extension Officer for the latest research, trials and events in your area.

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Technical Leads

Technical leads are experts in their fields and provide in-depth analysis, information and research to the industry, for the benefit of all growers. Contact the technical leads to learn more about water use efficiency, nutrition, soil health and much, much more.

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myBMP team

The myBMP team run the industry's best management practice program, myBMP. Contact the myBMP team to learn more about - or to participate in - myBMP.

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