Cotton Pest Management Guide 2018–19

The latest in cotton RD&E brought to you by
CRDC and CottonInfo

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Best Practice


NEW!
Residual registrations for summer crop establishment

Contents…

Cover photos courtesy Melanie Jenson and Johnelle Rogan.

Foreword

Susan Maas and Ruth Redfern, CRDC and CottonInfo

Welcome to the 2018–19 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 2018–19, CRDC will invest $24.3 million into approximately 300 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 Ltd. 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, *my*BMP, supported by Cotton Australia and CRDC, which sets the industry's best practice performance criteria and provides a framework by which growers can participate in, and be accredited in, best practice.

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

This year, for the first time, we have partnered with our fellow key industry organisation, Crop Consultants Australia (CCA), on the development of this Guide. This partnership sees the appointment of a 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 see some major changes in this year's Guide, including revised tables, a dedicated volunteer and ratoon cotton section, updated imagery, a regional disease update, and the addition of a locust section.

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 *my*BMP experts are standing by to assist you with all your cotton information needs (you can find our contact details on the inside back cover).

You can also find information from the CottonInfo team online at our website (www.cottoninfo.com.au), while best practice information for your farm is available at the *my*BMP website (www.mybmp.com.au). And you can find information about all of CRDC's investments online at 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, and the CCA Technical Review Panel members Bill Back, Elle Storrier, Sam Simons and Peter White for their input and guidance.

INDEX OF TABLES

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. If insecticides are required, they should be selected based on the Insecticide Resistance Management Strategy or IRMS (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.

For more information on IPM refer to page 47.

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 12-46), use the most selective effective insecticide (soft on beneficial insects), adhere to the IRMS (pages 63-66) and consider lowest label rate mixed with either salt or spray oils.

Selecting an insecticide

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 (‘broadspectrum’ 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 lady 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 the target pest, 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.

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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 (RDO) (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 lucerne (strips or block). 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.
	Practice Come Clean. Go Clean. all year round			
Consider options to escape, avoid or reduce pests	When planning cotton, consider proximity to sensitive areas, pest hosts and beneficial habitats. Consider spring trap crop. Manage areas of vegetation to encourage beneficials. Consider lucerne (strips or block) in autumn. If planning to release *Trichogramma*, plan to sow other crops (e.g. sorghum) that will host Helicoverpa.	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. Cultivate spring trap crops (following guidelines). Consider insecticide choice, food sprays or releasing beneficials to build beneficial numbers.	Monitor crop development to maintain a healthy crop. Maintain high beneficial numbers.	Slash and pupae bust last generation summer trap crop (follow guidelines). Follow pupae busting guidelines for Bt cotton. Practice Come Clean. Go Clean. to prevent spread of pests on, off and around farm.
Sample crops effectively and regularly	Remain up-to-date with key pests, beneficials, crop sampling and plant damage monitoring.	Sample for pests, beneficials, parasitism, fruit load and plant damage at least twice weekly throughout the season. Track pest trends. Use pest and damage thresholds and the beneficial to pest ratio.		
Grow a healthy crop	Consider the best rotation crop for your situation. Soil test to determine fertiliser requirements for cotton crop. Consider potential disease risks.	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 sampling method. 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] WW	Mite	Mir.	Aph.	Th	Persistence[6]	Overall[7]	Beneficial group: 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
Thiomethoxam	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 lady 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. Persistance: 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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TABLE 3: Impact of insecticides and miticides on predators, parasitoids and bees in cotton

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

Impact of insecticides & miticides on beneficials & bees – *sponsored by*

Emamectin	8.4	√						medium	moderate	L	VL	M	VL	H	H	H	H	H	L	M	M	—	M	VL	M				H
Propargite	1500		√					medium	moderate	M	H	H	M	M	H	VL	VL	L	VL	M	M	L	H	H	M		+ve	+ve	L
Acetamiprid	22.5				√			medium	moderate	M	M	VH	H	M	M	H	M	VH	L	VL	L	VH	H	VH	VH				M[15]
Clothianidin (low)	25			√				medium	moderate	M	VL	—	H	L	M	VL	VL	H	H	M	M	H	M	VH	VL			+ve	VH
Amitraz	400	√	√[9]		√[9]			medium	moderate	H	M	VH	H	L	—	—	—	H	VL	M	M	H	L	H	M				L
Fipronil (low)	12.5			√		√		medium	moderate	L	L	H	L	L	H	L	L	VH	L	M	M	—	M	VH	VH	+ve	+ve	+ve	VH
Chlorfenapyr (low)	200	√	√					medium	moderate	M	L	VH	VL	M	VL	H	H	VH	L	L	M	—	VH	H	M				H
Sulfoxaflor (full)	96			√	√		21	medium	moderate	H	L	M	H	L	VL	L	M	VH	H	L	M	—	H	VH	H	+ve		+ve	VH
Fipronil (high)	25			√		√		medium	moderate	L	VL	H	L	M	H	H	L	VH	L	M	M	M	M	VH	VH	+ve		+ve	VH
Imidacloprid	49			√	√			medium	moderate	H	L	VH	H	H	M	H	L	VH	L	L	L	VH	M	H	H	+ve		+ve	M
Clothianidin (high)	50			√				medium	moderate	H	VL	—	VH	M	M	L	VL	H	H	M	M	VH	H	VH	VL	+ve		+ve	VH
Dinotefuran (high)	75			√			√	medium	moderate	H	H	H	VL	H	M	VH	M	H	VL	L	M	—	VH	VH	H	+ve		+ve	VH
Methomyl	169	√						very short	high	H	L	VH	VH	M	L	VH	L	VH	M	M	M	VH	H	H	H	+ve			H[15]
Thiodicarb	750	√						long	high	VH	M	VH	VH	M	M	L	L	VH	VL	M	M	—	M	M	H	+ve	+ve		M[15]
Dimethoate (high)	200		√[18]	√	√[18]	√		short	high	M	M	H	H	M	H	—	H	H	VH	M	H	H	H	VH	M	+ve		+ve	H
Chlorfenapyr (high)	400	√	√					medium	high	H	M	VH	L	H	H	H	H	VH	L	M	M	—	VH	VH	M		+ve		H
OP's[5]		√	√	√	√	√		short-medium	high	H	M	H	H	H	M	H	H	VH	L	M	H	VH	H	VH	H	+ve			H
Carbaryl[3]								short	high	H	—	—	—	H	—	—	—	—	—	—	—		—	—	H	—	—	—	H
Pyrethroids[4]		√	√[7]	√[7]			√[7]	long	very high	VH	—	—	—	VH	—	—	—	VH	VH	VH	VH	VH	VH	VH	VH	+ve	+ve	+ve	H

1. Total predatory beetles – lady beetles, red and blue beetles, other predatory beetles
2. Total 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. 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); VL (very low), less than 10%; L (low), 10-20%; M (moderate), 20-40%; H (high), 40-60%; VH (very high), > 60%. A '-' indicates no data available 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. Similarly 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 lady beetle and other lady beetles for wet spray, moderate impact for dried spray.
14. Data Source: British Crop Protection Council. 2003. The Pesticide Manual: A World Compendium (Thirteenth Edition),. Where LD50 data is not available impacts are based on comments and descriptions. Where LD50 data is available impacts are based on the following 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 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 lady 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 (QDAF) and on ranking for *E. mundus* (P. De Barro, CSIRO, unpublished) and for *E. eremicus* (Koppert B.V., The Netherlands (http://side-effects.koppert.nl/#))
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.

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

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Management of key insect and mite pests

Sandra Williams, CSIRO and CottonInfo

Acknowledgements: Sally Ceeney (Cottoninfo); Susan Maas (CRDC); Sharon Downes, Simone Heimoana, Tanya Smith, Lewis Wilson, Mary Whitehouse (CSIRO); Lisa Bird, Grant Herron, Kate Langfield, Robert Mensah (NSW DPI); Paul Grundy, 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 57-66). 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 135. Carefully follow all label directions.

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 52.

Key beneficial insects

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

Parasitoids of pupae – banded caterpillar parasite

*See ratio formula on page 14.

Selecting an insecticide

The insecticide products registered for the control of Helicoverpa in cotton are presented in Table 4 on page 17. 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 63-66).

Resistance profile

H.armigera in Conventional cotton

Widespread use of Bt cotton has reduced reliance on chemical insecticides. However large plantings of Bt cotton does not change the overall frequencies of 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. While resistance to indoxacarb (Steward), avermectins (Affirm), rynaxypyr (Altacor) and organophosphates (chlorpyrifos) are low, recent testing has identified that frequencies of resistance to bifenthrin (SP) have increased to 40%. This means that field failures are now likely for this product. Resistance to general pyrethroids has increased to 90%. The use of conventional chemistries for control of *H.armigera* in conventional and Bt cotton crops should be according to the relevant thresholds and the principles of the IRMS (pages 57-66).

Pupae busting is another key tactic for mitigating resistance risk to all insecticides targeting *H.armigera*, including Bt cotton. Individuals that have survived seasonal selection by insecticides can be controlled before they have a chance to mate, thereby reducing carryover of resistant insects from one season to the next.

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

H.armigera in 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 67.

Over-wintering 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. Across all regions (Central Queensland, Macintyre, Namoi and Macquarie Valleys) 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.

Qld DAF, Toowoomba
Melina Miles: (07) 4688 1369.

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

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 the previous page. 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 page. 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 17. 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 67.

Over-wintering habits of *H.punctigera*

Though *H.punctigera* has always had the capacity to over-winter as diapausing pupae, extensive research conducted in the early 1990's 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 over-wintering 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) 4688 1369

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

TABLE 4: Control of Helicoverpa

Active ingredient	Insecticide group	Resistance *(H.armigera)*	Overall impact on beneficials*	Comments#
Bacillus thuringiensis	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. Maximum 2 applications per season.
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	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 >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 *H.punctigera* 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 2 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, 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. *H. armigera* 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 *H.punctigera* >10 mm and/or *H.armigera* <5 mm. Maximum 1 application per season.
Lambda-cyhalothrin	Group 3A	Widespread – high	Very High	Use low rate as ovicide and/or for newly hatched larvae. Maximum 1 application per season.
Piperonyl butoxide	Synegist	—	Very High	Use as a synergist when applying synthetic pyrethroids. 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.

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).

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 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.


Aphids and mummies. (Lewis Wilson, CSIRO)

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 cm^2. 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.

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 118 for hosts of CBT.

SEEDLING TO FIRST OPEN BOLL	FIRST OPEN BOLL TO HARVEST
Calculate the Cumulative Season Aphid Score (page 21)	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 – lady beetle adults and larvae, red and blue beetles, damsel bugs, big-eyed bugs, lacewing larvae, hoverfly larvae, 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 5 on page 20. 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/omethoate, 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.

Over-wintering 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:

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TABLE 5: Control of cotton aphid (*Aphis gossypii*) and Green peach aphid (*Myzus persicae*)

Active ingredient	Insecticide group	*A. gossipii* 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% per terminal use in a mixture with another aphicide.
Pirimicarb	Group 1A	Occasional – moderate & cross resistance	Very low	Thorough spray coverage essential for best results. Maximum 2 applications per season.
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 to an actively growing crop prior to cut-out with a developing aphid population. Maximum 2 applications per season.
Afidopyropen (Versys Insecticide)	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.
Thiamethoxam	Group 4A	Cross-resistance between all the neonicotinoids	Moderate	Apply to aphid population in early stages of development. DO NOT apply more than twice per season or as consecutive sprays. Do not use as first foliar if neonicotinoid seed treatment used. Maximum 2 applications per season.
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.
Flonicamid	Group 29	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)
Phorate	Group 1B	Occasional – low	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. Maximum 1 application per season.
Acetamiprid	Group 4A	Cross-resistance between all the neonicotinoids	Moderate	Ensure good coverage. Use high rate under sustained heavy pressure. Do not use as first foliar if neonicotinoid seed treatment used. Maximum 2 applications per season.
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 (high rate)	Group 1B	Occasional – low	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.
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.

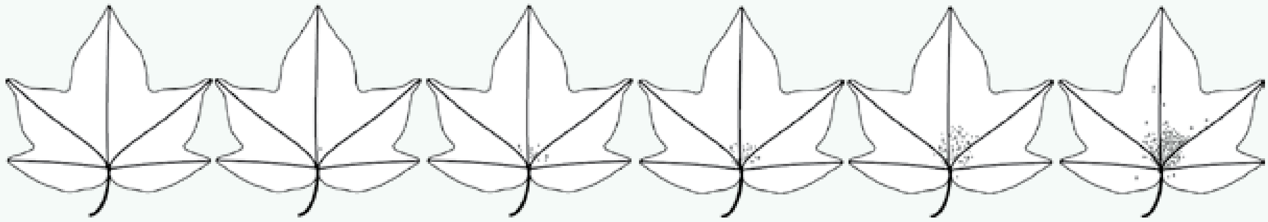
SAMPLING PROTOCOLS FOR COTTON APHID FOR USE UNTIL FIRST OPEN BOLL

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.



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

STEP 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 Cummulative 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 Cummulative 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

Mirids

Green mirid – *Creontiades dilutus*
Brown mirid – *Creontiades pacificus*
Yellow mirid (Apple Dimpling Bug) – *Campylomma liebknechti (Girault)*

Both the green and brown mirids are similar in appearance, however brown mirids are slightly larger and carry more dark pigments. 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 mite, 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 different responses from various sized squares, as well as changes in mirid feeding, likely due to a number of factors including temperature and the presence of natural enemies, mean that the relationship between mirid numbers and square loss is not always the same. 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.

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

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.

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.

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.

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.

TABLE 6: 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.

- **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 6 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.

TABLE 7: 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 (high rate)	Group 2B	Moderate	Apply spray to achieve thorough coverage. Use higher rate under sustained heavy pressure, 3-4 days to reach full effectiveness. Long residual impact on bees. Avoid repeated use of this insecticide group.
Flonicamid	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.
Emmamectin benzoate/acetamiprid	Group 6/4A	Moderate	Apply at or just prior to hatching. 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. On above threshold or increasing populations, suppression only may be observed. Use higher rate under sustained heavy aphid pressure. 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 always use SLW rate. Performance can be reduced in stressed crops or when senescing late season. Maximum 2 applications per season.
Phorate	Group 1B	High	Qld and NSW 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.

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 7. 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 16). 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

Mirids distinctly prefer lucerne to cotton. Lucerne strips or blocks have been used as trap crops to prevent the movement of mirids into cotton crops. 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: (07) 4991 0810 or 0407 059 066.
CSIRO, Narrabri – Mary Whitehouse: (02) 6799 1538 or 0428 424 205 or
Simone Heimoana: (02) 6799 2466 or 0427 992 466.
NSW DPI, Camden – Grant Herron: (02) 4640 6471.

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. Occasionally RGBs may survive through winter in cotton fields, living on stores of fallen sunflowers seeds from a preceding summer crop. The bugs maintain their populations on the seeds, migrating to cotton as seedlings emerge causing damage. This situation can also arise in fields with poor hygiene where weeds act as a winter host.

Little is known about the damage potential of RGB on crops other than sunflower, however, it has been reported that 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 DAFF 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 DAFF 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.

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 still 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 are more common. These species differ in damage potential so correct identification of the species present is crucial for good decisions.

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 30.

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.

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 30. 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.

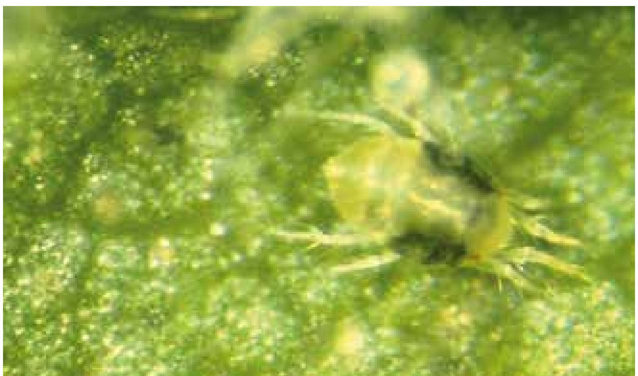
Thresholds

Thresholds and yield loss charts have been developed for two-spotted mites. 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 8 on page 31 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 8 on page 31 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 8 on page 31 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 an the time remaining until defoliation. These 'look-up' charts have been provided in Table 8, page 31 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 ie. 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, mite-eating ladybird, 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 9 on page 32. 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 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 at below damaging levels.

Abamectin resistance has occassionally 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-leafed weed species. Alternative winter and spring host crops include safflower, faba beans and field peas.

Further Information:

CSIRO Agriculture, Narrabri
Simone Heimoana: (02) 6799 2466 or 0427 992 466.

NSW DPI, Camden
Grant Herron: (02) 4640 6471.

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 (ie. 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 EMAI

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:

Dr Grant Herron
NSW DPI,
Elizabeth McArthur Agricultural Institute,
Woodbridge Road,
Menangle NSW 2568. Phone: (02) 4640 6471

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.

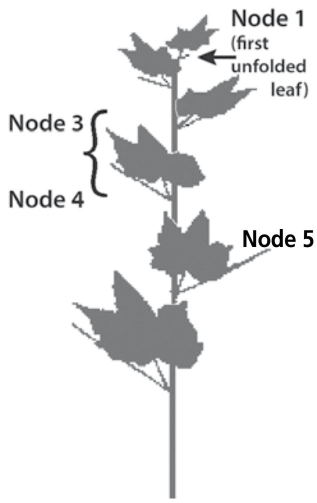


TABLE 8: Yield reduction caused by mites

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 9: 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.
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 as spray before mite infestations reach damaging levels as maximum efficacy is not reached until 2 weeks after spraying. Maximum 2 applications per season.
Amitraz	Group 19	No data	Moderate	Suppression when used for controlling Helicoverpa. Maximum 4 applications per season.
Dimethoate (high rate)	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 stockfood 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.
Phorate	Group 1B	No data	High	For short residual control at time of planting. For extended period of control. Only use the highest rate on heavy soils when conditions favour good emergence. Maximum 1 application per season.
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.

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 vaporiorum*) and Australian Native whitefly (*Bemisia tabaci*) can be present in cotton but are not considered pests, as their honeydew secretions do not cause problems for textile processing, and they are both 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.

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) 4629 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.

Sampling

Sample for Species and Population

Species: Verify which whitefly species are present before implementing any management strategies. Species composition may change rapidly during the season due to factors such as insecticide applications and climate. If large increases in population occur, this probably indicates the predominance of SLW. Consider insecticide application history for the crop as a clue to species composition – if the crop has been sprayed in the last few weeks then it is most likely the whitefly present are SLW.

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)**

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).

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 30.
- 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.

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 under-estimate 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 36).

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 35). 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.

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.

A Red Eye nymph. Check the middle canopy for Red Eye nymphs and pupa to estimate population growth over the next 7-10 days. (Photo: QDAF)

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.

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 optimium 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. 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. 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 80 days, while in the Macintyre, Gwydir and Namoi valleys, generation time increases to 120 days.

Alternative hosts

The availability of a continuous source of hosts is the major contributing factor to a severe whitefly problem. Even a small area of a favoured host can maintain a significant whitefly population. Preferred weed hosts include: sowthistle, melons, bladder ketmia, native rosella, rhynchosia, vines (cow,

TABLE 10: Control of silverleaf whitefly (*Bemisia tabaci* B-biotype)

Active ingredient	Insecticide group	Mite 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. Multiple applications are more effective.
Pyriproxyfen	Group 7C	Rare – moderate	Very low	Ensure thorough coverage. Maximum 1 application per season.
Clitoria ternatea extract	No Group	Unknown	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	Unknown	Low	Apply when population densities are 10-20% leaves infested. Note: The label indicates that the product may not give satisfactory control of populations >25% infested leaves. This is based on an overseas sampling model. For Australian conditions this equates to ~45% infested leaves. Maximum 2 applications per season.
Afidopyropen (Versys Insecticide)	Group 9D	Unknown	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	Unknown	Moderate	Target early developing populations. 2 consecutive applications 10=15 days apart may be required. Maximum 2 applications per season.
Spirotetramat	Group 5	Unknown	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. Silverleaf whitefly adults and eggs may not be controlled, however a decline in the total silverleaf whitefly population will occur over time as the juvenile stages are controlled. Maximum 2 applications per season.
Emmamectin benzoate/acetamiprid	Group 6/4A	Widespread – low	Moderate	Apply at or just prior to hatching. Use non-ionic surfactant as per label. Maximum 2 applications per season.
Dinotefuran (High)	Group 4A	Widespread – low	Moderate	When mirids and SLW are present always use SLW rate. Performance can be reduced in stressed crops or when senescing late season. Maximum 2 applications per season.
Bifenthrin	Group 3A	Widespread – high 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.

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 4688 1152 or 0475 825 340. Paul Grundy: 0427 929 172

Qld DAF, Emerald – Richard Sequeria: (07) 49901 810 or 0407 059 066.

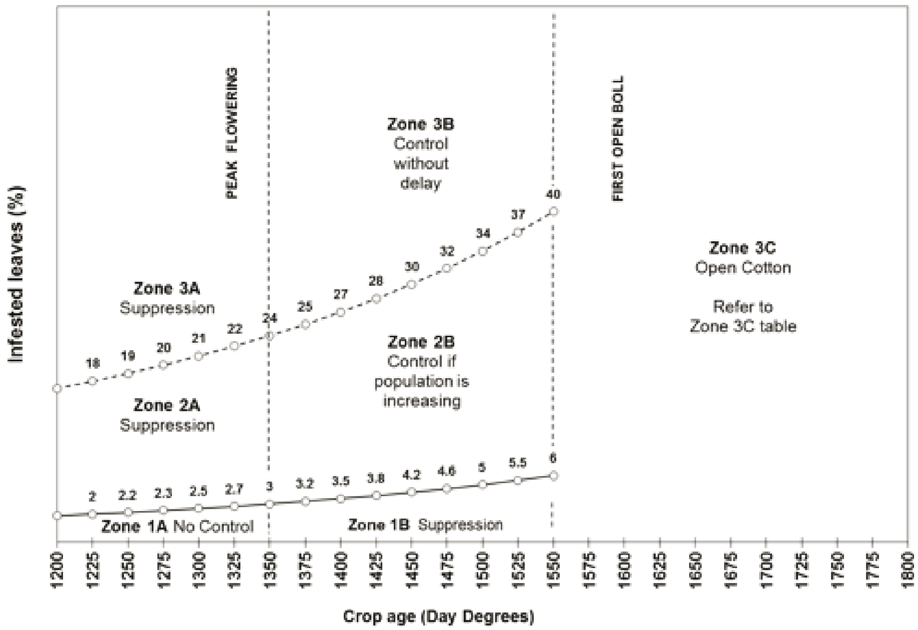
Natural enemies play a vital role in the successful management of whitefly. Minimise impact on these beneficials by using thresholds for all pests and consider the impact on beneficials when selecting an insecticide.

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

Time to defoliation (days)	Contamination level (visual diagnostic)	Adult population growth rate**	Action recommended
14 or less	No or light contamination	≤3% per 50 DD (every 3-4 days)	No action; continue monitoring.
		>3% per 50 DD (every 3-4 days)	Knockdown insecticide in first 7 days if % infested leaves ≥10% and/or large nymphs present on most lower canopy leaves and/or consider early defoliation; otherwise, no action and continue monitoring.
	Moderate contamination	≤3% per 50 DD (every 3-4 days)	Knockdown insecticide in first 7 days if % infested leaves ≥10% and/or large nymphs present on lower canopy leaves; otherwise, no action and consider early defoliation if contamination level increasing.
		>3% per 50 DD (every 3-4 days)	Knockdown insecticide in first 7 days; consider early defoliation.
15-21	No or light contamination	≤3% per 50 DD (every 3-4 days)	No action; continue monitoring.
		>3% per 50 DD (every 3-4 days)	Knockdown insecticide in first 7-14 days if % infested leaves ≥10% and/or large nymphs present on most lower canopy leaves; otherwise, no action and continue monitoring.
	Moderate contamination	≤3% per 50 DD (every 3-4 days)	Knockdown insecticide in first 7-14 days if % infested leaves ≥10% and/or large nymphs present on lower canopy leaves; otherwise, no action and consider early defoliation if contamination level increasing.
		>3% per 50 DD (every 3-4 days)	Knockdown insecticide in first 7 days and defoliate early if resurgence is evident.
>21	No or light contamination	≤3% per 50 DD (every 3-4 days)	No action; continue monitoring.
		>3% per 50 DD (every 3-4 days)	Use control/knockdown insecticide* in first 7 days if % infested leaves ≥10% and/or large nymphs present on most lower canopy leaves; otherwise, no action and continue monitoring.
	Moderate contamination	≤3% per 50 DD (every 3-4 days)	Use control/knockdown insecticide* in first 7 days if % infested leaves ≥10% and/or large nymphs present on lower canopy leaves; otherwise, no action and consider early defoliation if contamination level increasing.
		>3% per 50 DD (every 3-4 days)	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.
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 °C – 12) + (Min °C – 12)] ÷ 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 35) for management guidelines	Chemistry: Aim for selective/soft. • Oils. • Sero-X. • Cyantraniliprole (single application). • Afidopyropen (Versys Insecticide). • Spirotetramat (lower label rate).
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 Pyriproxyfen 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). • Cyantraniliprole (if used twice in succession within 10-15 days). • Spirotetramat (higher label rate).
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 35). • 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). • Cyantraniliprole (knockdown/control). • Spirotetramat (control). • Dinotefuran (high rate) (knockdown). • Acetamiprid/emamectin (knockdown). • Bifenthrin (pyrethroid) (knockdown).

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

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.

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 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.

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)

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.

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 11: Control of thrips

Active ingredient	Insecticide group	Overall impact on beneficials*	Comments#
Tobacco thrip (*Thrips tabaci*) and Tomato thrip (*Frankliniella schultzei*)			
Fipronil (high rate)	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**	Apply by ground rig or air. Do not harvest for 14 days after application. Maximum 2 applications per season.
Western flower thrip (*Frankliniella occidentalis*)			
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, lady beetles.

Selecting an insecticide

The insecticide products registered for the control of thrips in cotton in Australia are presented in Table 11, page 37. 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 2466 or 0427 992 466.

NSW DPI, Camden – Grant Herron: (02) 4640 6471.

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 tight lock 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.

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

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

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.

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

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
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 parasites 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.

TABLE 12: Control of green vegetable bug (*Nezara viridula*)

Active ingredient	Insecticide group	Overall impact on beneficials*	Comments#
Fipronil (high rate)	Group 2B	Moderate	Apply when pests appear. Use higher rate when higher infestations are present. Avoid repeated use of this insecticide group.
Emmamectin benzoate/Acetamiprid	Group 6/4A	Moderate	Apply at or just prior to hatching. Use non-ionic surfactant as per label. Maximum 2 applications per season.
Clothianidin (high rate)	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 (high rate)	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 stockfood for 14 days after application. 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.

Selecting an insecticide

The insecticide products registered for the control of GVBs in cotton in Australia are presented in Table 12. Mid-season use of dimethoate for GVB control should be carefully considered as this compound also selects for organophosphate/carbamate resistance in aphids.

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, Agriculture, Narrabri – Tanya Smith: (02) 6799 2465

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, 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.

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)

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 lambdacyhalothrin (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 may be incidentally controlled when carbamates such as carbaryl or organophosphates such as dimethoate are used. Any decision to use broad spectrum insecticides such as pyrethroids 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 Plant Industry, Narrabri
Simone Heimoana: (02) 6799 2466 or 0427 992 466

Solenopsis mealybug

Phenacoccus solenopsis

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

Mealybug predators cryptolaemus lady beetle larva (left) and lacewing lavae (right), can look very similar to mealybugs. (Zara Hall and Paul Grundy, Qld DAF)

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.

If mealybugs are found, contact:
Richard Sequeira (07) 4991 0810 to arrange identification and to help track distribution of the species.

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. Chemical control may be warranted in certain situation, Sulfoxaflor (Transform) can now be used under permit, e.g. early infestation with the potential for severe yield loss and/or plant death. However, there are currently no IPM-friendly insecticides registered for the control of mealybugs.

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.**

There are a number of management options that can reduce the size of infestations, and the overall impact of this pest. Minimise the build-up of mealybug in volunteers, ratoons and weeds, particularly in fallows where cotton will be planted. Ensure effective crop destruction and continue to monitor fields post cotton for potential hosts. Avoiding early season use of broad spectrum insecticides will help preserve natural enemies that may contribute to the control of mealybug infestations. Once mealybug are known to be in an area, consider increasing thresholds for other pests, and review all insecticides for their impact on mealybug predators prior to use. Once mealybug are detected in the field:

- Mark infested plants/spots;
- Monitor regularly for mealybug and key beneficials (lacewings, cryptolaemus and three banded lady beetles and aenasius parasitoid); and,
- Beneficials are highly effective in keeping mealybug population in check; chemical insecticides should be used for mealybug control as a last resort if beneficials are absent or at very low densities.

Check the APVMA website for other control options that may become available under permit or registration during the season – www.apvma.gov.au.

Key beneficial insects

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

Parasitic wasps – *Aenaisus bamabwalei*, 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 more 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.

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 (07) 4983 7410, Paul Grundy 0427 929 172.

Plague Locusts

Chortoicetes terminifera

Very rarely are plague locusts a problem for cotton, but large swarms of plague locusts during autumn can result in significant egg lays. Locusts are able to travel up to 500 km in a night on the winds so can be a threat even if not experienced locally in the previous season. Whilst cotton is not a preferred food source for locust there have been a number of instances in southern NSW where control has been required.

Threat of attack could be from bands of hatchlings for instance in adjacent areas or from swarms that fly in from elsewhere. Locusts can actually mow the cotton plants down and can cause significant damage especially when cotton is at the seedling stage.

Damage symptoms

Severe damage directly attributed to chewing.

This swarm of spur-throated locust were seen destroying leaves and branches on an established cotton crop. (S. Logan)

Sampling

An important aspect of responding to the threat of locust plagues is surveillance and monitoring. In NSW, land managers have a legal obligation to report the presence of locusts on their properties to their Local Land Services (LLS). In Queensland, landholders are asked to report the presence of locusts to Biosecurity Queensland (BQ), although there is no legal requirement. While high numbers will be seen very easily visually, it will pay to inspect the perimeters of fields to detect the occurrence of any banding of emerging locust as early as possible. These state authorities may also implement surveillance and monitoring programs to determine the extent of locust outbreaks in an area and evaluate the success of control methods.

Threshold

The threshold is based on plant damage. Locust can cause significant damage in a short period of time especially if the cotton is small.

Key beneficials

Birds do eat locusts yet there are no beneficials that could control the numbers present when swarming occurs.

Selecting an insecticide

In selecting control options it is essential to consider the risk of flaring secondary pests. Choosing an appropriate chemical that fits within the IRMS will be a challenge. As an occasional pest, there are few products registered for their control in cotton. Diazinon and chlorpyrifos are registered – check label for rates and further information. In some states free insecticide may be available for locust control in certain circumstances. In NSW, the LLS coordinate locust control activities. The primary aim of this service is to protect crops and pastures, but the circumstances in which free insecticide may be provided may not be consistent with what is required to protect cotton crops. In NSW, free insecticide will only be provided to LLS rate payers once locust nymphs have banded. BQ coordinates locust control in Qld, and undertake strategic aerial control of locusts where there is any threat of migration to/within the area where local governments make contribution to the Contingency Fund. BQ does not directly protect crops.

Further Information:

In NSW – contact your local land services www.lls.nsw.gov.au

In Qld – contact your local Biosecurity Officer 13 25 23

Australian Plague Locust Commission (APLC)
www.agriculture.gov.au/pests-diseases-weeds/locusts

www.daff.gov.au/animal-plant-health/locusts

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 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.

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)

2. Bury a dessertspoon full of the seed under 1 cm of soil at each corner of a 5x5 m square at five widely spaced sites per 100 ha.
3. Mark the position of the seed baits as high populations of soil insects can completely destroy the baits.
4. One day after seedling emergence, dig up the plants and count the insects.

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 grains stubble prior to planting cotton may increase the damage potential of black field earwig populations as it can cause them to switch feeding activity from stubble to seedlings. Wireworms are found under a range of cultivation and stubble retention regimes.

True and False Wireworms

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 and recently fields west of Moree and Dalby. However, whether crop damage is solely attributable to Symphyla or a broader complex of soil pests and disease is 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.

TABLE 13: Control of armyworm (Lesser) *Spodoptera exigua* and cutworm *Agrotis* spp.

Active ingredient	Insecticide group	Overall Impact on beneficials*	Comments#
Chlorpyrifos	Group 1B	**High**	Armyworm: When 'army' is moving treat broad strip over and in advance of the infestation. Use higher rate for larvae > 3 cm. Cutworm: Apply immediately infestation is observed. Apply in a minimum of 100 L of water. 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

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 careful 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 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.

TABLE 14: Control of wireworm (Wireworm *Apryprius 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. Use rates for row spacing of 1 m. Apply as band spray at least 10 cm wide into open furrow at sowing. 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. Rate is based on 1m furrows. 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. Rate is based on 1m furrows. 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.

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 (High rate)	Group 4A	Moderate	Apply when numbers reach threshold levels requiring treatment. Maximum 2 applications per season.
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 (High rate)	Group 1B	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. Rate is based on 1m furrows. 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 or 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 high rate for large larvae. Maximum 1 application per season.
Cypermethrin	Group 3A	Very high	Rates vary. See product label for specific rates. Use highest rate when canopy is dense. Effectiveness is lower for established and concealed infestations. 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	WA & 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 repeating as necessary. 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 Helicoverpa 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

Sandra Williams, CSIRO and CottonInfo

Acknowledgements: Lewis Wilson (CSIRO); Sally Ceeney (CottonInfo); Susan Maas (CRDC); Robert Mensah (NSW DPI); Jamie Hopkinson (Qld DAF); Sharna Holman (Qld DAF and Cottoninfo); adapted from early version by Tracey Leven, (formerly CRDC)

Introduction

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.

The key challenge is to prevent over-reliance on chemical control of pests that will lead to insecticide resistance and render insecticidal control options ineffective. Insecticide resistance can destroy an industry and the collapse in 1975 of the cotton industry in the Ord River Irrigation Area in Western Australia is testament to this. History has shown that reliance on a single pest control tactic will result in resistance problems, and the cotton industry in eastern Australia has been seriously challenged by insecticide resistance in its 50-year history.

What is IPM?

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.

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. Take a year round approach.
3. Think of the farm and surrounding vegetation as a whole system.
4. Have good on-farm hygiene.
5. Consider options to escape, avoid or reduce pests.
6. Sample crops effectively and regularly.
7. Aim to grow a healthy crop.
8. Evaluate pest abundance against established thresholds.
9. Choose insecticides wisely to conserve beneficials.
10. Apply good resistance management principles.

Developing an IPM strategy

As part of your plan to grow cotton, identify your in-crop risks and identify how different tactics will be applied in-crop for different pest scenarios. Identify what your overall IPM goals will be, some examples include:

- Start each cotton season with low/no pest populations.
- Avoid unnecessary insecticides especially early season.
- Follow the cotton industry's IRMS for all insecticides.
- Make non-crop areas more productive for beneficials.
- Avoid pest outbreaks that are generated within the farm.
- Minimise impact on bees and beneficials.
- Participate in Area Wide Management.

Communicate your IPM goals and planned tactics with your entire farming team, neighbouring farmers and beekeepers in the area.

As insecticides still play an important role in an IPM system, develop and implement a pesticide application management plan (PAMP), to minimise the risks associated with a pesticide application specific to your farm. A PAMP will help to establish good communication with everyone involved and interested in the application of pesticides, both pre-season, and during the season, as well as ensuring appropriate application techniques and procedures are used and that sufficient records are kept. For more information and assistance in developing a PAMP go to the *my*BMP website (www.mybmp.com.au).

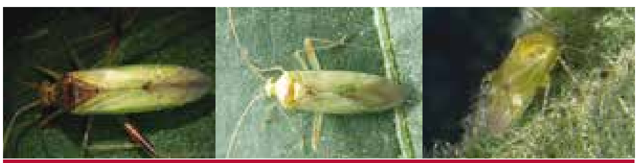
What can I do to avoid or suppress pests on my farm?

Upfront tactics

1. Know your enemy and your friends

'The enemy of your enemy is your friend!' Knowledge of pest species, and their damage, and beneficials and the pests they feed on is critical in evaluating the potential for economic loss.

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.



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)

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).

2. Take a year round approach

Seasonal conditions and farming practices during the winter months can have a big influence on summer pest populations. Divide the year up into logical phases and consider what actions could be taken in each phase to reduce overall risk, refer to the IPM calendar page 6.

Take into account factors such as;

- Crop history – for some pests if a field had a problem with that pest last year it may be more prone to the same pest next year (mites are an example).
- Crop sequences – can encourage build up and movement of the same pest between crops (e.g. late soybeans will inherit silverleaf whitefly populations from nearby maturing cotton).
- Management of weeds in fallows and crops.

Seasonal conditions are a major driver of outbreaks of pests. For example, a wet winter and spring will increase the risk of a number of key cotton pests because they are able to survive on hosts (often weeds) that grow on the unseasonal rainfall. Conversely, a wet summer in southern regions of Australia may promote the likelihood of winter pest outbreaks. Being aware of how the conditions may influence pest pressure will help assess the risk of pest outbreak.

3. Think of the farm and surrounding vegetation as a whole system

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.

Consider this situation – if you were to spray all of the fields on your property at once with a disruptive insecticide there will be a large decline in the abundance of predators and parasites in those fields. This places those fields at risk because other secondary pests not controlled by the insecticide may then increase without being controlled by beneficials. Also pests which enter the crop after a disruptive insecticide application will survive better and potentially cause more economic damage. If beneficials are disrupted, where will new beneficials come from to re-establish in the crop?

One source of beneficials could be unsprayed crops on the farm or nearby farms – reinforcing the notion that it is only sensible to control pests in the fields where they warrant control. This 'site-specific' management means unsprayed fields will harbour beneficials and are a source of beneficials to re-colonise sprayed fields. To build beneficials across the farm, apply IPM principles to manage all crops, not just cotton.

Another source of beneficials is native vegetation both on farms and in the region. When it comes to pest management, *'Veg is Valuable'* is an important source of beneficials (including birds and bats). This is especially so because these areas are permanent and usually complex, with a range of species and layers, and so provide continuous prey as well as habitat for beneficials year round, whereas cropped fields may be fallow for long periods. When looking to enhance IPM value of areas of vegetation consider the following:

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

- Managing for groundcover and diversity.
- Prioritise connectivity.
- Enhance habitat with water ways.
- Control pest hosts, especially volunteer cotton.

The Cotton Pest and Beneficial Guide and the Australian Cotton Production Manual provide more information on enhancing natural assets to improve IPM values.

Area Wide Management (AWM) acknowledges that insects are mobile and that the management regimes used on one farm can have implications for the surrounding locality. Sharing your strategies and coordinating tactics with neighbouring cotton growers, other farmers as well as any local beekeepers, will increase the success in implementing IPM. These may include weed management, conserving beneficials, delaying use of disruptive insecticides, reducing the risk of drift between farms, shared adherence to IRMS, planting windows, maintenance or enhancement of local native vegetation areas and the planting of trap crops. A key element of most groups that have worked well has been regular meetings before and during the season to share information, discuss strategies and build rapport.

4. Have good on-farm hygiene

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 which can cause significant loss of yield. 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 12-45 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 81-84 for more information.

5. Consider options to escape, avoid or reduce pests

Pre-season planning to reduce pest risks can help to identify upfront opportunities to suppress or avoid the incidence of pests throughout the season.

Field selection

Consider proximity to other host crops, as well as sensitive areas such as watercourses, pastures and buildings, relative to the prevailing wind direction. For example, cotton planted near a canola crop can incur damage if extremely large populations of Rutherglen bugs are present in the canola. Once the canola stubbles dry down, the Rutherglen bugs will move into neighbouring cotton crops. The heavy and continuous feeding that occurs in these situations can result in cotton seedling death. Growing Bt crops maybe most appropriate for fields adjacent to sensitive areas. Conventional cotton may benefit from being embedded amongst Bt cotton and rotation crops. In this situation pest loads are diluted across all the crop area. The conventional crops may gain some protection by Bt crops intercepting some of the Helicoverpa population, and surrounding 'low spray' Bt crops can act as sources for the re-entry of beneficials into conventional crops if sprays are required. Bt crops adjacent to conventional cotton crops may also suffer boll damage from large Helicoverpa larvae (4-6 instar) unaffected by Bt toxin, migrating from conventional crops. Conventional crops (particularly unsprayed refuge) and Bt crops should be separated by at least a 20 m buffer or should not be planted side by side on the same field.

As part of field selection, stubble loads and soil pest activity should be monitored in the lead up to planting. There are no insecticidal control options for symphyla or nematodes – field selection is an important component of managing the rare but serious risks associated with these pests. Refer to page 43 for more information about soil-dwelling pests.

Also worthy of consideration is whether the intended location of cotton fields creates 'stepping stone' linkages between areas of crops and vegetation to enable movement of beneficials through the landscape.

Varietal selection

Select a variety that suits the growing region in terms of season length.

Bt cotton is ideally suited to IPM as the level of control of Helicoverpa provided by the plant reduces the need to spray for those pests. This in turn increases beneficial numbers, which naturally suppresses populations of other pests.

Seed treatment

Seed treatments provide prophylactic protection against early season/establishment pests. In general they are less disruptive to beneficial populations than spraying the crops with a foliar insecticide because most options available are not very selective. Prior to using a seed treatment, refer to the current Insecticide Resistance Management Strategy (IRMS) for your region for more information on insecticide use when seed treatments are used.

Seed bed preparation and strategic planting time

Vigorous, healthy, early growth enables crops to recover from what can at the time appear to be significant early season damage from soil-dwelling pests such as wireworm, cutworm and symphyla as well as plant pests such as thrips. Planting during optimal temperatures for germination, contributes to this early vigour and can reduce the need for prophylactic insecticidal seed treatments, as well as improve tolerance towards seedling disease and herbicides.

Very late planted crops which have delayed maturity can be susceptible to influxes of pests such as whitefly at the end of the season. See page 34 for further information on late season whitefly control.

Create a diversion

Summer trap cropping aims to concentrate a pest population into smaller less valuable areas by providing the pest with a host crop that is more preferred and attractive than the crop you are aiming to protect, for example lucerne can be used as an effective trap crop for mirids. In Central Queensland, pigeon pea is used as a summer trap crop as part of the RMP for Bt cotton.

Spring trap cropping with chickpeas is designed to attract *H.armigera* adults as they emerge and reduce the first generation through strategic crop destruction. It is important to ensure that the chickpea crop does not become a nursery for multiple generations of moths.

Spring trap cropping is a more important tactic in a non Bt cotton system.

Pupae busting

In NSW and Southern Qld, cultivation of cotton fields through winter, kills diapausing *H.armigera* pupae in the soil, and has proven to assist in the management of resistance. In some situations pupae busting is mandatory following harvest of Bt cotton (page 76) and is recommended by the industry's IRMS for all cotton (page 63).

Build bigger populations of beneficials

Careful farm management and planning can enhance beneficial populations and increase their contribution to controlling pests. The abundance of beneficials in a cotton crop is affected by food resources, mating partners, proximity to other sources of habitat, climatic conditions and insecticide sprays. In addition to enhancing opportunities to build beneficials in nearby habitat, such as rotation crops and perennial vegetation, tactics to attract and build beneficials early in the crop should be considered.

The application of food sprays in cotton crops attracts and retains beneficial insects. There is currently only one type of food spray commercially available for use in cotton. Predfeed is a yeast based food spray that attracts beneficial insects and should be applied when a cotton field does not have enough beneficial insects.

What can I do to manage pests in my crops?

Active tactics

6. Sample crops effectively and regularly

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

TABLE 18: Food sprays and spray additives

Active ingredient	Formulation	Application rate of product	Trade name	Marketed by	Comments
Food concentrate (yeast based)	WP	2.5 kg/ha	Predfeed	Growth Agriculture	Beneficial insect attractant. Apply prior to increase of pests. See label for notes on spray coverage.

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 12-46) 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.

How to sample for pests and beneficials

There is a range of sampling techniques available. Make sure you familiarise yourself with these techniques and use those that are appropriate for the pests, beneficials and threshold.

Visual sampling: This involves looking at the entire plant, including under leaves, along stems, in squares and around flowers and bolls. Check at least 30 plants or 3 to 4 separate metres of cotton per 50 ha.

Beat sheet sampling: A sheet of yellow canvas 1.5 m × 2 m in size is placed in the furrow and extended up and over the adjacent row of cotton. A metre stick is used to beat the plants 10 times against the beat sheet, moving from the base to the tops of the plants. Insects are dislodged from the plants onto the canvas and are quickly recorded. Preliminary studies indicate that at least 8-10 metres are required per field (~50 ha).

D-vac sampling is more common as a research tool, however, can be used as an additional method when sampling beneficial insects and spiders.

Sweep net sampling: This method can be used as an alternative to the beat sheet when the field is wet. Sweep netting is an effective method for sampling flighty insects such as mirid adults, and each sample consists of 20 sweeps along a single row of cotton using a standard (380 mm) sweep net. Studies indicate that at least 6 sweep net samples are required per field (~50 ha).

DECISION MAKING PROTOCOL (beneficial to pest ratios)		
Conventional cotton		
Ratio	**Helicoverpa**	**Action**
> 0.5	< 2	Do nothing.
0.4-0.5	< threshold (mostly eggs)	Yeast based food spray might be applied.
0.4-0.5	< threshold (mostly larvae)	Sugar based food spray and biological insecticide or petroleum spray oil (PSO)
< 0.4	> threshold	Selective insecticide.
Bt cotton		
The beneficial to pest threshold is essentially the same as above with a slight addition. If in the next check after a food, PSO or biological spray, Helicoverpa neonate numbers are above threshold, mix PSO with soft chemical and apply to crop		
Ratio	**Helicoverpa**	**Action**
Increasing	≥ threshold	Repeat food/biological spray mixture
No change or 0.42-0.45	≥ threshold	Selective pesticide (possibly mix with PSO)
0.4	> threshold	Selective insecticide (possibly mix with PSO)
For more information on the use of PSOs see the Research Review 'Use of Petroleum Spray Oils to Manage Cotton Pests in IPM Programs' available from www.myBMP.com.au		

Sampling specific pests: Aphids, spider mites and whitefly have specialised sampling methods. See their relevant pest section to find out more.

Fields are rarely uniform in crop growth and attractiveness to insects. For example mealybugs are more likely to build up in areas of plant stress, such as water-logged tail drains, while other pests may be more likely to lay eggs in areas of lush growth. Awareness of such areas and their size helps you to determine how many sample points are required in a crop.

Note: Increasing the number of samples will increase the level of accuracy.

Monitoring predators and levels of parasitism provides useful detail for IPM decision making. Where high levels of beneficials are recorded, this can provide confidence in delaying an insecticide. Refer to Table 19 'Friends in the field' for which beneficials target what prey.

Insect numbers should be recorded either as numbers per metre or as a percentage of plants infested, to easily compare numbers with the appropriate industry threshold and to allow a beneficial to pest ratio to be determined.

Guidelines for the beneficial to pest ratio

Beneficial to pest ratio for sucking pests has not been determined. However, the ratio for Helicoverpa has been determined and given below for both 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:

The beneficial to pest ratio is calculated as –

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

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 sufficient time to be found by *Trichogramma* spp.

TABLE 19: 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.
Lady beetles		X	X	X	X		X	X	Lady 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								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.

7. Understand how your crop is progressing

It is important to include an assessment of crop health and development as well as damage when making pest management decisions because insect numbers alone may not give an accurate indication of the need for control.

It is important to understand how cotton develops and grows to ensure that the crops needs are met. Growing a healthy cotton crop optimises its yield potential, fibre quality and capacity to compensate for pest damage. While yield (and quality) potential will largely be determined by a range of factors, IPM provides a strategy to help manage the risk of economic losses due to pests, in the current season, as well as future crops. For more information on the physiology of the cotton plant, refer to the Australian Cotton Production Manual.

Monitoring crop as well as insects

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.

What to monitor?

Leaf damage

Research on seedling cotton (up to 6 nodes) has found that loss of leaf area did affect maturity, but only treatments with more than 80% loss of leaf area were affected.

Tip damage

Tip damage caused by thrips appears as extensive crumpling and blackening of the edges of the small leaves within the terminal. If only the terminal is blackened, damage could be considered light. If the terminal plus one or more true leaves are blackened, damage could be considered heavy. Tip damage caused by Helicoverpa larvae in conventional cotton is more evident as the terminal will normally be completely destroyed. In many cases, the secondary terminal will also be damaged or destroyed. Tip damage caused by the cotton tipworm in conventional cotton is also obvious as larvae will often be still entrenched or burrowed into the terminal.

Development of squaring nodes

For most Australian cotton varieties it is expected that the first fruiting branch will develop on about the seventh mainstem node. On a well grown crop, by the time of first flower (~750 DD) there will be about 8 squaring nodes. Fewer than 8 will often reduce yield potential. Measuring squaring nodes can provide early indication of stress in time for remedial action. Once flowering commences it may be too late to recover.

Fruit development

It is important to ensure that crop growth translates into fruit production at a rate that will help to attain a profitable yield. The rate of fruit production can be calculated from weekly square and boll numbers per metre. The same metre of row can be monitored throughout the season.

Nodes above white flower (NAWF)

At the time of first flower, there should be about 8 nodes above the first position white flower, or 8 NAWF. The bolls produced on these fruiting branches will contribute a large proportion of final yield. Once boll set commences and the crop is allocating resources to the developing fruit, the rate at which the crop can produce more squaring nodes is in decline.

Once there are 4 or fewer NAWF, the crop is said to be 'cut-out'. This signifies that the crop has ceased putting resources into further vegetative growth and that yield potential is dependent on the retention of fruit already produced.

Vegetative Growth Rate (VGR)

VGR is the industry recommended approach for identifying excessive growth. The VGR tracks the rate of change in plant height relative to the rate of node development.

VGR is calculated using the following equation:

$$\text{VGR (cm/node)} = \frac{\text{This week's height (cm)} - \text{Last week's height (cm)}}{\text{This week's node number} - \text{Last week's node number}}$$

Measurements of height and nodes should start as the crop approaches first flower and continue whilst squaring nodes are being produced. In making a decision as to whether Mepiquat Chloride can help, it is important to consider causes behind any excessive growth.

Refer to the Australian Cotton Production Manual for more information.

First position fruit retention

Monitoring first position fruit retention is a technique that is best used from squaring to early flowering. It is a quick and effective way to estimate early signs of pest damage.

Percentage of first position fruit retention =

$$\frac{\text{Count first position fruit (either top five or all fruiting branches)}}{\text{Count total fruiting branches}}$$

Monitor both tipped and non-tipped plants using the dominant stem, not vegetative branches.

Aim to have first position fruit retention of 50-60% by first flower. Low retention (<50%) increases the risk that yield or crop maturity will be affected. However, very high fruit retention, in excess of 80% may also be associated with premature crop cut-out. For the first five fruiting branches on the plant, first position fruit retention can be as low as 30% without affecting yield or maturity, however such levels should trigger close monitoring and a reduction in thresholds. Refer to Figure 1 right.

Final retention at maturity

Boll numbers will vary according to variety, stage of growth and yield potential. At the end of the season a crop will hold less than 50% of all possible fruiting sites. First position retention will vary from 50-70%. Cotton variety and boll size will also affect final yield.

Fruiting factor

Fruiting factors allow total fruit load to be monitored throughout the season. Fruiting factors should be used when first position retention falls below recommended levels (ie. 50-60%), to ensure excessive fruit loss has not occurred or in situations where a crop is heavily tipped out and retention is difficult to determine.

From 10-14 days after flowering, the monitoring of first position fruit retention may be less relevant than fruit counts. The fruiting factor technique allows a rapid interpretation of the fruit counts. The technique considers both fruit present and the number of fruiting branches (potential fruit development).

To save time in monitoring the fruiting factor, only count first and second position fruit (squares and bolls), from the main stem and the first dominant vegetative branch. In irrigated crops this should account for 90% of the fruit that will be picked.

To determine the fruiting factor for a crop, simply divide the fruit count by the number of fruiting branches.

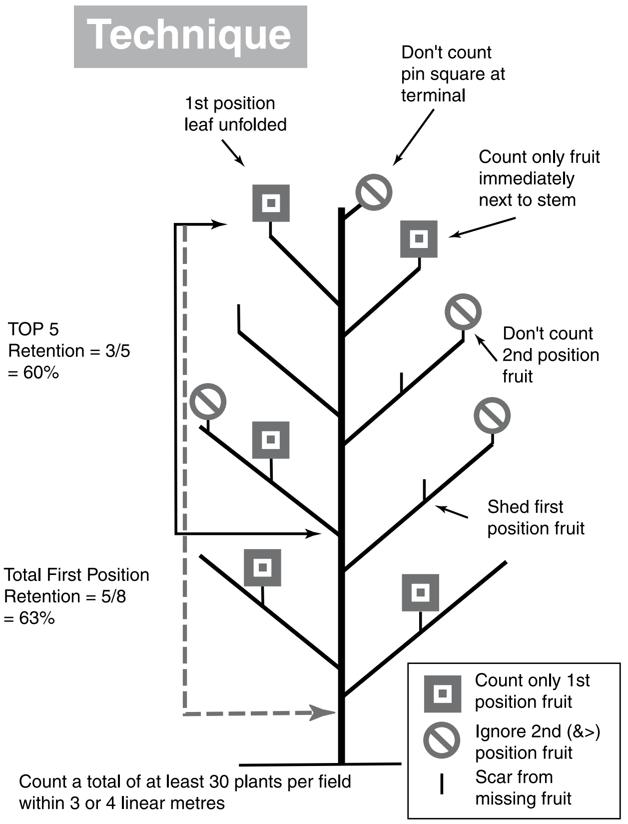
$$\text{Fruiting factor} = \frac{\text{Total fruit/m}}{\text{Total number of fruiting branches/m}}$$

The ideal fruiting factor will increase throughout flowering as the plants produce a large number of squares. As the crop matures and concentrates on maturing the set fruit, the fruiting factor naturally declines.

Eventually, at maturity the fruiting factor approaches 1.0, which represents the natural maximum fruiting load that plants can carry through to yield.

A key period for measuring fruiting factors is at around early flowering. Values between 1.1 and 1.3 will provide optimum yield potential. Values less than 0.8 or greater than 1.5 can reduce yield.

FIGURE 1: A technique for checking fruit retention



GUIDE TO USING FRUITING FACTORS THROUGHOUT THE SEASON	
Stage of growth	**Fruiting factor**
Pre flowering	0.8-1.0
Flowering	1.1-1.3
Peak Flowering	1.3-1.4
Boll maturity	1.0

GUIDE TO USING FRUITING FACTORS AT FIRST FLOWER	
Fruiting factor at first flower	**Impact on yield and maturity**
< 0.8	High risk of yield decline and maturity delay (particularly in cooler regions)
1.1-1.3	Optimum for yield
> 1.5	Risk of premature cut-out and yield decline.

8. Evaluate pest abundance against established thresholds

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 usually derived from experiments where pest densities are manipulated so that the relationship between pest abundance or amount of damage and yield can be established. Once this is known it is possible to determine 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 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 (perhaps due to an earlier spray) then immediate control with an insecticide may be the best option. Refer to the 'beneficial to pest ratio' on page 52 to assist these decisions by indicating a ratio above which the pest is likely to be effectively controlled by the beneficial population.

Ensure that the threshold used is appropriate for the crop stage, sampling method and region. For example the mirid threshold accounts for the reduced ability to compensate for damage in cool regions, variation in yield loss due to crop stage and differences in effectiveness of different sampling techniques. The mirid threshold also provides crop damage levels that need to be considered in conjunction with pest and 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, so consideration of the forecast conditions should be part of the decision. 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.

9. 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, use the most selective effective insecticide (soft on beneficial insects), adhere to the IRMS and consider a reduced rate mixed with either salt or spray oils.

Selecting an insecticide

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 ('broadspectrum' 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 63-66).

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 newer neonicotinoid product, clothianidin (tradename Shield), will reduce populations of lady 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 lady 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 147 for more information on how to manage the risk to bees.

It is also very important to note that the data supporting Table 3 (pages10-11) on product disruptiveness is based on results after a single application. Multiple applications of a product with a low rank can be as disruptive as applying a product with a high rank.

Consider alternatives

Consider the use of reduced rates of synthetic insecticides mixed with either salt or petroleum spray oils. In some instances this will provide greater selectivity and better efficacy.

The use of biopesticides such as NPV (Gemstar, Helicovex, Heliocide and Vivusmax) foliar Bt, petroleum spray oils (PSOs) or semiochemicals, such as Sero-X for a range of pests or the Helicoverpa moth attractant Magnet can help to conserve beneficial insects, minimise insecticide use and make it less likely to flare other pests.

Late season pest problems can sometimes be avoided by a successful defoliation. The silverleaf whitefly matrix illustrates that control of whitefly to protect crop yield and quality is required between peak flowering and 60% open bolls. As the crop approaches the point where it can be defoliated, the reliance on insectide intervention declines.

Application

Ensure spray applications are accurate, timely and triggered by pest thresholds. Always follow label directions. Understanding how different insecticides work can help when considering how efficacious they will be in a given situation. For example, 'contact' insecticides must be absorbed by the pest, and so application method (e.g. nozzle selection, higher water rates and use of ground rig) may improve impact on the pest. Systemic pesticides can be moved (translocated) throughout the plant where they kill chewing or sucking insects.

Some insecticides only target particular stages of a pest lifecycle. For example, the insect growth regulator, pryiproxifen, does not kill adult silverleaf whitefly, however it prevents egg hatching and progression from larval to adult stage, as well as sterilising of adult female insects. As this means it takes a while for the population to decline (maybe 10-14 days) before long term effective control of all life stages is achieved, this should be factored in, both in terms of managing honey dew risk from silverleaf whitefly, as well as assessing spray efficacy and defoliation decisions.

Pests such as aphids and mites often infest the edges of a field, not the entire field area. Consider whether it is possible to manage this type of infestation by only spraying the field borders. This may enable beneficial populations to keep pace with the remainder of the pest population in the field.

10. Apply good resistance management principles

Resistance management strategies and IPM strategies are complimentary. IPM aims to support resistance management by reducing the need to spray. Similarly, resistance management supports IPM by ensuring that the key insecticides as well as traits that are needed, to control pests remain effective.

In cotton, where insecticide resistance has been a major problem there are well defined industry sanctioned Insecticide Resistance Management Strategies (IRMS) (pages 63-66). Responsible stewardship of Bt cotton is also important. Refer to the Resistance Management Plan (pages 67-77).

Insecticide Resistance Management Strategy (IRMS) for 2018–19

Sally Ceeney, CottonInfo

Acknowledgements: Nicola Cottee (formerly Cotton Australia); 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 75-77). 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 36).

Checklist

- Use recommended thresholds for all pests to minimise insecticide use and reduce resistance selection. Refer to pages 12-46.
- Monitor first position fruit retention at flowering and aim to retain at around 60% or alternatively maintain a fruiting factor of between 1.1 and 1.3. Refer to IPM section page 47.
- 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 63-66).
- 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 omethoate or dimethoate. When targeting mirids, it is particularly important to avoid early season dimethoate/omethoate 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). In Bollgard 3 cotton fields, cultivation must be completed before the end of July.
- 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 2018–19 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 Emamectin (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 66. 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.

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/omethoate for the control of mirids can inadvertently select for both dimethoate/omethoate 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.

Does the IRMS seek to manage resistance in 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 36, for additional industry recommendations on the best way to utilise the available products with the lowest risk of developing resistance.

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 47 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.

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 omethoate/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 (ie. 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 organophoshates (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/omethoate during which other chemistries should be used. The use of alternative chemistries should minimise the number of pirimicarb resistant aphids being exposed to dimethoate/omethoate.

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 ie. 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 TIMS Troubleshooting Committee (TTC) was established by TIMS 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 TIMS Committee.

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

The TIMS 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 TIMS 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.

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, Grant Herron (02) 4640 6471 and Lisa Bird (02) 6763 1128**
- **For whitefly, Jamie Hopkinson (07) 4688 1152.**

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 2018–19

Name	Telephone	Email
Lisa Bird, NSW DPI (Chair person)	0438 623 906	lisa.bird@dpi.nsw.gov.au
Sally Ceeney, CottonInfo	0459 189 771	sally@ceenag.com.au
Policy Officer R&D and Stewardship, Cotton Australia	(02) 9669 5222	
Jamie Hopkinson, QDAF	(07) 4688 1152	Jamie.Hopkinson@daf.qld.gov.au
Simone Heimoana	(02) 6799 2466	Simone.Heimoana@csiro.au

Insecticide Resistance Management Strategy 2018/19

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 (Gemstar, Vivus)				
Pirimicarb Group 1A				Note 1
Paraffinic Oil (Canopy, Biopest)				
	Pyriproxyfen - Regional 30 day window Group 7C		Use an alternative from open cotton	Note 3, 9
Sero-X				
Etoxazole (Paramite)				
GROUP 28: Max 4/season	**Chlorantraniliprole (Altacor)** Group 28			Note 3
	Cyantraniliprole (Exirel) Group 28			Note 3
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				Note 3
Sulfoxaflor (Transform) Group 4C				Note 2
Flonicamid (MainMan) Group 29				
Abamectin Group 6			Group 6: Max. 3/season	Note 8
Emamectin Group 6				
start date = squaring **Propargite** Group 12C				
Amitraz Group 19				
Fipronil Group 2B				Residual bee risk
Neonicotinoids (clothianidin, dinotefuran, imidacloprid, thiamethoxam) Group 4A				Note 2, 4
	Chlorantraniliprole +Thiamethoxam (Voliam Flexi) Group 4A + Group 28			Consider risk to each group
Acetamiprid + Emamectin (Skope) Group 4A + Group 6				Consider risk to each group
Phorate Note 1		**Carbamates (methomyl, thiodicarb)** Group 1A		Note 5
		Dimethoate Group 1B		Note 1
		OPs (chlorpyrifos, methidathion) Group 1B		
		Synthetic Pyrethroids (bifenthrin) Group 3A		Note 3, 7

Feb-01

Light green	Avoid repeated use of same group
Teal	No more than 1 application
Light blue	No more than 2 applications
Purple	No more than 3 applications
Magenta	No more than 4 applications

Note 1: If a phorate side dressing is used at planting then do not use a pirimicarb or dimethoate first foliar spray as there is cross resistance between them all. Dimethoate/omethoate use will select catastrophic pirimicarb resistance in aphids so do not use pirimicarb and dimethoate/omethoate 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 2018/19 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 then the end of August to reduce resistance risk.

Note 7: High resistance is present in *Helicoverpa armigera* popluations. 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 (available at www.cottoninfo.com.au/stewardship and www.cottonaustralia.com.au/cotton-growers/resources/resistance-management-plans). Limit pyriproxyfen use to no more than 1 application per season.

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 2018/19

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	
	15-Nov	15-Dec	15-Jan	

Product	Group	Window / comment	Note
Helicoverpa viruses (Gemstar, Vivus)		Stage 1 – Stage 4	
Pirimicarb	Group 1A	Stage 1 – Stage 4	Note 1
Paraffinic Oil (Canopy, Biopest)		Stage 1 – Stage 4	
Pyriproxyfen	Group 7C	Stage 2 – Stage 4; Use an alternative from open cotton	Note 3, 9.
Sero-x		Stage 1 – Stage 4	
Etoxazole (Paramite)		Stage 1 – Stage 4	
Chlorantraniliprole (Altacor)	Group 28	Stage 2 – Stage 4 (GROUP 28: Max 4/season)	
Cyantraniliprole (Exirel)	Group 28	Stage 2 – Stage 4 (GROUP 28: Max 4/season)	
Afidopyropen (Versys)	Group 9D	Stage 1 – Stage 4	
Diafenthiuron	Group 12A	start date = canopy closure	Note 3
Pymetrozine (Chess)	Group 9B	Stage 1 – Stage 2	
Indoxacarb	Group 22A	Stage 1 – Dec-31	
Spinetoram (Success Neo)	Group 5	Stage 1 – Stage 4	
Spirotetramat (Movento)	Group 23	Stage 1 – Stage 4	Note 3
Sulfoxaflor (Transform)	Group 4C	Stage 1 – Stage 4	Note 2
Flonicamid (MainMan)	Group 29	Stage 1 – Stage 4	
Abamectin	Group 6	Stage 1 – Stage 2; Stage 4: Group 6: Maximum of 3 / season	Note 8
Emamectin	Group 6	Stage 1 – Stage 4	
Propargite	Group 12C	start date = squaring	
Amitraz	Group 19	Stage 1 – Stage 4	
Fipronil	Group 2B	Stage 1 – Stage 4	Residual bee risk
Neonicotinoids (clothianidin, dinotefuran, imidacloprid, thiamethoxam)	Group 4A	Stage 1 – Stage 4	Note 2, 4
Chlorantraniliprole +Thiamethoxam (Voliam Flexi2)	Group 4A + Group 28	Stage 2 – Stage 4	Consider risk to each group
Acetamiprid + Emamectin (Skope)	Group 4A + Group 6	Stage 1 – Stage 4	Consider risk to each group
Phorate		Stage 1 (at planting); Note 1	
Carbamates (methomyl, thiodicarb)	Group 1A	from Feb-01	Note 5
Dimethoate	Group 1B	from Feb-01	Note 1
OPs (chlorpyrifos, methidathion)	Group 1B	from Feb-01	
Synthetic Pyrethroids (bifenthrin)	Group 3A	from Feb-01	Note 3, 7

Light green	Avoid repeated use of same group
Teal	No more than 1 application
Light blue	No more than 2 applications
Purple	No more than 3 applications
Pink	No more than 4 applications

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

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

Note 3: Cross check with Silverleaf Whitefly Threshold Matrix in the 2018/19 Cotton Pest Management Guide.

Note 4: Imidacloprid (neonicitinoid) resistance in cotton seedling thrips is likely. If resistance is suspected, phorate is an appropriate at planting alternative. Consider non neonicitinoid 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 then the end of August to reduce resistance risk.

Note 7: High resistance is present in *Helicoverpa armigera* popluations. 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 Central Queensland despite a long history of use. As such a regional window is not required at this stage, however the SLW risk associated with the wide planting period should be managed through the continued adoption of IPM and limiting pyriproxyfen use to no more than 1 application per season.

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 2018–19 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/

Key Changes for the 2018–19 cotton season

- **Inclusion of Afidopyropen (Versys).** Versys is a new insecticide group, 9D, for the control of cotton aphid (low rate) and suppression of SLW (high rate).
- **Inclusion of resistance warning for Imidacloprid.** Imidacloprid (neonicotinoid) resistance in cotton seedling thrips is likely. If resistance is suspected phorate is an appropriate at planting alternative. When considering your first foliar spray use a non neonicotinoid alternate.
- **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.

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 20: Insecticide groups with resistance rating

Active ingredient (proprietary trade names)	Insecticide group	Chemical group	Resistance rating
Helicoverpa viruses (Gemstar, Vivus)	Not a member of a group	Nuclear polyhedrosis virus	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 *Bacillus thuringiensis* (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
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, CottonInfo

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

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 II cotton contains both Cry1Ac and Cry2Ab. For *H.armigera* and *H.punctigera* the assumed baseline frequency of Cry2Ab resistance genes in populations was substantially higher than expected. Bollgard II cotton is only available in limited quantities in 2018–19 and will be fully replaced by Bollgard 3 in 2019-20. Bollgard 3 is based on the existing platform of Bollgard II with the addition of a third gene, Vip3a. 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.

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.

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.

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

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; Monsanto Australia 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 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 detected so far are of the same kind. These protocols were immediately adopted by Monsanto. 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.

From 2002 to 2012 CSIRO continued to perform tests which showed that all newly isolated resistances to Cry2Ab were the same type that was initially identified. Similarly, work on Vip3A from 2009 to 2012 showed that all newly isolated resistances were the same type that was initially identified. In 2013 CSIRO 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 and Monsanto will incorporate F2 screens into the program to check for any new recessive forms of resistance.

The data in the following sections is sourced from Monsanto's annual program and the industry funded CSIRO program. There is currently no field level resistance to any of the proteins in Bollgard 3 for either *H.armigera* or *H.punctigera*. The following sections refer to the status/frequency of 'field level' resistance alleles/genes found in the population of both species.

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 (ie. 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, which is higher than for F2 screens. The frequencies obtained from the F1 screens are likely to most accurately reflect the situation in the field.

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. As with *H.armigera*, the Cry2Ab resistance frequency in *H.punctigera* for F1 screens is higher than that determined with the F2 tests. 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*?

CSIRO F2 data for *H.armigera* from 2002 to 2012 (the most recent sampling year) suggest a gradual increase in frequency of Cry2Ab resistance genes. The frequency obtained for 2010–11 was significantly greater than for previous years, but did not continue to increase until 2012. Monsanto began collecting F2 screen data for *H.armigera* in 2003–04 and since then there has been no significant change in frequency of Cry2Ab resistance genes over time with an average of 1 in 250 (0.004 or 0.4%).

Since 2004–05 Monsanto has used the F1 protocol developed by CSIRO to screen for resistance to Cry2Ab. CSIRO also has F1 screen data for *H.armigera* since 2007–08. Both 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*?

At the end of 2008-09 the F2 and F1 data sets from CSIRO demonstrated significant increases in the frequency of Cry2Ab resistance genes in field populations of *H.punctigera*. CSIRO began collecting F2 screen data for *H.punctigera* in 2002–03 and afterwards there was a gradual increase in resistance frequencies over time which became statistically significant in 2007–08 and remained highly significant in 2008-09. After declining in 2009–10, resistance frequency increased again in 2011–12 to the highest recorded level (2 in 100, 0.02 or 2%) before declining to 1 in 100 (0.01, 1%) in 2012–13. The complete data set demonstrates a gradual increase in frequency over time.

Monsanto began F2 screens with *H.punctigera* in 2007–08 and in 2010–11 detected a Cry2Ab resistance frequency that was significantly higher than in previous years. However, this may have been an overestimate in frequency as all positives were from one larval collection. The Cry2Ab resistance frequency is at a similar level to that recorded in 2008- 09 (1 in 185, 0.005 or 0.5%). If the probable overestimation in frequency in 2010–11 is taken into account there has been no significant change in the Cry2Ab resistance frequency over time.

The 2008-09 CSIRO F1 data set for *H.punctigera* demonstrated a 5-fold increase in frequency compared to 2007–08 (from 1 in 100 to 5 in 100 or 0.01 to 0.05). The frequencies obtained from 2009–10 until 2014–15 were lower than those detected in 2008-09 and most recently have declined to the levels first detected in 2007–08. Monsanto began F1 screens for *H.punctigera* in 2009–10 and have recorded no change in frequency of Cry2Ab resistance genes over time with an average of 1 in 100 (0.01 or 1%).

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*?

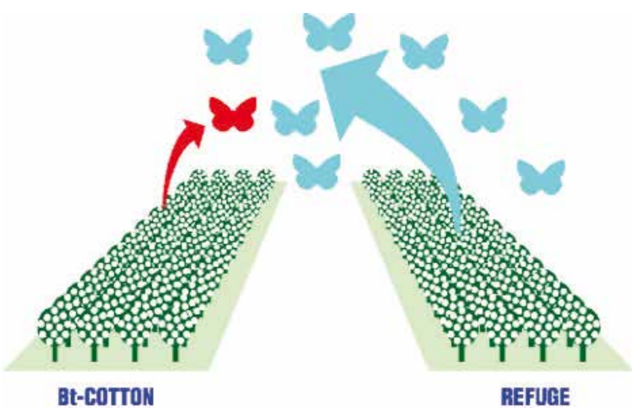
Monitoring for resistance to the Vip3A protein has revealed that resistance genes for this protein already exist in *H.punctigera* and *H.armigera*. Data obtained by CSIRO suggest that the frequency of Vip3A resistance genes in *H.punctigera* is around 1 in 100 (0.01, 1%). This estimate is based on F2 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 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 1 in 100 (0.01 or 1%).

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, Monsanto and the TIMS Bt Technical Panel will continue to work together to annually assess new information on resistance frequencies in Helicoverpa 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.



Moths produced from refuges dilute resistance genes in the population.

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. 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 Bollgard II 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 78.

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. Monsanto 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.

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 *H.armigera* 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 *H.armigera* 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 *H.armigera* 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 60).

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

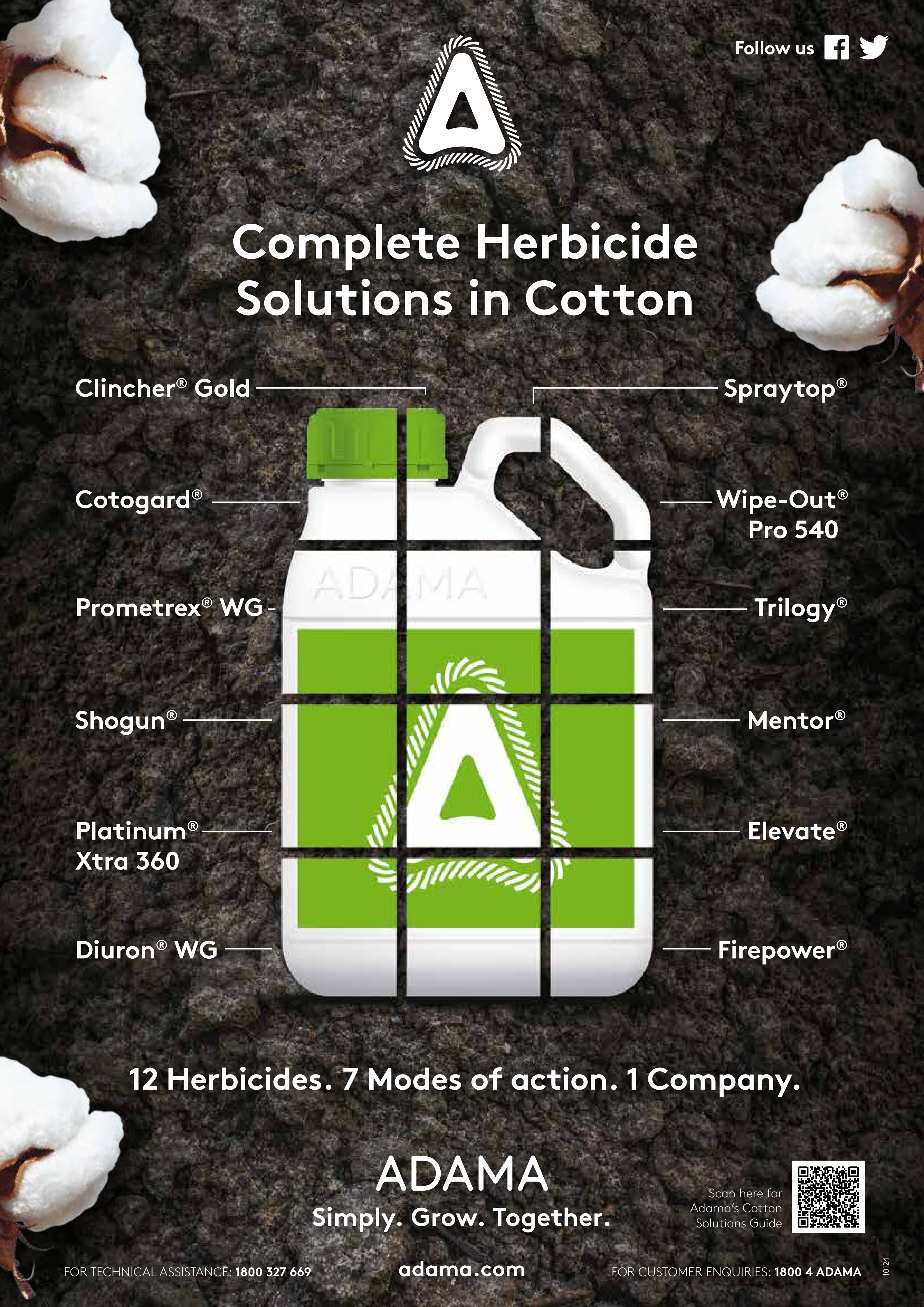
Since 2005–06 there have been occasional reports of larvae surviving for several weeks at threshold levels in Bt fields. All affected fields were at mid-flowering to late-flowering and the survivors included *H.armigera* and *H.punctigera*.

Work conducted by CSIRO and Monsanto 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 Monsanto 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



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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: 02 6799 1576 – 0427 480 967; or,**
- **Kristen Knight 07 4634 8400 – 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 63-66). The beneficial/pest ratio (described on page 52) should also be given careful consideration when the application 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 14.

For the Bollgard II Schedule, refer to your Technology User Agreement (TUA). Information on the Resistance Management Plan for Bollgard II 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 heliocide can be applied. For the purposes of this Resistance Management Plan, conventional cotton includes any cotton varieties that do not have Bt proteins in the plant that control Helicoverpa 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 over-wintering pupae according to the following key guidelines:

If first defoliation of a Bollgard 3 field occurs on or before March 31, the Bollgard 3 field must be slashed or mulched and controlled to prevent regrowth within 4 weeks of harvesting.

If first defoliation of a Bollgard 3 field occurs after March 31, the Bollgard 3 field must be slashed or mulched and controlled to prevent regrowth within 4 weeks of harvesting and pupae busting must be 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 48m x 48m. If no sprayed conventional cotton is grown on that farm unit: the trap crop must be at least 24m x 24m.
Planting time	The trap crop should preferably be planted 4 weeks after the associated Bollgard 3. Note: if growers choose to plant their trap crop to coincide with the planting of pigeon pea refuges, they must manage the trap crop in such a way that it remains attractive to Helicoverpa 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 Helicoverpa 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 67.

Unsprayed pigeon pea refuge agronomy

Sally Ceeney, CottonInfo

Acknowledgements: Susan Maas (CRDC); Mary Whitehouse (CSIRO); Kristen Knight (Monsanto Australia Limited); 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 commences 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.

TABLE 21: 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	
Haloxyfop*	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 trifoliate 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 unwanted cotton is an essential part of good integrated pest and disease management and general farm hygiene. Unwanted cotton is generally described as either:

- **Volunteer cotton –** plants that have germinated, emerged and established unintentionally and can be in-field or external to the field (roadsides, fence lines etc).
- **'Ratoon' cotton –** also known as 'stub' cotton, ratoon is cotton that has regrown from left over root stock from a previous season.

Control of volunteers

Cultivation and herbicides are the two most common methods of volunteer cotton control. Both require the cotton plants to have germinated and emerged 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 (ie. 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 22 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 22: 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. Tank mix with glyphosate, or products containing paraquat. Refer to label for adjuvant recommendation.
Paraquat + diquat	L	Apply in 50-100 L water/ha. For best results, spray during humid conditions in the late evening.
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	Liberty® 200 is registered for non-residual control of conventional cotton volunteers in Liberty Link crops. Basta® is only registered for summer fallow situations. Do not apply more than 3 applications per season. DO NOT APPLY TO COTTON VARIETIES OTHER THAN LIBERTY LINK COTTON.
Metribuzin	C	Registered for control of volunteer cotton in pigeon pea. Refer to label for critical comments.
Fluroxypyr	I	Summer fallow.
Saflufenacil	G	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 23: 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	1L/ha followed by 1L/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.
		1L/ha followed by Shirquat 2L/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.
		1L/ha + 1L/ha Amicide Advance 700/ha	For a single pass operation apply Comet + Amicide Advance 700. Ensure sufficient leaf regrowth has occurred on the ratoon cotton to maximise chemical uptake.

Refer to the Comet 400 registration label for further details on control rates for optical spot spray technologies.
Note that control rates are based on L/ha for broadacre application and L/100L(spot spraying rate) for optical sprayers.
Label changes are expected for this product, refer to https://portal.apvma.gov.au/pubcris.

From top:
18 Metre Boss Supaflex Planter with Boss 12000ltr Steerable Cart at North Star NSW
BOSS 9000ltr Steerable Air Seeder
12 Metre Boss Bridge frame with TX65C Row Units on 9" Spacings
Boss TX65C Hydraulic Row Unit

In conducting this cultivation an additional aim is to destroy over-wintering 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 23 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/cottoninfoaust

Herbicide resistance management in Australian cotton farming systems

Eric Koetz, NSW DPI

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

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 495 unique cases (species x mode of action) of herbicide resistant weeds globally across 255 species (148 dicots and 107 monocots). Weeds have evolved resistance to 23 of the 26 known herbicide sites of action and to 161 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 recent 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). While there are significant resources available for control of specific weeds and a plethora of information is available on integrated weed management, a need to develop an industry wide strategy in conjunction with industry stakeholders was identified. 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 draft strategy was circulated widely to industry and modified based on industry feedback, prior to its ratification by the TIMS committee.

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 raingrown cropping systems. The models indicate that in irrigated cotton, crop competition provides higher weed control than in raingrown 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

TABLE A: Confirmed glyphosate resistant weeds in Australia

Weed species	Year first documented	Number of confirmed populations as at January 2018
Annual ryegrass (*Lolium rigidum*)	1996	678
Barnyard grass (*Echinochloa colona*)	2007	102
Liverseed grass (*Urochloa panicoides*)	2008	4
Flaxleaf Fleabane (*Conyza bonariensis*)	2010	65
Windmill grass (*Chloris truncata*)	2010	11
Wild radish (*Raphanus raphanistrum*)	2010	2
Great brome (*Bromus diandrus*)	2011	5
Tall fleabane (*Conyza sumatrensis*)	2012	10
Sowthistle (*Sonchus oleraceus*)	2014	23
Red brome (*Bromus rubens*)	2014	1
Sweet summer grass (*Moorochloa eruciformis*)	2014	1
Prickly lettuce (*Lactuca serriola*)	2014	1
Feathertop Rhodes grass (*Chloris virgata*)	2015	4
Tridax daisy (*Tridax procumbens*)	2016	1
Winter grass (*Poa annua*)	2017	3
Willow-leaved lettuce (*Lactuca saligna*)	2017	2
Northern barley grass (*Hordeum glaucum*)	2018	1

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

Will the HRMS change in the future?

It is expected that the HRMS will go through a similar process of annual reviews for continuous improvement like the Insecticide Resistance Management Strategy (IRMS). The IRMS started from a basic position and has matured overtime with the benefit of stakeholder feedback. It is anticipated that HRMS will be expanded to include more scenarios, tactics, and combinations of tactics as well as mature to be relevant in a multi-herbicide-trait cotton system.

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 is 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.

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 reistance in windmill grass (*Chloris truncata*), feathertop Rhodesgrass (*Chloris virgata*) and barnyard grass (*Echinochloa crus-garli*) in three cotton growing regions. The intent is to expand the HRMS to incorporate other modes of action and multi-trait HR cotton varieties.

How to use the HRMS

Given that modelling shows glyphosate resistance takes around 18 years to develop when used alone in an irrigated cotton cropping system and 14 years in raingrown, it is important to identify the likelihood of resistance development in your own operation. The HRMS table (pages 92-93) 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.

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)

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
Hordeum glaucum	Northern barley grass	1983	Victoria	Lucerne	Diquat (L)
Arctotheca calendula	Capeweed	1984	Victoria	Lucerne	Diquat (L)
Hordeum leporinum	Barley grass	1988	Victoria	Lucerne	Diquat (L)
Vulpia bromoides	Silver grass	1990	Victoria	Lucerne	Diquat (L)
Mitracarpus hirtus	Small square weed	2007	Queensland	Mangoes	Diquat (L)
Lolium rigidum	Annual ryegrass	2010	South Australia	Pasture seed	A/M – 2 populations
Gamochaeta pensylvanica	Cudweed	2015	Queensland	Tomatoes, sugarcane	
Solanum nigrum	Blackberry nightshade	2015	Queensland	Tomatoes, sugarcane	
Eleusine indica	Crowsfoot grass	2015	Queensland	Tomatoes, sugarcane	
Conyza bonariensis	Flaxleaf fleabane	2016	NSW	Grape vines	

BE A GOOD MATE STOP IT AT THE GATE

Together we can stop the spread of pests, weeds & diseases.

- ✔ Use farm vehicles to transport visitors around the farm!
- ✔ Keep a record of farm visitors!
- ✔ Have a sign-posted parking area away from fields!
- ✔ Regularly monitor all crops!
- ✔ Ensure all farm inputs are pest-free!
- ✔ Report any suspicious symptoms or pests to the Exotic Plant Pest Hotline: 1800 084 881!
- ✔ Develop a farm biosecurity plan!
- ✔ Place biosecurity signs at farm entry points!
- ✔ Make wash down facilities available on farm!
- ✔ Ensure vehicles & machinery come onto farm mud & trash free!
- ✔ Control volunteer cotton & weeds throughout the year!
- ✔ Communicate your farm biosecurity requirements to farm staff & visitors!

CottonInfo

myBMP

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

Do I have to adhere to the HRMS?

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

Assessing your own risk

For a more detailed assessment of the resistance risks for individual paddocks, use Qld DAF's Online Glyphosate Resistance Toolkit, available via www.cottoninfo.com.au. This tool allows you to check what your current level of risk is for developing glyphosate-resistant weed populations on your farm. The tool allows you to enter information on your current practices (including crop rotation, crop density, and weed control tactics) and to identify which weed species you usually have to control. 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
Raphanus raphanistrum	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	
Sisymbrium orientale	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
Sonchus oleraceus	Sowthistle	2015	Victoria	Winter cereal	2,4-D	
		2015	South Australia	Winter cereal	2,4-D, dicamba, clopyralid	
Arctotheca calendula	Capeweed	2015	South Australia	Winter cereal	2,4-D	

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

The online Glyphosate Resistance Toolkit is available through the CottonInfo and Qld DAF websites. The toolkit also contains a herbicide resistance quiz which explains the important drivers in herbicide resistance development.

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 involves growing large numbers of plants in 'ideal' conditions, then at particular growth stages applying the herbicide at a range of rates and observing the responses. Generally, seed is collected from the suspect plants and is sent for testing. However, the dormancy mechanism in some species, such as barnyard grass, creates problems with this process. It is difficult to get sufficient quantities of seed to germinate uniformly in short time frames.

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 96.

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

Herbicide Resistance Management Strategy 2018/19 Explanatory Notes:

The HRMS is designed as a tool to manage the risk of herbicide resistance in irrigated and raingrown 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 (raingrown) 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 raingrown 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
- Raingrown 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 raingrown 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 91 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
↓ High - Resistance risk - Low ↑ / ↓ Decreasing - Survivor control – Increasing ↑	Very high survivor control after **each** OTT glyphosate	Very high	Control all survivors of OTT glyphosate applications. Don't use glyphosate alone to control the last in-crop flush
	2 x strategic in crop cultivations	Very high	Time the second cultivation to control last weed flush and escapes prior to row closure
	Pre-plant residual plus residual layby	Very high	Consider plant-back period restrictions
	Very high survivor control after **first** OTT glyphosate	Very high	Control survivors from first flush which has highest weed germination
	Grass selective in-crop herbicide + cultivation	High	Resistance to Group A herbicides may already be present in some populations. Controlling survivors is essential, follow with cultivation
	Moderate survivor control after **first** OTT glyphosate only	Low	Survivors allowed to set seed will increase the speed of selection for resistance. Test survivors for glyphosate resistance
	Glyphosate only	Very low	Survivors allowed to set seed will increase the speed of selection for resistance. Test survivors for glyphosate resistance

Raingrown cotton every second summer

Risk	Summer fallow tactics	In Crop Tactics 3 x OTT glyphosate applications PLUS	Seed Bank Control in cotton phase	Comments
↓ High - Resistance risk - Low ↑ / ↓ Decreasing - Survivor control – Increasing ↑	2 non-glyphosate tactics	Very high survivor control after **each** OTT glyphosate	Very high	The most effective scenario for delaying glyphosate resistance
	Glyphosate only fallow	Very high survivor control after **each** OTT glyphosate	Very high	Very high frequency & efficacy of survivor control is required if in-crop only tactics are used
	2 non-glyphosate tactics	Moderate survivor control after **each** OTT glyphosate	High	Lower intensity in-crop tactics can give excellent results if backed up with robust control in summer fallows. Specific, frequent, well-timed control of glyphosate survivors 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;

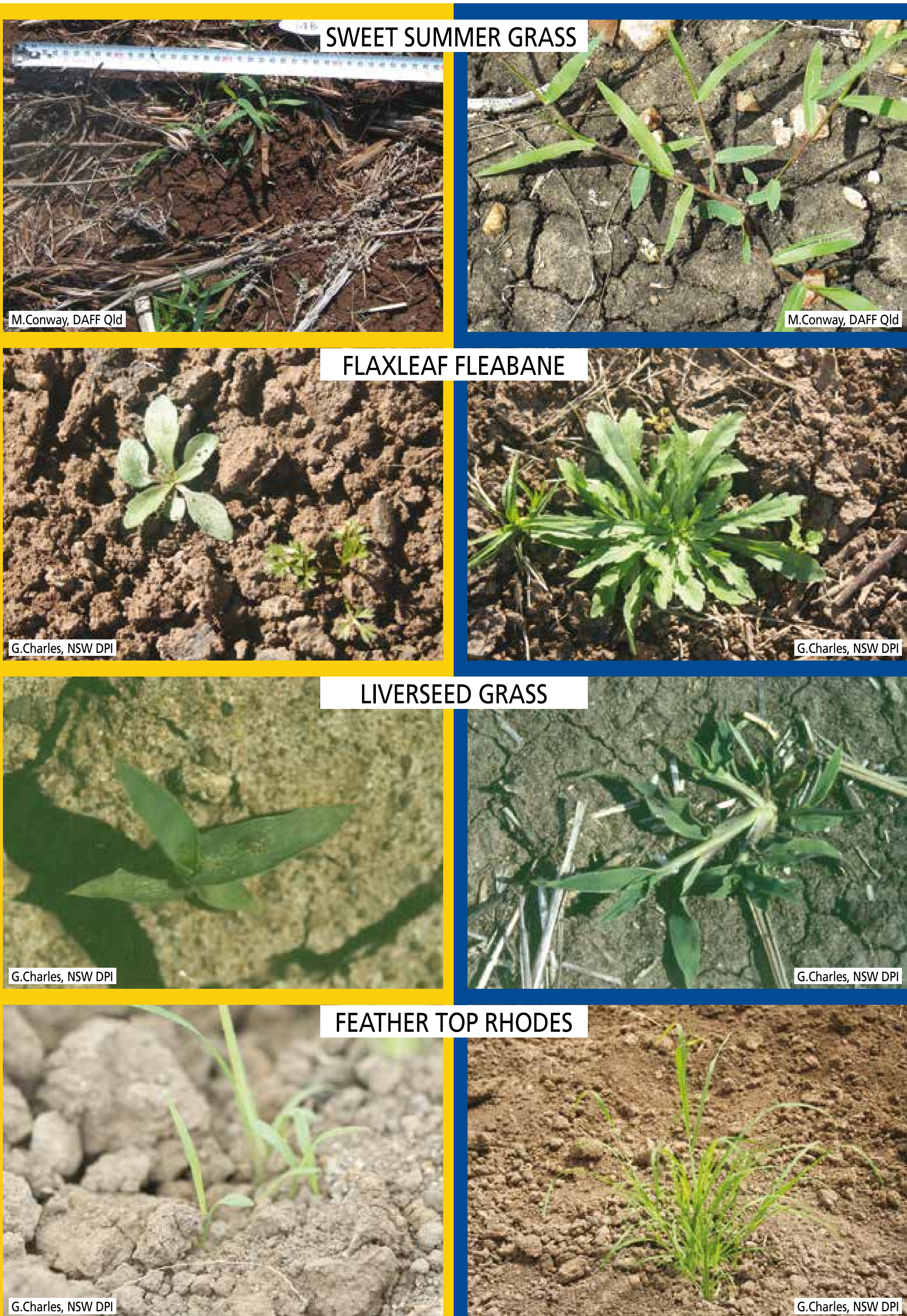
- Windmill grass
- Fleabane
- Feathertop Rhodes grass
- Awnless barnyard grass
- Sowthistle
- Liverseed grass

- Annual ryegrass is a significant issue in Southern valleys and is emerging as a problem in Northern NSW. There are reports of cross resistance to glyphosate and Group A 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



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

COBBLER'S PEG

COMMON SOWTHISTLE

MILKWEED

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. Deployment of tactics recognises the full range of farming system's inputs that impact on weeds and the interactions of these inputs, as shown in the diagram on page 97. 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. Similar species may respond differently to control measures. For example, the strong seed dormancy mechanisms of cowvine (*Ipomoea lonchophylla*) make it less responsive to a tactic like the spring tickle than bellvine (*Ipomoea plebeia*) which has very little seed dormancy. Herbicide susceptibility can also differ between similar species. 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. Cultivation may be a more cost-effective option to control large or stressed weeds, but additional costs can be avoided through being prepared and implementing controls at the optimum time.

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.

SUGGESTED INTERVALS FOR SOME COMMON DOUBLE KNOCK HERBICIDE COMBINATIONS IN THE NORTHERN GRAINS REGION

Weed	First application	Second application	Recommended timing	Comments
BROADLEAF WEEDS				
Most broadleaf weeds	glyphosate	Group L (e.g. paraquat)	Optimal timing is generally 10 to 14 days	
Difficult to control broadleaf weeds such as fleabane (*Conyza bonariensis*)	Group I with or without glyphosate	Group L (e.g. paraquat)	Optimal timing is generally 7 to 10 days	If interval is greater than 14 days, use maximum label rates of Group L herbicide
	glyphosate plus saflufenacil	Group L (e.g. paraquat)	Optimal timing is generally 10 to 14 days	Only target rosettes less than 6 leaf
Difficult to control broadleaf weeds such as sowthistle/ milkthistle (*Sonchus oleraceus*)	glyphosate	2,4-D	2 to 4 days	Recommended to split applications due to incompatibility within the plant. As both products are systemic, the interval needs to be short.
	glyphosate	Group L (e.g. paraquat)	7 to 10 days.	Only target small rosettes
	glyphosate plus saflufenacil	Group L (e.g. paraquat)	Optimal timing is generally 10 to 14 days	Only target small rosettes
GRASS WEEDS				
Most grass weeds including: Annual ryegrass (*Lolium rigidum*) Barnyard grass (*Echinochloa colona* & *E. crus-gali*)	glyphosate	Group L (e.g. paraquat)	Optimal timing is generally 5 to 7 days	
Feathertop Rhodes grass (*Chloris virgata*)	propaquizafop	Group L (e.g. paraquat)	Optimal timing is generally 7 to 10 days	
Windmill grass (*Chloris truncata*)	quizalofop	Group L (e.g. paraquat)	Optimal timing is generally 7 to 10 days	Refer to APVMA permit 13460 (NSW ONLY)

SOURCE: Independent Consultants Australia Network

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
Fallow Strategic cultivation Double knock Optical Sprayers Patch management Cover crops Non Glyphosate options for fallow*** Group C (bromoxynil, terbuthylazine) Group G (pyraflufen, saflufenacil) Group H (isoxaflutole) Group L (paraquat, paraquat/diquat) Group L/Q (amitrole/paraquat) Group N (glufosinate) Group I (2,4-D, dicamba, fluroxypyr) **Rotation Crops ★** Crop competition Rotate MOA Plant back restrictions cover crops	**Pre/at plant** Cultivation **Knockdown MOA** Group C (bromoxynil, terbuthylazine) Group D (chlorthal dimethyl) Group G (pyraflufen, flumioxazin, saflufenacil, oxyflurofen) Group I (dicamba, fluroxpyr) Group L (paraquat, paraquat/diquat) Group L/Q (amitrole/paraquat) Group N (glufosinate) **Residual MOA ★** Group C (flumeturon, prometryn, terbuthylazine) Group D (pendimethalin, trifluralin) Group K (S-metolachlor, metolachlor)	**Post-emergent #** In-crop cultivation Manual chipping Rogueing **Post-emergent OTT MOA** Group A * (sethoxydim, clethodim, butroxydim, propaquizafop, haloxyfop) Group K (S-metolachlor**) Group Z (MSMA) **Lay-by, directed or shielded spray** Group C (flumeturon, prometryn, terbuthylazine, diuron) Group D (pendimethalin, metolachlor) Group G (flumioxazin**)	**Survivor control** Aim for 100% control Cultivation, chipping or spot spraying

NO SURVIVORS

Survivor control

Aim for 100% control

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

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: 14439, 85049, 13460, 12941 for fallow use

Crop competition

Most agronomic decisions have some impact on weed management. An evenly established, vigorously growing cotton crop can compete strongly with weeds, especially later in the season. Decisions such as cotton planting time, pre-irrigation versus watering-up, methods of fertiliser application, stubble retention and in-crop irrigation management all have an impact on weed emergence and growth. 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. There are a number of opportunities, particularly in irrigated cotton, where tillage can be used. 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. 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/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 emergences. Biosecurity: http://cottoninfo.com.au/

Irrigation water can be a source of weed infestation with weed seeds being carried in the water. While it is not practical to filter seeds from the water, growers should be on the lookout for weeds that gain entry to fields via irrigation. Give special consideration to water pumped during floods, as this has the greatest potential to carry new seeds. If possible, flood water should be first pumped into a storage to allow weed seeds to settle out before being applied to fields. 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.

For a range of reasons, situations will occur when some weeds escape control by herbicides. Missed strips due to blocked nozzles, inadequate tank mixing, poor operation of equipment, insufficient coverage due to high weed numbers, applying the incorrect rate and interruptions by rainfall, are just a few reasons why weeds escape control. If herbicide resistant individuals are present, they will be amongst the survivors. It is critical to the longer term success of an IWM strategy that survivors not be allowed to set seed.

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 below.

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. Historically chipping has been an important part of the cotton farming system, however this has dramatically reduced in recent years. As a tool to prevent survivors setting seed, chipping has been shown to be a very cost effective option.

Spot spraying

Spot sprayers may be used as a cheaper alternative to manual chipping for controlling low densities of weeds in-crop. Ideally, 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, oxyflurofen), Group I (2,4-D, dicamba, fluroxypyr), Group L (paraquat, paraquat/diquat), Group M (glyphosate), Group N (glufonsinate) 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. Refer to Table 25: Plant-backs to cotton for herbicides used in seedbed preparation, page 101.

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) 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 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. Tables 24 to 27 provide information on some plant-back limitations. 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.

Using cotton varieties with herbicide tolerant traits means that growers don't have to rely on pre-planting and at-planting residual herbicides for weed control, as weeds can be controlled after emergence, meaning herbicide applications can be timed to have maximum impact on weed populations. 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 102-103 for more information.

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).

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, 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 81).

TABLE 24: Herbicide plant-backs from rotation crops to cotton

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.
Atrazine	C	6 months	Following treatments of up to 1.4 kg/ha.
		18 months	Following treatments of 1.4 kg/ha to 3.3 kg/ha.
Atrazine +	C+K	6 monts	When rates up to 3.2 L/ha are used.
S-metolachlor		18 months	When rates up to 3.2 L/ha are used. On alkaline soils, a bioassay or analytical test should be undertaken.
Chlorsulfuron	B	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	When rates up to 30 g/ha are used.
		6 months	When rates of 30-120 g/ha are used
		24 months	When rates above 120 g/ha are used. For all rates at least 100 mm rain required during plant-back period.
Diuron	C		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
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.
Isoxaflutole	H	7 months	350 mm rainfall (do not include flood/furrow irrigation) between application and planting the subsequent crop.
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.
Imazethapyr	B	22 months	Raingrown cotton.
		18 months	Irrigated only. (Providing rainfall and irrigation exceeds 2000mm)
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	Soil pH Less than 7.5, 700 mm rainfall between application and sowing the plant back crop.
		18 months	Soil pH 7.6-8.5.
Triclopyr + picloram	I	4 months	0.2 L/ha. During drought conditions (<100 mm rainfall in a 4 month period) the plant-back is significantly longer.
+ Aminopyralid		6 months	0.4 L/ha.
Imazamox	B	10 months	Must have 800 mm of rainfall or irrigation
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	Rates < 1.5 L/ha. This could be longer if there have been long dry periods between crops.
		12 months	Rates > 1.5 L/ha.
Metsulfuron-methyl + mefenpyr-diethyl	B	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.

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 gyphosate for controlling summer weeds means that summer weeds are only exposed to one mode of herbicide action. The Herbicide Resistance Management Strategy recommends at least two non-glyphosate tactics in summer fallows in addition to two non-glyphosate tactics in the cotton crop. Residual herbicides and double knock tactics provide good alternatives to a glyphosate only fallow herbicide. Refer to Table 24, 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 Table 34 "Registerred Cotton Herbicides", Pages 106-107.
The Australian Cotton Production Manual includes information on weed control tactics.

TABLE 25: 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 26: 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 27: 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	Safflower	Linseed	Sunflower
chlorthal dimethyl	8	8	8	8	8	8	8	8	8	8	8	8	8	8	FH	FH	8	FH	8	8	8	8
diuron	24	24	24	24	24	24	24	24	24	24	24	24	24	24	12	24	24	24	24	24	24	24
fluometuron	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
fluometuron + prometryn	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
halosulfuron-methyl	24	2	24	24	2	24	3	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
metolachlor	6	0	6	6	0[1]	6	6	6	6	6	6	6	6	6	6	6	6	0	6	6	6	0
norflurazon[2]	24	21	NI	24	21	24	24	NI	3	NI	24	NI	NI	NI	NI	21	NI	3	NI	18	18	27
pendimethalin	6	0[3]	12	12	12	NI	NI	NI	NI	NI	NI	NI	NI	NI	6	NI	NI	NI	6	NI	NI	NI
prometryn	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
s-metolachlor	6	0	6	6	0[1]	6	6	6	6	6	6	6	6	6	6	6	6	0	6	6	6	0
trifloxysulfuron sodium	6	22	22	6	22	22	6	22	18	22	7	22	22	22	22	9	15	15	22	22	22	22
trifluralin	12	12	12	12	12	12	12	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH	FH

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

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

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 publication 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.

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.**

TABLE 28: Control of weeds in dry channels

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

TABLE 29: Control of weeds around aquatic areas

Active ingredient	Mode of Action group
Glyphosate	M

TABLE 30: Weed control before planting

Active ingredient	Mode of Action group
2,4-D as the iso-propylamine salt	I
Amitrole + paraquat	L + Q
Bromoxynil	C
Carfentrazone-ethyl	G
Carfentrazone-ethyl + glyphosate	G + M
Dicamba	I
Diuron	C
Fluometuron	C
Fluometuron + prometryn	C
Flumioxazin	G
Fluroxypyr	I
Glyphosate	M
Glyphosate Glufosinate-ammonium	M N
Glyphosate glufosinate-ammonium metolachlor	M N K
Norflurazon	F
Oxyfluorfen	G
Paraquat	L
Paraquat + diquat	L
Pendimethalin	D
Prometryn	G
Pyraflufen-ethyl	G
s-Metolachlor	K
Terbuthylazine	C
Triclopyr	I
Trifluralin	D

TABLE 31: Weed control at or after planting and before crop emergence

Active ingredient	Mode of action group
Chlorthal dimethyl	D
Diuron	C
Fluometuron	C
Fluometuron + prometryn	C
Metolachlor	K
Paraquat + diquat	L
Pendimethalin	D
Prometryn	C
Terbuthylazine	C
s-Metolachlor	K

TABLE 32: Weed control pre-harvest

Active ingredient	Mode of Action group
Glyphosate	M

TABLE 33: Weed control after crop emergence (includes layby)	
Active ingredient	**Mode of Action group**
Butroxydim	A
Chlorthal dimethyl	D
Clethodim	A
Diuron	C
Fluazifop-p	A
Fluometuron	C
Fluometuron + prometryn	C
Flumioxazin	G
Glufosinate-ammonium	N
Glyphosate	M
Halosulfuron–methyl	B
Haloxyfop-r	A
MSMA	Z
Paraquat	L
Prometryn	C
Propaquizafop	A
Terbuthylazine	C
Trifloxysulfuron sodium	B

Herbicide tolerant technology

Roundup Ready Flex® technology

Developed by **Monsanto Australia** in association with the TIMS Herbicide Tolerance Technical Panel

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 (over page). 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 affects 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 survellience

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, Monsanto 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 three critical herbicides, Roundup Ready® Herbicide with PLANTSHIELD® by Monsanto, Verdict® and Select®.

Monsanto have pre-printed testing envelopes that can be used for weed seed collection. Please email cotton@monsanto.com to arrange for the number of envelopes you need to be posted to you.

Testing will be anonymous. Monsanto 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 81-84 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/

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.

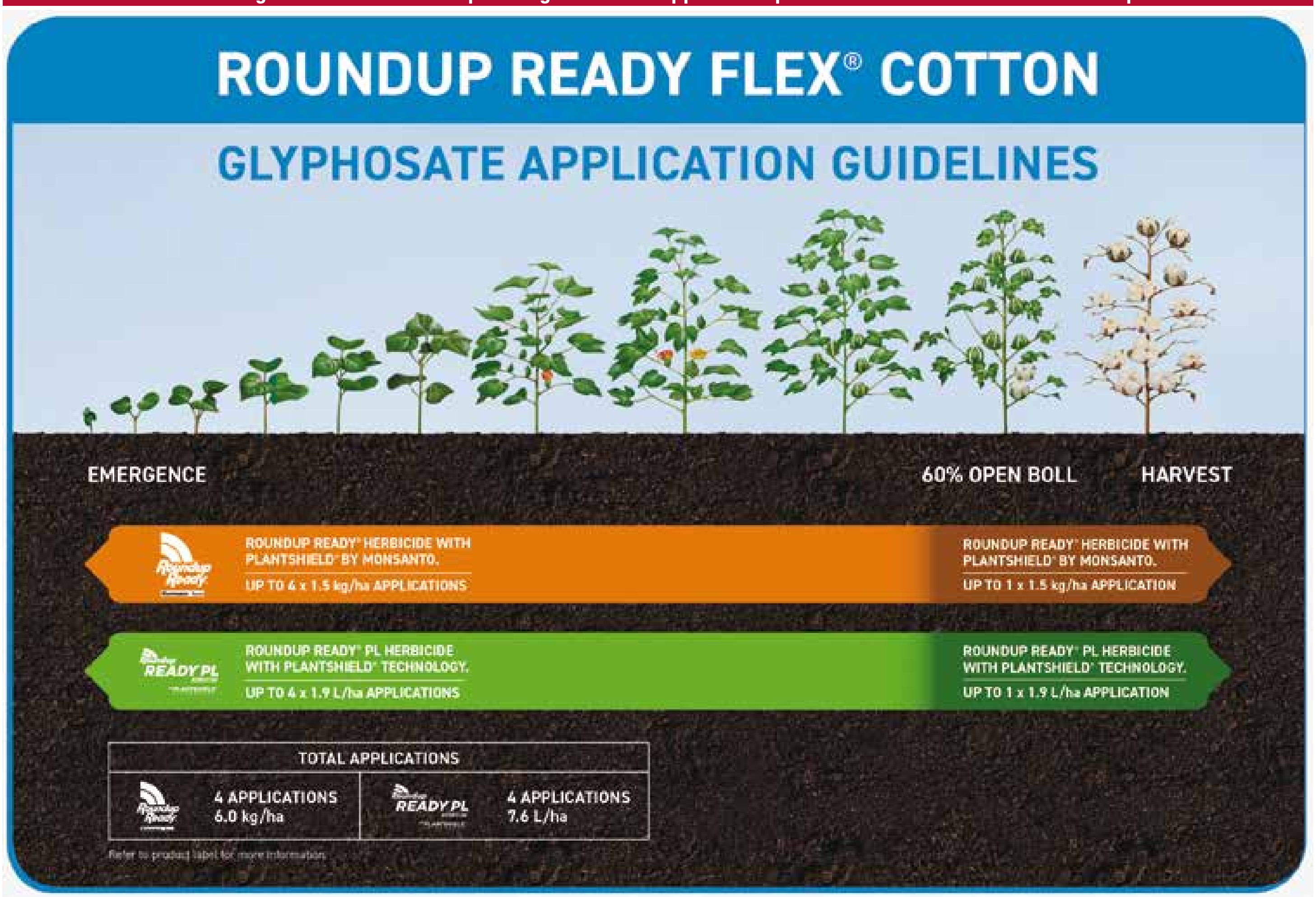


TABLE 34: Registered cotton herbicides – fallow, at planting, in crop – including resistance rankings and frequency

Herbicide active ingredient	Comment	Before planting	At planting	Post emergent	Mode of Action
MSMA		N	N	Y	Z
Amitrole + paraquat		Y	N	N	Q+L
Amitrole + ammonium thiocyanate		Y	N	N	Q
Paraquat		Y	Y	Y	L
Paraquat + Diquat		Y	Y	N	L
Glufosinate-ammonium		Y	N	N	N
Glyphosate	Roundup Ready Flex® varieties only	Y	Y	Y	M
s-Metolachlor or Metolachlor	Bouncer® formulation only	Y	Y	Y	K
2,4-D	15mm rainfall required before plant back period begins	Y	N	N	I
Dicamba	15mm rainfall required before plant back period begins	Y	N	N	I
Fluroxypyr		Y	N	N	I
Fluroxypyr+ aminopyralid		Y	N	N	I
Triclopyr		Y	N	N	I
Triclopyr + picloram		Y	N	N	I
Triclopyr + picloram + aminopyralid		Y	N	N	I
Carfentrazone-ethyl		Y	N	N	G
Flumioxazin	Valor® formulation only.	Y	N	Y*	G
Oxyfluorfen		Y	N	N	G
Saflufenacil		Y	N	N	G
Norflurazon		Y	N	N	F
Pyraflufen	Sledge (R)	Y	N	Y	G
Pendimethalin	Rifle® formulations	Y	Y	Y	D
Trifluralin		Y	Y	N	D
Chlorthal dimethyl		Y	Y	Y	D
Bromoxynil		Y	N	N	C
Diuron		Y	Y	Y	C
Fluometuron		Y	Y	Y	C
Terbuthylazine	Extreme (R)	Y	Y	Y	C
Fluometuron + prometryn		Y	Y	Y	C
Prometryn		Y	Y	Y	C
Isoxaflutole	350 mm rainfall required before plant back period begins	Y	N	N	H
Halosulfuron–methyl		N	N	Y	B
Trifloxysulfuron sodium		N	N	Y	B
Butroxydim*		N	N	Y	A
Clethodim*		N	N	Y	A
Fluazifop-p*		N	N	Y	A
Haloxyfop*		N	N	Y	A
Propaquizafop*		N	N	Y	A

*Group A herbicides already exhibit widespread resistance in several species. Controlling survivors is essential.
For herbicide resistance management tactics refer to page 97. Do NOT rely on glyphosate to manage weeds in non-crop areas.
Always read the label for detailed use patterns and application rates.

Fallow leading up to planting (plantback)	Estimated generations to resistance	Distribution of resistance (widespread, occassional, rare)	Number of species (multiple, some, few)
	N/A	Rare	Few
	>15	Rare	Few
	N/A	Rare	Few
	>15	Occassional	Some
	>15	Occassional	Some
	10-15	Rare	Few
	>12	Widespread	Multiple
	>15	Rare	Few
10 to 21 days depending on use rate	10-15	Occassional	Multiple
7 or 14 days depending on use rate	10-15	Rare	Few
14 or 28 days depending on use rate	10-15	Rare	Few
9 months	10-15	Rare	Few
14 days	10+	Rare	Few
9 months	10+	Rare	Few
9 months	10+	Rare	Few
	10	Rare	Few
	10	Rare	Few
	10	Rare	Few
6 weeks	N/A	Rare	Few
	15+	Occassional	Some
1 hour	N/A	Rare	Few
	10-15	Occassional	Some
	10-15	Occassional	Some
	10-15	Occassional	Few
	10-15	Occassional	Some
	10-15	Rare	Few
	10-15	Rare	Few
	10-15	Rare	Few
	10-15	Rare	Few
	10-15	Rare	Few
7 months	10	Rare	Few
	4	Widespread	Multiple
	4	Widespread	Multiple
	6-8	Widespread	Multiple
	6-8	Widespread	Multiple
	6-8	Widespread	Multiple
	6-8	Widespread	Multiple
	6-8	Widespread	Multiple
	Lowest resistance risk		
	Moderate resistance risk		
	Highest resistance risk		

Integrated Disease Management

Sharna Holman, Qld DAF and CottonInfo

Acknowledgements: Susan Maas (CRDC); Stephen Allen (CSD); Karen Kirkby, Peter Lonergan (NSW DPI); Linda Smith, Linda Scheikowski, 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. Therefore effective integrated disease management involves a range of control strategies which must be integrated with management of the whole farm.

Disease control strategies should be implemented regardless of whether or not a disease problem is evident, as the absence of 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.
- Carefully position fertiliser and herbicides in the bed to prevent damage to the roots.
- Fields should have good drainage and not allow water to back-up and inundate plants.

Sowing date/temperature

Sowing in cool and/or wet conditions favours disease. While cotton can be planted once the soil reaches 14°C or above, at 10 cm depth, at 8am, from a disease perspective, it is best to plant when temperatures are 16°C and rising. Refer to the Australian Cotton Production Manual 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 can be higher, increasing the importance of planting resistant varieties and using a range of IDM strategies.

There are a number of varieties that have good resistance to Verticillium wilt or Fusarium wilt, with levels of resistance indicated by higher V rank and F rank 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 Australian Cotton Production Manual 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 Alternartia 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 late in the season when temperatures have cooled. 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 with optimisied nutrition and irrigations and with the use of growth regulators where required.

If Black root rot is present, either manage for earliness to get the crop in on time (in short season areas) or manage for 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. Both Fusarium and Verticillium wilt favor the conditions provided by the excessive use of nitrogen. While excess nitrogen also greatly increases 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 symptoms. Refer to NUTRIpak or the Australian Cotton Production Manual for more information on cotton nutrition.

Conduct your own in-field disease survey

It is important to be aware of what diseases are present, where they are present on farm and whether or not the incidence is increasing. Monitoring and recording disease assessments allows a comparison over time of the disease presence, incidence and severity in fields (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
Exotic Plant Pest Hotline 1800 084 881
Refer to the Cotton Symptoms Guide or page 123 for instructions on how to send a sample.

In-season disease trouble shooting

Early season

- The early season disease survey is conducted within 4 weeks from planting.
- Compare number of plants established per metre with number of seeds planted per metre. Refer to the Australian Cotton Production Manual 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

- The late disease surveys are conducted after the final irrigation but before defoliation.
- Walk field and look for plants that are dead, show signs of poor vigour or have unusual symptoms.
- Cut stems of plants showing symptoms of disease 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 from cotton bunchy top.

Crop residue management

The different pathogens that cause Verticillium wilt, Fusarium wilt, Black root rot, boll rots, seedling disease and Alternaria leaf spot can all survive in association with cotton and some rotation crop residues. Crop residues should therefore be managed carefully to minimise carryover of pathogens into subsequent crops.

If Fusarium wilt is known to be present in a field, residues should be slashed and retained on the surface for 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 afford 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.

Aerial photo of fusarium damage.

The pathogen that causes Verticillium wilt has a large host range and most legume crops are hosts of the Black root rot pathogen. Legumes such as mungbeans and soy beans are known hosts of the Fusarium wilt pathogen. 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 exchange. Bare fallow for more than 3 to 4 seasons or removal of top-soil (especially more than 40 cm) may result in a severe lack of mycorrhiza. A cereal or green-manure crop may restore sufficient mycorrhizal fungi for cotton.

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

IDM all year round

Control of insect vectors

Diseases caused by a virus or phytoplasma are often prevented by controlling the vector that carries the pathogen. Cotton bunchy top (CBT) can be transmitted by aphids feeding on infected plants then migrating 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 47).

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 considering machinery movements within the farm and having a strategy for ensuring clean movement of machinery onto and around the farm. NOTE: A fact sheet on available washdown products is available from www.cottoninfo.com.au

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:
***my*BMP www.mybmp.com.au**
CottonInfo www.cottoninfo.com.au/publications/cotton-symptoms-guide

Regional disease update 2017–18

Sharna Holman (Qld DAF and CottonInfo),
Linda Smith (Qld DAF) and **Duy Le** (NSW DPI)

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

National disease surveys

Commercial cotton crops across New South Wales and Queensland were inspected in October–December 2017 and February–April 2018. 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 53 and 50 fields that were surveyed in NSW and Queensland respectively. This represents the 34th consecutive season of quantitative disease surveys of cotton in NSW and the 15th consecutive season of cotton disease surveys in Queensland. As part of a new approach to the disease survey, analysis of yield, management, soil microbial analysis as well as disease incidence from the survey aim to provide improved insights into suppression of disease. For example fallows have been found to lower fungal diversity, which is associated with disease conducive soils This means that the disease lowering impact of a fallow may be short lived once cotton is grown as the soil his less resilient.

A dry winter provided ample opportunity for early ground preparation to take place, and enabled growers to take advantage of the planting window, which for many, commenced in mid-September. In Central Queensland (CQ), a large number of growers took the opportunity for an August/September plant, following the success of early planted cotton last season, which resulted in some excellent yields. However, 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 may have been favourable for ground preparation, but it can affect the amount of trash present at planting due to reduced stubble breakdown, 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 cool, wet start to the season provided highly conducive conditions for the development of seedling disease. Later in the season, over the first week of February, the average temperature dropped below 25°C in many cotton growing districts. The milder temperature regimes, as well as rainfall and associated cloud cover, provided conditions ideal for the development of Verticillium and Fusarium wilts.

During the 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.

Key findings early season

The cool, wet start provided highly conducive conditions for the development of seedling disease, which is caused by a complex of pathogens including *Thielaviopsis basicola* and species of Pythium, Rhizoctonia and Fusarium.

Black Root Rot, which is caused by *T. basicola*, was a significant disease issue for the majority of regions (Figures 1 and 2). This disease is a particularly serious problem for southern NSW because of its cooler climatic conditions which favour the pathogen. However, even in Queensland, significant root damage was observed due to this pathogen, particularly in the earlier planted crops and where cool conditions occurred. The level of disease observed and number of replants due to BRR disease highlights the urgency for the development of more effective management strategies for this pathogen.

Figure 1: Cotton seedlings with symptoms of BRR (NSW). (Photo: Duy Le)

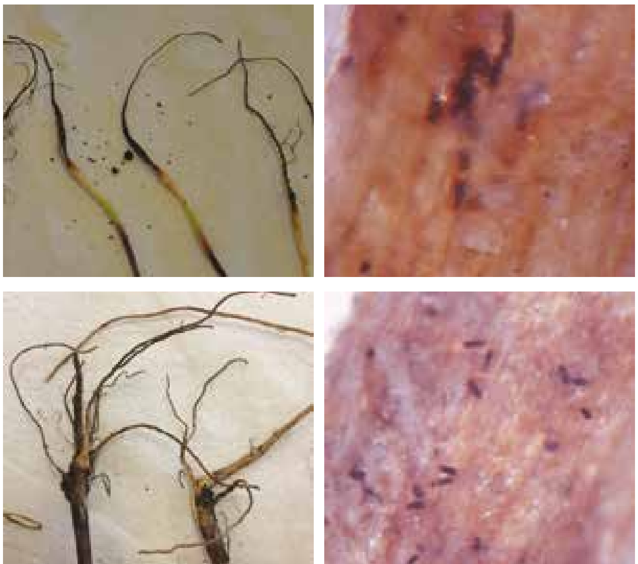


Figure 2: Cotton seedlings with symptoms of BRR (top left) and chlamydospores of the pathogen observed on the root surface using a microscope (right). Roots (bottom left) also displaying the effects of growing in a compacted soil (Qld). (Photo: Linda Scheikowski)

Alternaria leaf spot could be considered as a major disease this

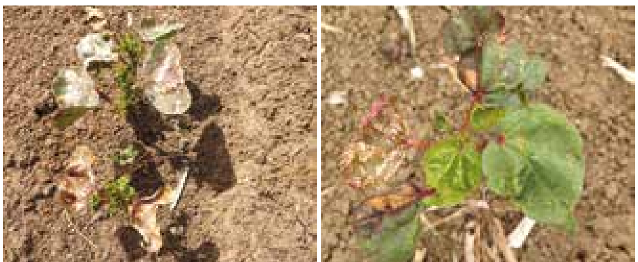


Figure 3: Alternaria affected seedlings in the Murrumbidgee (left) and Lachlan (right) regions. (Photo: Duy Le)

STRATEGIC RD&E PLAN

2018–2023

The Strategic RD&E Plan 2018-2023 is CRDC's primary RD&E planning document and provides a high-level overview f CRDC's strategic direction for the next five years.

Our vision is to power the success of Australian cotton through world-leading RD&E, and the Plan sets out how this will be achieved: the goals, investment approach, and planned impact.

The Plan is ambitious: over the course of the five years, CRDC aims to contribute to creating $2 billion in additional gross value of cotton production through investments in RD&E.

visit us at: www.crdc.com.au

season in southern NSW, with serious infection of young seedlings being observed (Figures 3 and 4). Some of the fields or nearby fields have had histories of Alternaria late in the previous season which has provided a source of inoculum for early season infection under conducive conditions. Research is being conducted to better understand the species of Alternaria contributing to this leaf spot disease, as well as evaluation of fungicidal efficacies to provide supporting evidence for emergency permit application in preparation for the season 2018–19.

Figure 4: Severe symptoms observed in early December 2017. (Photo: Allan Jones)

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

Soil compaction is a well-known risk with most cotton soils and can have significant consequences for productivity. Roots will grow through compacted soils if there are cracks and bio-pores through the profile, but not if compaction has resulted in pores smaller than the diameter of the root. Hence, soil compaction may restrict root growth, water and nutrient uptake. There was evidence of the effect of soil compaction on root growth in several regions (Figure 2).

End of season summary

Central Queensland

Emerald: Due to weather, late season disease surveys were delayed and only late planted crops were assessed on 26th April 2018. No Fusarium or Verticillium wilts were detected. Boll rot and seed rot was low with an average of 3.6% and 3.7% of bolls infected respectfully. The average incidence of tight lock was moderate at 18% (Figure 10), however the highest incidence was at 40%. This high level was due to the crop having a tall and dense canopy with a very high level of humidity. Mealybugs were prevalent in some fields causing significant damage, particularly to the tops of plants, however natural predators were evident in the crop (Figure 5). Sooty mould was observed on the lint at a low level (Figure 5).

Figure 5: Mealybug and sooty mould evident in a late planted crop. (Photo: Linda Smith)

Theodore: Fusarium wilt was detected in two fields with an average of 1.5% and 11.2% in the infested fields. No Verticillium wilt was detected. The average incidence of boll rot, seed rot and tight lock of fields surveyed was 4.3%, 2.3% and 4.4% with a range of 0-8.9%, 0-9.6% and 0-14.2% respectively. A low incidence of cotton bunchy top (CBT) was observed. A low incidence of Alternaria leaf spot was present.

Darling Downs

Fusarium wilt incidence was low with an average of 3%, with a range of 0-20%. No Verticillium wilt was recovered from stems with vascular browning. Alternaria leaf spot was minor, although this could not be determined for all fields as some had defoliant applied. Boll rot, tight lock and seed rot incidence was low with an average of 1%, 3% and 1% respectively. No viral diseases were observed. One field had more than 30% of stems with what appeared to be a vascular browning (Figure 6). However, where symptoms were more typical of Verticillium wilt, no pathogen was isolated. Lack of recovery of Verticillium from defoliated or drought suffered crops from stems with typical symptoms, was observed in both Qld and NSW. The pathogen may have switched over to the survival stage and therefore does not have many active mycelia and conidia which easily germinate on synthetic media. Alternatively, it is not known if the defoliant may have caused a physiological reaction in the stem.

FIGURE 6: Vascular browning observed in late season cotton from which Fusarium oxysporum f sp. vasinfectum was isolated from stem 7, however no pathogens were recovered from stems 6, 8 or 9. (Photo: Linda Smith)

St George

Fusarium wilt was the major pathogen detected, present in nearly half of the fields surveyed. The average incidence of Fusarium wilt was 8%, with a range of 0-46%. No Verticillium wilt was detected. Tight locked bolls were observed in every field surveyed, with an average incidence of 3%, ranging from 1-10%. Seed rot and boll rot were prevalent with an average of 5% and 2% respectively. Whitefly was widespread and mealybug was observed in one field.

Macintyre

Both Fusarium and Verticillium wilts were prevalent in this region, with an average disease incidence of 12% and 5% respectively. Fields with an incidence as high as 60% and 44% were recorded for Fusarium and Verticillium wilt respectively. Some fields were detected with the presence of both Fusarium and Verticillium wilts, which could be challenging in terms of stubble management and the selection of tolerant cultivars for the next season. The average percentage of tight lock, boll rot and seed rot was 1%, 6% and 3% respectively.

Gwydir

Fusarium, Verticillium wilts and Alternaria leaf spot incidence varied from zero to lower than 20% on surveyed farms/fields. However, there was an exception, where the incidence of Fusarium and Verticillium wilts were as high as 56%. Some fields were detected with the presence of both Fusarium and Verticillium wilts, which could be really challenging in terms of management of stem stubbles and selection of tolerant cultivars for the next season. Boll and seed rots were observed in most of the surveyed fields with the incidence mostly below 10%, excepting for one field where boll rot incidence was up to 40%. CBT was occasionally observed (Figure 7).

Figure 7: Confirmed Bunchy Top in the Gwydir. (Photo: Aphrika Gregson)

Lachlan

Alternaria leaf spot was prevalent in the late season surveyed fields (Figure 11). Disease severity, indicated by percentage of infected leaves was as low as 3% to up to 52%. For some fields where the disease severity was recorded above 25%, levels high enough to cause yield concerns. Fusarium and Verticillium wilts were not spotted in the surveyed transects; however, a number of Verticillium infected stems were present in several fields. Non-defoliating pathotype of *Verticillium dahliae* was recovered from these stems and confirmed with DNA markers. This highlights a concerning spread of Verticillium wilt into Southern regions. Boll and seed rots were also infrequently observed, the incidence was around 0-1% in most fields, except for one where the incidence was up to 3% on average. CBT was occasionally observed.

Murrumbidgee

Alternaria leaf spot was also prevalent in the late season surveyed fields. Disease severity was as low as 1% to up to 35% with levels above 25% high enough to cause yield concerns.. Fusarium and Verticillium wilts were not spotted in the surveyed transects; however, Verticillium infected stems were present and confirmed in one field. Non-defoliating pathotype of *Verticillium dahliae* was also confirmed with DNA markers. This highlights a concerning spread of Verticillium wilt into Southern regions. Boll rot was very infrequently observed, the incidence was around 1% in several fields. CBT was occasionally spotted.

Macquarie

Alternaria leaf spot appeared as a major disease in the late season surveyed fields. Disease severity was as low as around 2% to up to 24%. For some fields yield reduction related to the disease may be of concern. Presence of either Fusarium or Verticillium wilts was confirmed in some fields in the valley; however, with the incidence around 1-2%, yield reduction on these infested fields may be very minimal. It is noticed that both defoliating and non-defoliating pathotypes were present in the infested fields and confirmed with DNA markers. Boll and seed rots were infrequently observed; however, boll rot incidence in some fields may be up to 7%. CBT and tight lock were occasionally spotted.

Namoi

Upper Namoi: Verticillium wilt was detected in most of the surveyed fields (Figure 8). The disease incidence in the infested fields was as low as 1% to up to 98%, commonly found between 25-50%. Yield losses driven by Verticillium wilt might be significant in some fields, where there was early Verticillium infection and wilt expression in January and the Verticillium wilt incidence above 30%. Both pathotypes, defoliating and non-defoliating were detected in the region. For some fields, both of the pathotypes were recovered from the same fields. Fusarium wilt was also detected in some fields where the disease incidence remained around 1-10%; however, higher levels of up to 30% were observed. Alternaria leaf spot was minor in the region with the disease severity mostly below 5%. Boll and seed rot were quite prevalent where detected, the incidence varied from 1-10% on average. CBT was present.

Lower Namoi: Verticillium wilt was detected in all surveyed fields. The disease incidence in the infested fields was as low as 1% to up to 80%, commonly below 20%. Yield losses driven by Verticillium wilt are likely to be significant in some fields where incidence of early Verticillium infection and wilt expression in January was above 30%. Both pathotypes, defoliating and non-defoliating were detected in the region. Fusarium wilt was also detected in some fields where the disease incidence remained around 1-10%. Alternaria leaf spot was minor in the region with the disease severity mostly below 5%. Boll and seed rot were quite prevalent, where detected the incidence varied from 1-10% on average. Viral diseases: CBT was present.

Figure 8: Namoi – Verticillium 'hot spots'. (Photo: Aphrika Gregson)

Late season Fusarium

It is important to highlight the high incidence of Fusarium wilt in fields this season (Figure 9). Disease incidence was as high as 60%, 46%, 47% and 20% for the Macintyre, St George, Gwydir, Namoi and Darling Downs respectively. Highest incidence recorded in Central Queensland was only 2%. No Fusarium was detected within transects surveyed in the Lachlan or Murrumbidgee.

It is important to not become complacent of this disease and rely solely on host resistance. An integrated approach to management is extremely important to manage this disease, as it is with all soil borne pathogens.

Figure 9: High incidence of Fusarium wilt shown by vascular discolouration of stem cut plants. (Photo: Linda Scheikowski)

Figure 10: Tight locked boll. (Photo: Duy Le & Aphrika Gregson)

Figure 11: Cotton crop was severely affected by Alternaria leaf spot; leaf colour was significantly changed from green (front) to purple red (back). (Photo: Duy Le)

Common diseases of cotton

Sharna Holman, Qld DAF and CottonInfo

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

Alternaria leaf spot

Alternaria macrospora
Alternaria alternata

Symptoms

A. macrospora: brown, grey or tan lesions (spots) 3 to 10 mm in diameter on lower leaves, sometimes with dark or purple margins. Circular dry lesions on bolls. When a susceptible crop is exposed to a favourable environment then defoliation occurs rapidly (especially in Pima varieties). Affected leaves develop an abscission layer, senesce and then drop to the ground.

A. alternata: purple specks or small lesions with purple margins on bolls 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.
- Pima varieties are most susceptible.

Alternaria leaf spot. (Chris Anderson, NSW DPI)

Host range

The host range of *A. macrospora* includes cultivated cotton and some malvaceous weeds such as bladder ketmia, sida and anoda weed.

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.
- Use foliar fungicide applications for Pima varieties – NOT before flowering.
- Incorporate crop residues as soon as possible after harvest.
- Control alternative weed hosts and volunteer cotton plants.

Black root rot

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. Non-hosts include cereals, sunflower, brassicas such as canola and broccoli, onions and woolly pod vetch.

Black root rot. (Stephen Allen, CSD)

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 CompleteTM 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'.
- Time sowing to avoid cool temperatures if possible, but sow early if conditions are warm enough (minimum soil temperature of 16°C and rising). Temperature measurements should be taken in the fields where black root rot occurs.
- 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. FarmCleanse (used at 10%) is effective against *T. basicola* and is a useful aid to decontaminate vehicles after mud is removed. An alternative is Bio-Cleanse.
- Rotate with non-host crops (e.g. cereals, canola) for more than one season if possible.
- 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).
- Avoid legumes and control weeds.
- Control volunteer and ratoon cotton.
- 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 tight lock

Boll rots are caused by a number of pathogens, including fungi and bacteria. Tight lock refers to a type of boll rot, where the lock remains hard and fails to fluff out. The term seed rot is used to describe a boll rot which begins in the seed.

Phytophthora boll rot

Infected bolls quickly turn brown and become blackened (sometimes with areas of white mould on the surface before opening prematurely). The locks, which remain compact and do not fluff out, can be easily dislodged and fall to the ground. Symptoms are most prevalent on the lower bolls. Phytophthora boll rot usually occurs when soil is splashed up onto low bolls that are beginning to crack open or when low bolls are subject to inundation by tail water backing up into rows.

Sclerotinia boll rot

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 cottony 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.

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 and 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 high risk of infection.
- Boll rots and tight locks 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 fungi and bacteria involved in boll rots and host range varies between species. 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

- Field drainage should 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, if possible avoid rank and dense crop canopy 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.

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.

CBT has a distinctive leaf mottling. (Stephen Allen, CSD)

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 over-wintering 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, 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.
- Growers should also control volunteer cotton plants on their farms, especially near sheds, head ditches, water ways, riparian areas and roads.
- 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.

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.

Fusarium wilt. (Linda Smith, Qld DAF)

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 between 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 managed in-crop and during fallow periods.

IDM tactics

- If your farm is free from this disease, try to 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 CompleteTM 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 123 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 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 has a worldwide distribution within tropical and subtropical regions and was confirmed as a new pest to Australian cotton in late 2012, first identified in Central Queensland. 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 any weeds and cotton volunteers 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, but DO NOT STORE SAMPLES IN THE FRIDGE.
- Include information about the sample sheet (see page 123 for a form and checklist on sending plant samples for diagnosis).

Seedling diseases

Seedling diseases may be caused by numerous pathogens 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 (ie. by rain) and infection by other pathogens.

Host range

Seedling disease pathogens have a wide host range and can survive on the residues of many crops and weeds. 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 *Vertillicum 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).

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 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.

Verticillium wilt. (Stephen Allen, CSD)

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 also 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.

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 (ie. 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 123 for a form and checklist on sending plant samples for diagnosis.
- 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.

SENDING A SAMPLE FOR DIAGNOSIS BY A PATHOLOGIST – ATTACH A COMPLETED FORM TO EACH SAMPLE

Collected/Submitted by: (e.g. Cotton Regional Extension Officer)	Address/Email/Fax/Telephone:
Property name and field number:	Date collected:
Grower/Agronomist	Grower's address or area/locality:

Mark (X) as appropriate

SYMPTOMS	DISTRIBUTION	INCIDENCE/SEVERITY	CROP GROWTH STAGE
☐ Poor emergence or seedling depth	☐ One field only	☐ All plants	☐ Irrigated
☐ Leaves: spots or dead areas	☐ In several fields	☐ Scattered single plants	☐ Raingrown
☐ Leaves: discoloured	☐ In all fields	☐ Scattered patches of plants	☐ Seedling stage
☐ Leaves: mottled	☐ One variety only	☐ In a large patch (>5 m)	☐ Setting squares
☐ Leaves or shoots: distorted or curled	☐ Several varieties affected	☐ In a small patch (1-5 m)	☐ Early flowering
☐ Plants stunted	☐ Some rows more affected	☐ In a small patch (<1 m)	☐ Peak flowering
☐ Plants wilting	☐ On lighter soil types	☐ Plants dead	☐ First bolls open
☐ Premature plant death	☐ On heavier soil types	☐ Plants defoliating	☐ Defoliated
☐ Bolls: spots or dead areas	☐ In poorly drained area(s)	☐ One to a few plants only	☐ Ready to pick
☐ Roots: discoloured, bent, pruned, etc.	☐ Other: (please specify)		

OTHER INFORMATION

- Cultivar..
- Paddock History..
- Nearby crops..
- Rainfall in last 10 days..
- Average temperature range over the last 10 years..
- Date of last irrigation..
- Date of last cultivation..

Please contact your 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 noted. 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.**

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 35: 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 and Rene van der Sluijs (CSIRO)

Plant Growth Regulators

Excessive vegetative growth is a problem because it reduces the retention of fruit and delays maturity resulting in reduced efficacy of insecticides due to poor penetration of 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 additional to GA, cell expansion is driven by a number of factors including water availability, humidity and temperature.

For more information refer to 2018 Australian Cotton Production Manual.
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.

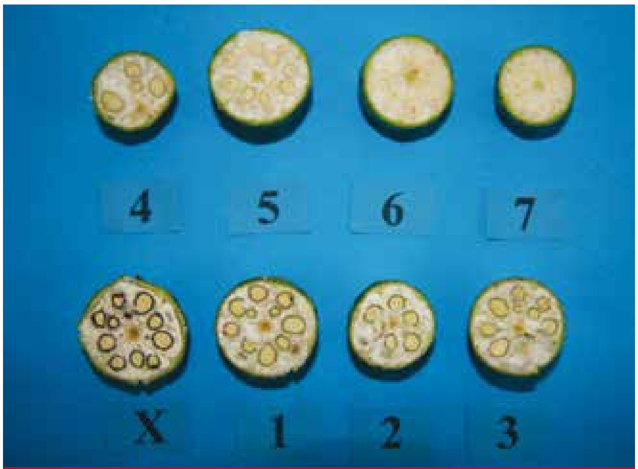
Defoliation

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 2018 Australian Cotton Production Manual.



X boll is the cracked P1 (position 1) boll and all the bolls above it are each P1 going up the plant. Note 1-4 bolls are mature whilst 5-7 bolls are immature with the last couple having `jelly seed'. (Photo: Paul Grundy, QDAF)

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 though 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, Cyclanillide, Aminomthanane, Dihydrogen Textraoxosulfate) – 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 36: 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	Cotton seed oil
	Paraffinic oil/non-ionic surfactant adjuvants
	Petroleum oil

- Wetting agents and spray adjuvants are available to assist with defoliation as cool temperatures, low humidity and water stress prior to defoliant application can result in increasing waxiness 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 beneficial because leaves deep in the canopy can be covered fully.

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.

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 can affect everyone, farmers, agronomists and the community, it is important that everyone plays a part in biosecurity, preparing for and managing threats. 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. In Queensland this responsibility is imposed as a 'General Biosecurity Obligation' (GBO) and in New South Wales as a 'General Biosecurity Duty' (GBD). Please see the links at the end of this section for more information regarding your responsibilities.

Anyone going on to farms has a biosecurity responsibility

- **Come Clean. Go Clean. –** Vehicles, farm equipment and people can carry pests, 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 tor 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.

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 131. It is important that users follow label directions for rates and use patterns.

Industry has a biosecurity responsibility

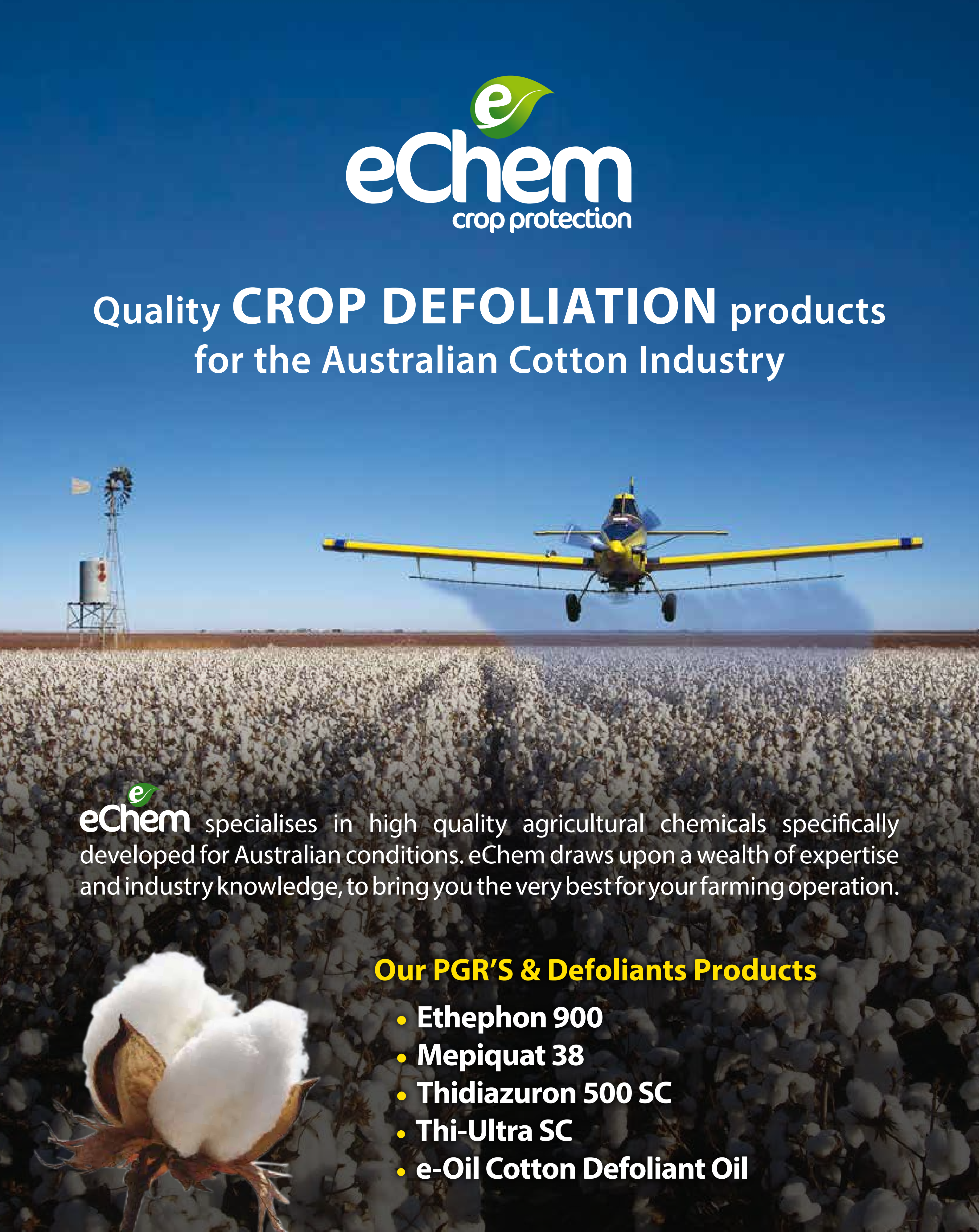
Plant biosecurity in Australia operates as a partnership between governments and industries, with all parties sharing responsibility for maintaining the integrity and performance of the plant biosecurity system. Plant Health Australia (PHA) is the national coordinator of the government-industry partnership for plant biosecurity in Australia, funded equally by the Australian Government, State/Territory Governments and plant industry members. Cotton Australia is a member and CRDC is an associate member of PHA.

Industries that join PHA are permitted to sign the Emergency Plant Pest Response Deed (the EPPRD) which is the formal legally binding agreement that sets out how eradication responses to emergency plant pest incidents are to be managed and funded. It also outlines a framework for reimbursing growers whose crops or property are directly damaged or destroyed in the course of a response plan.

Cotton industry biosecurity

The Industry Biosecurity Plan for the Cotton Industry was developed in consultation with the Industry Biosecurity Group, coordinated by PHA and included representatives from Cotton Australia, the Australian Government, relevant state/territory agriculture agencies, researchers and PHA. PHA, with funding from CRDC, has led the third review of the Cotton Industry Biosecurity Plan. 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.

A risk assessment carried out during the development of the Industry Biosecurity Plan identified 15 high priority pests that currently do not exist in Australia, that could establish in our farms and threaten production. These are described in the following section. While these threats have been highlighted through this process, it is important to ensure reporting of any unusual plant symptoms or pests.


eChem
crop protection
Quality CROP DEFOLIATION products
for the Australian Cotton Industry
eChem specialises in high quality agricultural chemicals specifically developed for Australian conditions. eChem draws upon a wealth of expertise and industry knowledge, to bring you the very best for your farming operation.
Our PGR'S & Defoliants Products
• Ethephon 900
• Mepiquat 38
• Thidiazuron 500 SC
• Thi-Ultra SC
• e-Oil Cotton Defoliant Oil

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

For more information on Come Clean. Go Clean. including available wash down products please refer to www.cottoninfo.com.au

TABLE 37: 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 38: Agricultural decontaminants

Active ingredient	Product name	Registrant
Benzalkonium chloride	Bactex CF	Whiteley Corporation
Didecyl dimethyl ammonium chloride	Path-X	Nutri-Tech Solutions
	Sporekiller	Nufarm
	Steri-Max	AgriCrop
Dodecylbenzene sulfonic acid sodium salt	Virkon S Broadsprectrum	Lienert Australia
Poly (hexamethylene biguanide)	F10SC Veterinary Disinfectant	Health and Hygiene Pty Ltd
	Microtech 7000 General purpose	Chemetall (Australasia) Pty Ltd
Potassium peroxymonosulfate	Virkon S Tablets	DuPont
Sodium dodecylbenzene sulphonate	Virugard	Farm Care
	Viraban	Bayer
	ViralFX	Spick N Clean Products

Department of Primary Industries

GRAINS FARM BIOSECURITY PROGRAM

Queensland Government

CottonInfo

Come Clean. Go Clean.

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

A GUIDE TO EFFECTIVE WASH DOWN OF VEHICLES AND MACHINERY

1 WASH DOWN

- Use compressed air or high pressure water to remove caked on trash and mud
- Get into crevices where mud or trash might be trapped
- Clean out the inside of the car, particularly foot pedals and mats regularly in contact with dirty footwear

WHERE

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

2 CLEAN

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

*unless otherwise directed by product label

Image: NSW DPI

REMEMBER

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

3 DECON

- After removing physical dirt, consider using an agricultural decontaminant to kill any remaining pests or pathogens
- Refer to the APVMA for registered decontaminants and follow label instructions
- An additional rinse step may be necessary following disinfection

NOTE

Make sure vehicles and equipment are clean and free of mud and trash before applying a decontaminant

Image: cleanandtry.net.au

4 RINSE

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

CHECK

Equipment that has not been cleaned on farm should be thoroughly inspected to ensure cleanliness

Images courtesy of Sharna Holman, QDAF, unless otherwise stated

Together we can stop the spread of pests, weeds and diseases.

BE A GOOD MATE STOP IT AT THE GATE

JN14825_APR18

Exotic pests and diseases of greatest threat to Australian cotton

Cotton boll weevil

Anthomonus 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 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.

Brown marmorated stink bug. (Source: Steven Valley, Oregon Department of Agriculture, Bugwood.org)

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

Thaumatotibia leucotreta

False codling moth is a pest of economic importance to many crops in its native habitat including avocado, citrus, corn, cotton, macadamia, peach and plum. Adult false codling moths are small, brownish-gray moths up to 20 mm, with a triangular mark on the outer part of the wing with a crescent shaped mark above it.

False codling moth larvae (left) and female moth (right). (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 disruptful 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 gossipyi – 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.

Best practices for aerial and ground 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)

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 and Application Management Plan (PAMP) is an important part of the Best Management Practice (*my*BMP) 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 ASABE[1] or BCPC[2] 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.

Be aware that the new ASABE standard (S572.1) has been introduced and requires nozzles to be tested with an adjuvant added (compared to the old standards that only required water). The new standard makes the spray qualities appear smaller than those previously published. Before purchasing a new set of nozzles, 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 NO SPRAY ZONE cannot be sprayed when the wind is towards the sensitive area (which may be a residence, public area, water body, pasture, terrestrial vegetation or another susceptible crop), ie. 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 now included on the label or permit of 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.

Open communications with neighbours is critical when using Roundup Ready Flex or Liberty Link cotton. Herbicide drift onto fields of cotton without the appropriate tolerance traits can result in serious yield losses.

Cotton is extremely sensitive to phenoxy via off-target application. To assist with reducing drift it is essential that you identify your cotton fields on the CottonMap website (www.cottonmap.com.au). This map will be used by spray contractors, resellers, agronomist and neighbours to identify crops.

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 Spraywisedecisions.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. Alternatively on-board weather stations that provide live weather information while the sprayer is operating (such as the Watchdog systems) are available.

***my*BMP 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

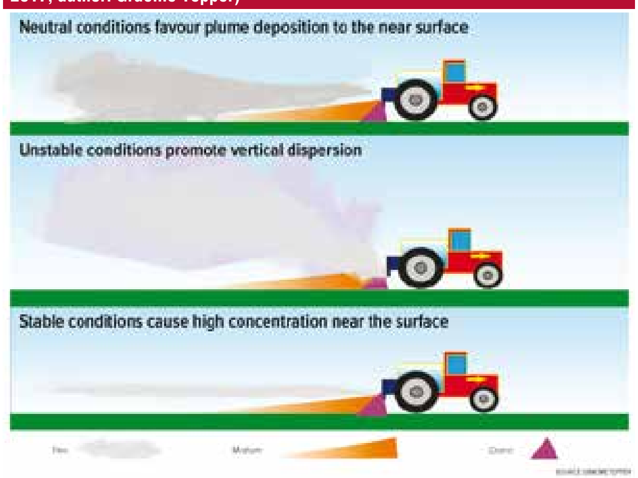
Higher ambient air temperatures and lower relative humidity conditions increase evaporation rates. Since droplet size of water-based sprays decreases rapidly with higher evaporation rates, drift tends to increase.

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 more than 2 and less than 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 *my*BMP 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.

***my*BMP resources: Tips for reducing drift fact sheet**

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 and Tips to reduce spray drift, or refer to 24 hour spray diagram on page 138.

***my*BMP resources: GRDC Surface temperature inversions and tips to reduce spray drift**

Vegetative plantings for spray drift barriers

Effective vegetative barriers can reduce drift by as much as 60 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, 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 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-drift-cotton

Summary of factors that influence spray drift and best practice

The aim of spray application is to transfer active ingredients through the atmosphere to the target in an effective manner with minimal off-target losses. 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

For more information on best practice for aerial and ground spray application go to www.myBMP.com.au.
(Photo: Cotton Australia – Jack Hawkins)

- Nozzle selection
- Maintenance and hygiene

These factors are expanded in the Australian Cotton Production Manual.

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, refer to legal responsibilities in use of pesticides chapter.

Operators should also be trained and accredited. Some examples of training and accreditation include:

- Operation Spray Safe is an Aerial Application Association of Australia (AAAA) initiative which aims for continuing improvement and professionalism in the application of agricultural chemicals by aircraft. More information can be found at http://www.aerialag.com.au/ResourceCenter/Programs/Spraysafe
- 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

[1]American Society of Agricultural and Biological Engineers
[2]British Crop Production Council

Further information:

2018 Australian Cotton Production Manual

Spray Drift Management Principles, Strategies and Supporting Information, www.publish.csiro.au/Books/download.cfm?ID=3452

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

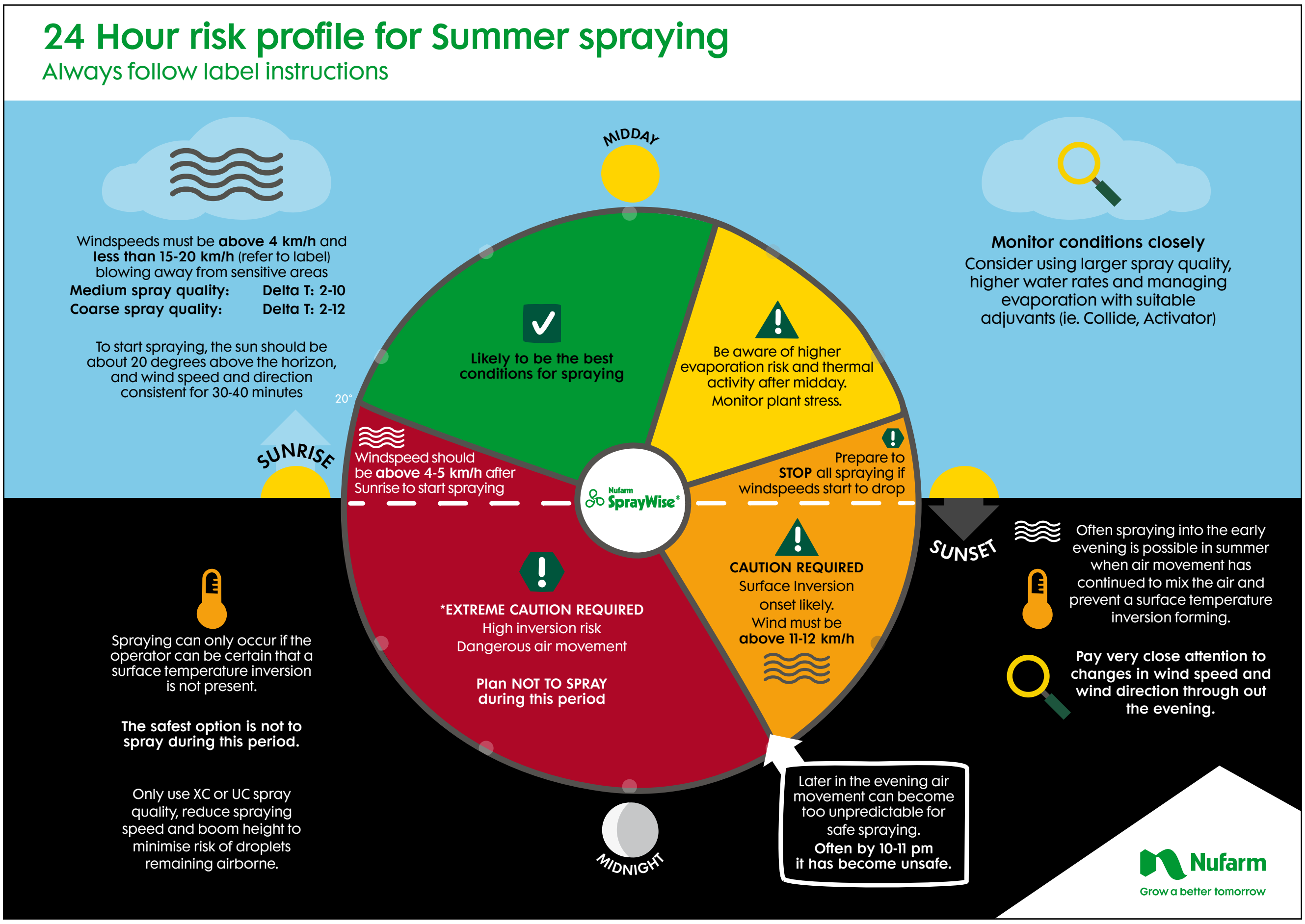
Spraywise – Broadacre Application Guide – Available through Croplands Distributors.

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/nrmpesticide-input-efficiency-using-vegetative-barriers-minimise-spray-drift-cotton

For aerially-applied 2,4-D sprays, from wind tunnel research, see www.aerialag.com.au

Additional resources can be found at www.myBMP.com.au



Calculating banded sprays

By **Bill Gordon**, Nufarm & **Graham Betts**

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/ha to the actual target area). There are often big differences between the consultant's recommendation, the applicator's instincts and what the machine can actually do with the nozzles available.

Often people want to know the actual application rate and how much chemical to put in the tank (based on green ha or sprayed ha), how far a tank will go (based on paddock ha) and what rate to put in the spray controller. Others want to know what nozzles they should use to achieve a recommendation they have received from their advisor.

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 (L/sprayed ha sometimes called L/green 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, (unless you want to play around with section widths)*.

Formula

(The following are a selection, there are many that work.)

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).

The application rate = **L/sprayed ha: L/sprayed ha = L/min/nozzle x 600 ÷ speed (km/h) ÷ 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.

Number of sprayed ha per tank = **Tank size (L) ÷ L/sprayed ha.**

Amount of chemical to add per tank = **Sprayed ha per tank x chemical rate/ha.**

Paddock ha per tank (solid plant): = **Sprayed ha per tank ÷ band width (m)**.

Paddock ha per tank (Skip Row Configurations): e.g. Double Skip on 1 m row spacing (only planted 1 out of every 2 rows), this would be the same as only spraying 12 x 1 m rows with a 24 m boom.

Paddock ha per tank (skip) = Sprayed ha per tank ÷ the band width (m) x width of boom ÷ row width (m) ÷ number of planted rows under the boom.

Rate to put in the Controller: = Tank Size (L) ÷ Paddock ha per tank

***This works if you don't want to change the section widths in the controller.**

Selecting the correct nozzle size for a particular job

To work out what size nozzles you need to get a particular L/sprayed ha, you need to know what the required flow rate of each nozzle (L/min/nozzle) should be. If all nozzles are the same size this is relatively easy, as the flow rate will be the same for each nozzle.

For example the average sprayed width per nozzle if you had 5 nozzles per 1 m row at 100% band would be 1 m ÷ 5 = 0.2 m.

If you had 4 nozzles per 1 m row and a 70% band, then the average sprayed width would be 0.7 m ÷ 4 = 0.17 m.

To calculate the required flow rate of each nozzle, the formula you need to use is: **L/min/nozzle = L/sprayed ha ÷ 600 x speed (km/h) x average width of each nozzle (m).**

If you are using different combinations of nozzle sizes, you can still use the same formula, but it helps to work out the total flow rate for each band (or row), to do this, change the average width per nozzle to the band width or spray width per band (row) to get the total flow required per band (or row) and select nozzles with flow rates that add up to that total (all at the same pressure). Once you have calculated the required L/min/nozzle use a nozzle flow chart to identify appropriate nozzle sizes and pressures, and don't forget to check the spray quality produced to ensure it is consistent with the product label.

Useful resources:

- **The *my*BMP 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**

Legal responsibilities in use of pesticides

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.

A regulation was gazetted in 2017 requiring all commercial pesticide users, ie. 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);

An example form that captures all the information required by the Pesticides Regulation 2017 is provided on page 144. 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.

Records must be made within 24 hours of application, be made in legible English, and kept for 3 years.

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.

The minimum prescribed training qualification will be the AQF2 unit of competency, 'Apply chemicals under supervision', although owner-applicators are encouraged to train and be assessed in the two higher AQF3 competencies, 'Prepare and apply chemicals' and 'Transport, handle and store chemicals'.

Growers are recommended to undertake the SMARTtrain course, Chemical Application, or the standard ChemCert course, both of which cover the higher AQF3 competencies. For growers with literacy and/or numeracy problems, the lower level AQF2 competency will provide a minimum qualification that satisfies the Regulation.

An important change in the 2017 regulation for cotton growers is: cotton growers who are accredited under a QA program that includes chemical recording and management records are no longer obliged to retrain every 5 years.

Cotton growers who would like to take advantage of this new addition to the regulation should contact the NSW Environment Protection Authority (EPA) for more information.

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 2018, 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, *drum*MUSTER/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. *my*BMP 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. *drum*MUSTER 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 *drum*MUSTER receival 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 *drum*MUSTER 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 *drum*MUSTER 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 *drum*MUSTER program phone 1800 008 707 or contact your local representative:		
Northern NSW	**Southern NSW**	**Queensland**
Phil Tucker	**Vernon Keighley**	**Colin Hoey**
0427 925 274	**0406 745 030**	**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.

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.

■ **Spray Application** – *sponsored by* CASE AGRICULTURE

Pesticide Application Record Sheet

NSW GOVERNMENT | Industry & Investment

Location, Applicator, Date of Application

Property/Holding: (residential address)					Date:
Applicator's Full Name:			Owner (if not applicator):		
Address:			Address:		
		Phone:			Phone:
Mobile:	Fax:	Email:	Mobile:	Fax:	Email:
Sensitive Areas (including distances, buffers): N W Treated Area E S			Comments (including risk control measures for sensitive areas):		

Host/Pest

Paddock Number/Name:	Paddock Area:	Order of Paddocks Sprayed:

Crop/Situation:	Type of Animals:
Crop/Pasture Variety:	Age/Growth Stage:
Growth Stage:	Mob/Paddock/Shed:
Pest/Disease/Weed:	Animals — Number Treated:
	Pest Density/Incidence: Heavy ❑ Medium ❑ Light ❑

Application Data

Full Label Product Name:			Rate/Dose:		Water Rate L/ha:
Permit No.:	Expiry Date:		Additives/Wetters:		
Total L or kg:	WHP:	ESI*:	Date Suitable for Sale:		
Equipment Type:		Nozzle Type:		Nozzle Angle:	Pressure:
Date Last Calibrated:	Water Quality (pH or description):				

Weather

Showers ❑ Overcast ❑ Light Cloud ❑ Clear Sky ❑

Rainfall (24 hours before and after)
Before: mm During: mm After: mm

Time (show time in this column)	Temperature °C	Relative Humidity (%)	Wind Speed	Direction	Variability (e.g. gusting)
Start					
Finish					

Comments:

* When using herbicides in mixtures with fungicides and insecticides, an ESI may apply to the non-herbicide component of the mixture.

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 *my*BMP.

Most insecticides are toxic to aquatic organisms, bees and birds. 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, ie 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.

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 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 (ie. 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) and Nicola Cottee (formerly Cotton Australia)

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 verroa 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. For the majority of insecticides used in cotton the residual toxicities are unknown. Table 39 (page 148) summarises the currently available information. 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 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

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

VIC DPI
Joe Riordan (Leading Apiary Inspector)
Ph: 03 5723 8668 Mob: 0417 348 457
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Qld Beekeepers Association
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Qld DAF
Biosecurity Queensland
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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 vacinity 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."

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:

- Register on BeeConnected and map your cotton fields in CottonMap;
- 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.

BeeConnected

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/

TABLE 39: Cotton insecticides with known residual toxicities to honeybees. This table highlights products with known residual toxicity to bees. Also refer to Primefact 149 (July 2015 edition) and Table 3 for a more extensive list of pesticides with toxicity to bees.

Active Ingredient	Chemical group	Residual toxicity to bees	Comment
betacyfluthrin	synthetic pyrethroid	>1 day	Longer residual expected in Australian conditions.
carbaryl	carbamate	up to 7 days	Up to 7 days for WP formulation; SC formulation will be less depending on rate.
chlorpyrifos	organophosphate	up to 1 day	Toxic to bees. DO NOT spray any plants in flower while bees are foraging.
clothianidin	neonicotinoids		Residues may remain toxic to bees several days after application.
chlorfenapyr	pyrole		Foraging behaviour could be affected for >2 days
chloratraniliprole/ thiamethoxam		5 days	Highly toxic to bees. No commercial hives near sprayed area for up to 5 after spray.
cyantraniliprole	diamide		Toxic to bees do not spray flowering plants.
dinotefuran		2-3 days	Highly toxic to bees. Do not spray when flowering.to protect long term viability of beehives remove or cover during application and for up to 5 days after treatment.
dimethoate	organophosphate	up to 3 days	Toxic to bees. DO NOT spray any plants in flower while bees are foraging.
emamectin benzoate		up to 7 days	Highly toxic to bees. do not spray any plants in flowering while bees are foraging.
esfenvalerate	synthetic pyrethroid	2 day	Dangerous to bees. Do not spray on any flowering plants while bees are foraging.
fipronil	phenyl pyrazole	7 to 28 days	Long residual. Extremely toxic to bees.
lambda–cyhalothrin	synthetic pyrethroid	not on label	Risks is reduced by spraying in the early morning or late evening. Do not spray when flowering.
methidathion	organophosphate	3 days	
spinetoram		3 days	Highly toxic to bees. will kill bees foraging in crop.
spinosad	spinosyn	not on label	Not hazardous once the spray has dried. Avoid drift onto hives.
sulfoxaflor			Highly toxic to bees before spray dries. Do not apply while bees are foraging.

Source: Primefact 149, Pesticides – a guide to their effect on honeybees, 2nd edition, July 2015.
Refer to Primefact 149 and www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/65963/pesticides-a-guide-to-their-effects-on-honey-bees.pdf for more information.

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.

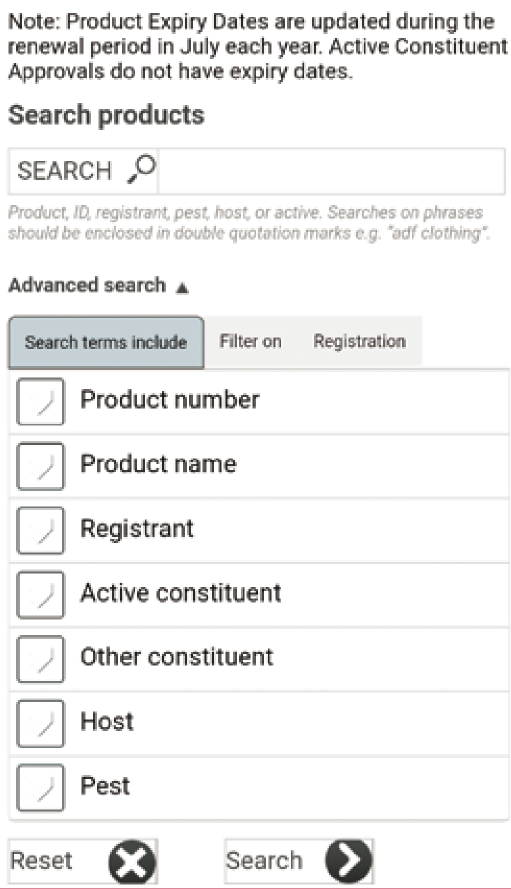
Guidance for applications to vary a product pack size and to vary product manufacture sites is available now, with more guidance for other common application types to be made available soon.

Access tailored guidance for applicants at: https://apvma.gov.au/node/27441

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



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.

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

Where no re-entry period is stated, a minimum of 24 hours should be observed or until the chemical has dried upon the crop, whichever is the later (subject to risk assessment), unless appropriate Personal Protective Equipment (PPE) is provided and worn as intended. Caution should be exercised when entering wet crops where chemicals have previously been applied, irrespective of the time lapse between application and re-entry.

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.

If entry is necessary before the time stated, limit duration of entry and wear cotton overalls buttoned to the neck and wrist (or equivalent clothing), a washable hat, and elbow-length chemical resistant PVC gloves. Clothing must be laundered after each use each day.

Re-entry periods may change or be added to labels as chemicals are re-evaluated. Always read the label before using.

TABLE 40: 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 12 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.
Chlorpyrifos	Do not allow entry into treated areas until spray deposits have 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.
Etoxazole	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 until spray deposits have dried.
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 re-entry into treated areas until spray has dried.
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.

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 41: 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
Bacillus thuringiensis	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.
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	Adhere to the withholding periods specified on the label of the companion products used.
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.
Pyripoxyfen	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.

Meet our team

Led by CottonInfo Program Manager Warwick Waters (0437 937 074, warwick.waters@crdc.com.au), and supported by Communications Manager Ruth Redfern (0408 476 341, ruth.redfern@crdc.com.au) the CottonInfo team of Regional Extension Officers, Technical Leads & *my*BMP experts are all here to help!

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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*my*BMP team

The *my*BMP team run the industry's best management practice program, *my*BMP. Contact the *my*BMP team to learn more about - or to participate in - *my*BMP.

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