MANAGING WEEDS IN COTTON

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Introduction

A successful cotton farm is a complex enterprise, integrating a wide range of competing needs into a sustainable, dynamic system. Insects, water, diseases, weeds, soil, environment, economic and social demands must all be juggled in a system that is sustainable in both the short- and long-term. The needs of each area must be met and balanced so that conflicting demands are directed into a dynamic equilibrium in a functioning farm system that is sustainable in the long-term.

Weed management has to be an important component of the sustainable farming system, with weeds managed to ensure they don't adversely compete with crops, don't contaminate product, and aren't going to be problematic in future years. Weed management systems need to be sustainable in economic terms, in environmental terms, and in functional terms.

Simple weed management systems centred around glyphosate have been widely adopted by farmers over the last decade and more, and have ticked many of the boxes.

Glyphosate centred systems have been highly effective for controlling weeds, are relatively inexpensive, can be targeted to growing weeds and can be rapidly applied to large areas. They have been able to replace most other weed management tools, improving timeliness of control and greatly reducing the machinery requirement and labour force needed to manage weeds. The glyphosate system has been an important part of achieving the very high yields that have become the normal in the Australian cotton industry of the new century, valuable both for weed control in-crop, and for managing weeds in fallows, facilitating the development of moisture conservation and stubble retention systems.

Glyphosate is a relatively benign herbicide in the environment. Off-target drift of glyphosate to sensitive areas has occasionally been a problem when sprays have been applied in very unsuitable conditions, but glyphosate is not particularly prone to drift issues and it has relatively few off-target issues in soil or water and so ticks the

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Weeds compete strongly with cotton. Weeds reduce yields, reduce lint quality, obstruct harvest operations and injure workers. This crop will be very low yielding and difficult to harvest due to the heavy weed infestation.

A cotton field severely impacted by glyphosate resistant Palmer amaranth in the US. A field like this will require large inputs of herbicides, cultivation and hand-hoeing to produce a cotton crop next season. Photo: J. Norsworthy.

environmental box as well or better than most other herbicides.

Even the long-term sustainability issue appears to be relatively minor with glyphosate. Repeated use of glyphosate will eventually lead to weeds developing resistance to this herbicide, but this problem will take a long time to develop, and when it does occur, it can be solved by simply reintroducing one of the other chemistries – or so we thought.

Unfortunately, we have been using a glyphosate centred system for many years now, and sufficient time has passed that resistance has developed, and in more than just one species. The system is rapidly falling apart. The system is no longer sustainable in the long-term or even the medium-term and failure to change our approach to weed management now will result in Australia joining a growing list of countries where glyphosate technology has already been effectively lost for many of their most troublesome weeds.

However, it doesn't just stop there. The loss of glyphosate for managing the worst weeds in these countries has been followed by the successive loss of the most useful alternative chemistries, with these herbicides also falling to resistance in rapid succession.

Much of the US cotton industry has gone from being a "magic" industry a decade ago, where all weeds were cheaply controlled by a couple of in-crop applications of glyphosate, back to a "slave' industry, where weeds are king, demanding heavy inputs of expensive herbicides, inter-row cultivation and large amounts of hand-hoeing to manage them. In some instance, requiring levels of inputs that would make the Australian cotton industry economically unviable, with multiple herbicides, cultivation and hand-hoeing bills of over $1000/ha in Australian terms, just to produce a harvestable crop.

That the industry has selected for glyphosate tolerant and resistant weeds over the last decade it not surprising. However, the trap of the glyphosate centred system, is the assumption that problems can be solved by re-introducing single components of the conventional system. A pre-planting application of diuron, for example, is becoming widely used to manage glyphosate-resistant flaxleaf fleabane. After all, diuron was routinely used for over 30 years without any resistance issues to this herbicide emerging, so it seems like a good option. However, this thinking fails to recognise that diuron was not formally used alone but as one part of a whole system of residual herbicides and other tools, with the system often including diuron, trifluralin, fluometuron, pendimethalin, prometryn, inter-row cultivation and hand hoeing. To now expose glyphosate-resistant fleabane to diuron without any of the other tools is to place very high selection pressure on this weed, and is likely to see resistance emerge within only a few years.

The need to develop an approach to weed management that is sustainable in economic terms, in environmental terms, and in functional terms is a far bigger challenge than it may at first appear. The adoption of a glyphosate centred system doesn't cut it, and can't be patched by just adding a 2nd herbicide to manage problem weeds. Persisting with a glyphosate centred system is a sure path to failure, with dire consequences, as the US industry are now proving, with many of the more problematic weeds in the US having multiple resistance often to 4 or 5 modes of herbicidal action.

A sustainable weed management system must embrace a farming systems approach. To achieve this, a cotton grower must manage weeds on his roads, irrigation channels, fence lines, non-cotton areas, fallows and rotation crops, as well as managing weeds in cotton crops. The costs of effective weed control may initially be high, but the benefits accrue over subsequent years.

To facilitate developing an integrated weed management system, this guide has been written in three sections.

A. WHY MANAGE WEEDS IN COTTON,

B. THE TOOLS FOR WEED MANAGEMENT, and

C. PUTTING IT TOGETHER.

Developing an integrated weed management system for cotton is further discussed in Section B3 of WEEDpak, Integrated Weed Management (IWM) Guidelines for Australian Cotton Production.

A. WHY MANAGE WEEDS IN COTTON

Direct impact of weeds

Weeds adversely affect cotton in many ways. Weeds primarily compete for available nutrients, water and light. They can also directly impact cotton quality through contamination of cotton fibre or through contamination of cotton seed. Contamination of cotton fibre may necessitate additional processing at the cotton gin or may result in downgrading of fibre quality. Weeds may also act as alternate hosts of pests or diseases that affect cotton, they may reduce irrigation, cultivation and harvesting efficiency, and they may cause physical injury to operators in cotton fields, such as bug checkers, machinery operators and irrigation staff.

Even a single weed, such as a large fierce thornapple (*Datura ferox*) can compete strongly with cotton. The economic threshold for controlling fierce thornapple by hand-hoeing may be less than 1 weed per 100 m of cotton row, based purely on cotton yield reductions through competition. In addition, thornapples can host heliothis, mites and verticillium wilt, can block cultivation and harvesting equipment, and can cause serious injury to field workers. Thornapple seeds may also contaminate cotton seed. Consequently, the decision to manage even a light population of thornapples may be justified on economic grounds when all these factors are combined and added to the expected future cost of control should the plants be permitted to set seed.

Weeds also impact cotton production indirectly, as many of the alternative tools used to manage weeds are expensive and can adversely affect cotton to some extent. Many of the residual herbicides registered for used in cotton can kill cotton seedlings if they are incorrectly applied, or if adverse weather conditions occur soon after application. Most of the residual herbicides will cause some degree of leaf or root damage even when correctly applied under suitable conditions, and may make plants more vulnerable to attack from pathogens.

While the degree of damage from residual herbicides is normally minimal, not affecting yield, it is still wise to avoid the overuse of these herbicides.

Even non-chemical weed control inputs, such as inter-row cultivation and hand-hoeing, have their costs, with cultivation inevitably pruning some surface roots and hoeing often leading to some inadvertent crop damage.

Weeds can compete strongly with cotton. Weeds reduce yields, reduce lint quality, obstruct harvest operations and injure workers. The economic threshold for hand hoeing fierce thornapple is 1 per 100 mm of row.

Weed competition

Cotton seedlings have relatively poor vigour and compete poorly against weeds early in the cotton season. Even moderate levels of weed infestation can reduce cotton yields.

Cotton seedlings are slow to emerge from the soil and grow slowly in cool spring conditions. This slow growth leaves a wide window for weed competition. Most weeds that emerge with the cotton grow more quickly than the crop, enabling them to shade the shorter cotton seedlings, and to better exploit water and nutrients from deeper in the soil than is available to the crop. This is especially a problem for dryland (non-irrigated) cotton production, where a lack of soil moisture near the soil surface can limit the growth of cotton seedlings.

All seedlings exploit water and nutrients from the moment they emerge from the soil, although especially in the cooler, southern areas, seedlings initially have very small requirements. Resource use rapidly increases as the seedlings grow. There will be no reduction in cotton yield if weeds are removed at or shortly after emergence. However, yield reductions may occur if weeds are not controlled soon after emergence, depending on the weed competitiveness and density.

Weed control needs to be maintained for many weeks after cotton emergence to achieve maximum cotton yields. Older, well-grown cotton plants have a large leaf canopy and a deep, extensive root system, enabling them to be very competitive, shading the soil surface and exploiting soil resources to depth. Consequently, weeds that emerge late in the season have no impact on cotton yield, although they may still cause problems with defoliation, can interfere with picking, can contaminate lint, can cause staining on the lint and can produce large amounts of seed, causing problems in later years.

In situations of limited soil moisture, cotton plants may not grow to shade the inter-row areas and not develop sufficiently well to compete strongly with weeds. Consequently, in these crops, weeds that emerge from summer rains may still have an impact through competition for soil moisture.

In skip-row cotton, weeds that emerge in the non-planted skips require long-term control. As there is no cotton planted in these rows, these weeds do not compete directly with the cotton crop early in the season and so may be tolerated for longer than weeds growing in the cotton rows. However, as these weeds grow, they begin to utilise the resources that may be required by cotton later in the season, and so compete directly with the crop. Mid- and late-season control of these weeds is important.

The precise length of this critical period of competition depends on the density of weeds, the growth rate of the crop and weeds, and the scarcity of resources.

Much more detailed information on the threshold densities for weed control can be found in Section B4 of WEEDpak, Optimising IWM Using a Weed Control Threshold.

Other effects of weeds

Weeds impact on cotton production in other, additional ways. Weeds can act as hosts of cotton pests and diseases, and volunteer cotton can itself be a 'weed' in cotton and rotation crops. Cotton volunteers with the Roundup Ready Flex® trait can be especially difficult to manage in systems where glyphosate is used as the primary means of weed control in fallows, as these plants have been genetically engineered to by resistant to all formulations of glyphosate.

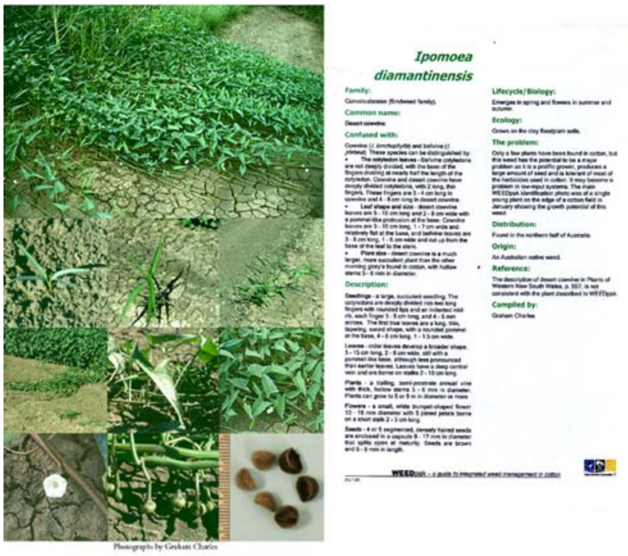
Weeds and volunteer cotton can also be hosts to aphids that are implicated with cotton bunchy top.

Cotton diseases may carry over on weeds, but many weeds in fallows are also hosts for VAM, which are beneficial soil microorganisms. Management of weeds on fields infested with fusarium wilt is an important issue as weeds may be symptomless hosts of fusarium.

Weeds may also adversely impact on cotton harvestability and lint quality. Large weeds such as thornapple, noogoora burr and sesbania can obstruct or damage cotton picker heads, leading to expensive breakdowns and down time. Vines such as cow vine, bell vine and yellow vine can tangle in picker heads, leading to significant down time as heads are cleaned.

All weeds have the potential to discolour or contaminate cotton lint. Grass weeds, such as nutgrass, which grow in the cotton row, or blow-away grass, which can be blown into the cotton row from non-cotton areas, are a particular problem as grass fibres are difficult to remove from lint. Consequently, weeds that emerge late in the season may still need to be controlled, as they impact on cotton harvestability and lint quality, even though they do not directly affect cotton yield.

All weeds should be controlled before they set seed, regardless of where they occur in the farming system. Research has shown that many of the weed problems that were formally attributed to hard-seededness in weeds, with the assumption that weed seeds survived for many years in the soil, were in fact due to the small number of late emerging weeds that occur every season and go on to produce a small amount of new seed, often undetected. This is not to discount the importance of weed seeds potentially surviving for many years in the soil, but does emphasise the need to prevent all weeds from setting new seed, perpetuating and often increasing a weed problem. The value of months of expensive weed control inputs earlier in the season can be nullified by a few unmanaged weeds at the end of the season.



Material to assist with identifying weeds at all growth stages is available in WEEDpak in Section A, the Weed Identification and Information Guide. This example is of desert cowvine, a native morning glory (Ipomoea) species occasionally found in cotton.

Weed identification

Common names for weeds can vary from area to area, often creating confusion when discussing control options.

Correct weed identification is an essential component of weed management. While inter-row cultivation does not discriminate between different weeds, herbicides have better activity against some weeds than others. Accurate weed identification is essential for correct herbicide selection and for selection of the appropriate chemical rate. While plants are most readily identified from their flowers, identification of plants at earlier growth stages is critical for efficient weed management. Often, small weeds can be most easily identified by finding larger examples in the field or surrounding areas.

Section A, the Weed Identification and Information Guide in WEEDpak is the first step for identification of weeds in cotton. This guide gives detailed information of a range of the weeds often found in the cotton system, with many photographs of each weed including seeds, seedlings, small plants and flowering stages.

Assistance with identification is also available through other publications, the internet, myself (Graham Charles) at NSW Dept. Primary Industries, Narrabri, Jeff Werth at the Queensland Department of Agriculture, Fisheries and Forestry, Toowoomba, and many of the industry support people including cotton consultants and chemical company representatives.

Alternatively, identification of flowering plants can be obtained from the herbariums located in the Botanical Gardens in each state.

In order to avoid misinterpretation in this document, the recommended common names used by Shepherd *et al.* are given precedence over other common names. Some of the more commonly confused local names are shown in Table 1.

Grass fibres are difficult to remove from cotton lint, downgrading cotton fibre quality.

Table 1. *Some weeds that are easily confused, or have more than one commonly used name. The common names listed here and accepted elsewhere in **WEED**pak are those accepted by Shepherd, Richardson and Richardson (2001), in Plants of Importance to Australia, A Checklist.*

Accepted common name	Botanical name	Other names
bellvine	*Ipomoea plebeia*	morning glory
cowvine	*Ipomoea lonchophylla*	peachvine
black bindweed	*Fallopia convolvulus*	climbing buckwheat
bladder ketmia (narrow leaf)	*Hibiscus tridactylites*	wild cotton
bladder ketmia (broad leaf)	*Hibiscus verdcourtii*	wild cotton
caltrop	*Tribulus terrestris*	cathead, bullhead
spineless caltrop	*Tribulus micrococcus*	yellow vine
caustic weed	*Chamaesyce drummondii*	caustic creeper, flat spurge
ground cherry	*Physalis ixocarpa*	annual ground cherry, Chinese lantern, physalis, gooseberry, wild tomato
wild gooseberry	*Physalis minima*	Chinese lantern, gooseberry, physalis
jute	*Corchorus olitorius*	native jute
legumes:		
• emu-foot	*Cullen tenax*	native lucerne, wild lucerne
• rhynchosia	*Rhynchosia minima*	ryncho
• sesbania pea	*Sesbania cannabina*	yellow pea bush, sesbania
liverseed grass	*Urochloa panicoides*	urochloa
melons:		
• wild melon	*Citrullus lanatus*	Afghan melon, camel melon, paddy melon, pie melon
• prickly paddy melon	*Cucumis myriocarpus*	paddy melon
polymeria	*Polymeria longifolia*	peak downs curse, polymeria takeall
annual polymeria	*Polymeria pusilla*	takeall, run-a-mile, inch weed
small-flowered mallow	*Malva parviflora*	marshmallow
common sowthistle	*Sonchus oleraceus*	sowthistle, milk thistle

B. THE TOOLS FOR WEED MANAGEMENT

Weed management tools

Weeds can be managed using a combination of the following tools:

- herbicides
    - in-fallow
    - pre-planting
    - post-planting
        - over-the-top
        - directed sprays
        - shielded sprays
        - lay-by sprays
    - spot-spraying
    - pre-harvest, and
    - post-harvest
- crop agronomy and management
- irrigation management
- transgenic, herbicide tolerant cotton varieties
- cultivation and inter-row cultivation
- hand weeding (hoeing)
- flame weeding
- field hygiene of
    - machinery
    - seed and other inputs
    - vehicles and water
- crop rotations
- management in fallows
- weed management on
    - rotobucks
    - roads
    - irrigation structures
    - fence lines
    - non-cropping areas

Selection of the ideal combination of weed management tools must be made on a year-by-year and field-by-field basis. Field history and expected weed pressure and diversity, expected cotton price and yield, available machinery and labour, available soil moisture and irrigation, crop growth stage, planting configuration and environmental conditions all affect weed management decisions. The cotton grower must weigh up the need for weed control against the cost of control, both in terms of the actual cost of the control measures, and in terms of the any potential cost of damage resulting from the control measures. He must also consider the potential increase in the weed pressure in following seasons as a consequence of not controlling weeds and allowing them to set seed.

All weed control tools have the potential to cause some damage to cotton. Inter-row cultivation, for example, prunes some surface cotton roots. Many herbicides also cause some damage to cotton and will delay crop maturity to some extent. This effect is minimised when management tools are used correctly and the yield impact from the tools is normally much smaller than the impact of the weeds if they were not controlled. In all cases, the key to effective weed control is timeliness of operation and the use of well set up equipment. Crop, soil and weather conditions must also be taken into consideration.

Over the last decade, the widespread adoption of weed management systems centred around cotton varieties with the glyphosate tolerant Roundup Ready Flex® trait has allowed cotton growers to avoid using most, if not all, of the less desirable tools of the weed management system, including residual herbicides, inter-row cultivation and hand hoeing. This concentration on glyphosate as the principle tool for weed control has been an important part of achieving the very high yields that are becoming the normal in Australian cotton. However, the reliance on a single management tool for weed control in NOT a weed management system and is failing rapidly, with the loss of the most cost effective, broad spectrum herbicide (glyphosate) from the system imminent, or in some situation already a reality for some of the more challenging weeds.

Glyphosate tolerant/resistant annual ryegrass, awnless barnyard grass, liverseed grass, feathertop Rhodes grass, windmill grass and flaxleaf fleabane are becoming increasingly common weeds in the cotton system. If cotton growers wish to continue to reap the benefits of glyphosate and the Roundup Ready Flex system, they need to act now and develop an integrated approach to weed management that will protect the value of glyphosate. Failure to act will result in an expensive failure of weed management that will be difficult to rectify.

Best yields are achieved from well-managed cotton, free from weed competition.

Ideally, a weed management program includes some residual herbicides, supplemented with non-residual herbicides as needed. Cultivation, shielded sprayers and spot sprayers are valuable for removing weeds from the inter-row area. Hand hoeing and spot sprayers are particularly valuable tools for managing low densities of larger weeds and survivors from spray applications.

Weed management in fallows

Where a field to be planted to cotton is fallowed prior to cotton, opportunity exists to control any weeds that may be present. Often these weeds are most easily and cost effectively controlled in the fallow. Although many weeds produce dormant seeds that may survive in the soil for a number of years, the vast majority of the weed seed-bank can be run down simply by maintaining a weed free fallow.

When fallows are maintained solely using herbicides (without cultivation), this strategy has the added advantage of retaining any stubble cover from the previous crop, maximising the retention of soil moisture and minimising soil erosion. Maintaining stubble cover is an essential strategy for minimising soil loss through erosion on fields with slope, and fields prone to flooding and water movement.

However, all too often, weed management on fallows has been achieved almost solely by relying on glyphosate or glyphosate and a phenoxy herbicide. This has led to increasing problems with species shift and the development of glyphosate resistant weeds. Grass weeds, particularly, have been under heavy selection pressure due to the glyphosate only approach, and glyphosate resistant grasses are becoming quite common in the cotton growing areas. Most common of the resistant grasses are:

- Annual ryegrass,
- Awnless barnyard grass, and
- Windmill grass.

Species shift to glyphosate tolerant feathertop Rhodes grass is also becoming increasingly common.

The obvious strategy to overcome this problem is to develop a more integrated approach to weed management in fallows, relying on a wider choice of herbicides, including residual herbicides, supplemented with strategic spot spraying and cultivation. However, growers must by careful to avoid the traps of long plant-back periods to some of these alternative herbicides, and the risk of over-relying on the alternative herbicides and developing resistance to these herbicides.

In the long term, the best way to manage a fallow is the same as the best way to manage a crop:

- Enter the fallow phase with low weed numbers,
- Control emerging weeds when they are small and most susceptible to the herbicides, and
- Control any survivors using an alternative management tool before they set seed.

The secret to success in weed management is to drive down the weed seedbank and keep it down.

Scouting for weed survivors following a fallow herbicide must be a vital part of a fallow control system. Any survivors must be controlled using an alternative management tool before they set seed. Failure to do this has led to the failure of an increasingly large number of northern fallows over the last couple of seasons, with many conservation fallow systems lost to feathertop Rhodes grass incursions, where the only tool left to manage this weed in a wet summer is repeated heavy cultivation.

Using a double-knock approach to managing fallow weeds is a valuable option for delaying the emergence of herbicide resistance, but is of limited value once resistance has already occurred and must still include scouting for survivors.

Scout every fallow after every herbicide application and control survivors with an alternative control tool before they set seed - EVERY TIME!

Failure to prevent feathertop Rhodes grass setting seed in this fallow has necessitated the repeated use of heavy cultivation to manage this weed.

Weed management in rotation crops

Rotation crops can also be valuable for managing weeds, as they often involve farming systems that differ from the typical cotton system. Winter and summer crops both have the advantage of drying out the soil profile, allowing strategic cultivation to manage soil and weed problems. In addition, a wider range of herbicides is available for use in rotation crops compared with cotton. Some weeds that are difficult to manage in cotton can be more easily managed with alternative herbicides in a rotation crop.

This is particularly the case with cereal crops, where most broad-leaf weeds can be readily controlled. Broad-leaf weed control remains a problem in most broad-leaf crops, including cotton.

When considering a rotation crop, always ensure that there are adequate weed control options available in the crop that will not cause problems for following crops. Some alternative herbicides may be very effective on the target weeds, but have a plant-back of 2 or even 3 years to cotton, making it very difficult to incorporate these herbicides into a cotton farming system.

Weed control can be difficult in broad-leaf rotation crops. This lablab crop failed due to poor establishment and poor weed control. There were no herbicides available for the weed spectrum in this crop that allowed the field to be rotated back to cotton in the following season.

Herbicides for fallows & rotation crops

The wider range of herbicides available for use in fallows and rotation crops provides an opportunity to control weeds which may be difficult to control in cotton, and to rotate herbicide chemistry, reducing the risk of selecting herbicide tolerant and herbicide resistant weeds. However, potential herbicide drift problems and plant-back periods must be considered with those herbicides that are not safe for use in cotton. Always refer to the product label for current recommendations and seek advice directly from the supplying pharmaceutical company if the recommendations are unclear or inadequate. Table 2 gives a guide to re-cropping intervals to cotton. Many herbicides are toxic to cotton and have the potential to kill or severely damage a following or neighbouring cotton crop. For example, 2,4-D amine applied to a sorghum crop under unsuitable weather conditions, such as atmospheric inversion, can, in a worst case scenario, cause severe damage to cotton many kilometres away.

The breakdown rates of herbicides in the soil can be quite variable and difficult to predict. Most herbicides need moist soils (significant rainfall or irrigation) to facilitate breakdown, particularly those broken down by microbial activity, and will breakdown more rapidly under warmer, rather than cooler conditions. These same herbicides break down very slowly or may not break down at all under cold and dry conditions. If in doubt as to whether a herbicide has broken down sufficiently before cotton planting, cotton growers should delay planting the field for as long as possible, or avoid planting the field altogether.

Prior to planting a doubtful field, growers should plant a test strip of cotton, or plant seeds into pots containing soil removed from the field to check for visual symptoms of herbicide damage on the seedlings. A doubtful field should be pre-irrigated before planting, if possible. However, even after these precautions, damage to cotton seedlings may still occur, or damage can occur later in the season as the roots of developing plants encounter a herbicide band in the soil. Herbicide damage may not be visually apparent, but may still occur and weaken or stunt cotton seedlings, predisposing them to attack from seedling diseases.

Detailed information on the damaged caused by many of these herbicides is covered in the Herbicide Damage Guide for Cotton, Section J of WEEDpak.

***Table 2**. A guide to re-cropping intervals for the herbicides commonly used in fallows and rotation crops. Plant-back periods for many of these herbicides could be much longer under cool and dry conditions. Always check the label.*

Product	Active ingredient	Chemical group	Soil ½-life (days)	Applied rate (/ha)	Re-cropping interval to cotton
2,4-D amine (various names)	625 g/L 2,4-D amine	I	10	up to 0.56 L 0.56 - 1.1 L 1.1 – 1.7 L	10 days after a minimum of 15 mm rainfall 14 days after a minimum of 15 mm rainfall 21 days after a minimum of 15 mm rainfall
2,4-D ester (various names)	680 g/L 2,4-D ester	I	10	up to 0.51 L 0.51 - 1 L 1 – 1.6 L	10 days after a minimum of 15 mm rainfall 14 days after a minimum of 15 mm rainfall 21 days after a minimum of 15 mm rainfall
Alliance®	250 g/L amitrole + 125 g/L paraquat	L + Q	14 + 1000	2 – 4 L	None
Amitrole T	250 g/L amitrole + 220 g/L ammonium thiocyanate	Q	14	4.3 – 5.6 L	None
atrazine (various names)	900 g/kg atrazine	C	60	up to 1.4 kg 1.4 – 3.3 kg	6 months 18 months
Balance® 750 WG	750 g/kg isoxaflutole	H	0.5 – 2.4	100 – 200 g	7 months
Basta®	200 g/L glufosinate-ammonium	N	7	3.75 L	14 days
bentazone (various names)	480 g/L bentazone	C	20	1.5 – 2 L	No re-cropping intervals specified
bromoxynil (various names)	200 g/L bromoxynil	C	7	0.7 – 2.1 L	No re-cropping intervals specified
carfentrazone-ethyl (various names)	240g/L carfentrazone-ethyl	G	1 - 5	50 – 100 ml	None
chlorsulfuron (various names)	750 g/kg chlorsulfuron	B	40	15 - 20 g	18 months with a minimum of 700 mm rainfall where soil pH is 6.6 - 7.5 Where soil pH is 7.5 – 8.5, grow cotton only if a field test strip of cotton has been successfully grown through to maturity in the previous season. Do not use where soil pH is above 8.5
clopyralid (various names)	300 g/L clopyralid	I	40	up to 75 mL 75 – 300 mL above 300 mL	3 months with at least 50 mm of rain or irrigation 6 months with at least 50 mm of rain or irrigation At least 2 years
dicamba (various names)	500 g/L dicamba	I	4	up to 280 mL 280 – 560 mL	7 days after a minimum of 15 mm rainfall 14 days after a minimum of 15 mm rainfall
diflufenican (various names)	500 g/L diflufenican	F	180 - 315	100 – 200 mL	No re-cropping intervals specified
fluroxypyr (various names)	200 g/L fluroxypyr	I	11 - 38	up to 750 mL 750 mL – 1.5 L	14 days 28 days
flumetsulam (various names)	800 g/kg flumetsulam	B	30 - 90	25 g 50 g	6 months with rainfall 9 months with rainfall
Harmony M®	682 g/kg thifensulfuron + 68 g/kg metsulfuron	B + B	12 + 30	40 g	Cotton should not be planted on land previously treated with Harmony M. Tolerance of cotton grown through to maturity should be determined on a small scale before sowing into larger areas
Hussar® OD	100 g/L iodosulfuron-methyl-sodium	B	1 - 5	75 – 100 ml	up to soil Ph 8.5, 12 months with 500 mm rainfall
imazapic (various names)	240 g/L imazapic	B	120	150 – 400 ml	24 months with a minimum of 550 mm rainfall

Product Active Chemical Soil half- Applied Re-cropping interval to cotton

	ingredient	Group	life (days)	rate (/ha)	
imazethapyr (various names)	240 g/L imazethapyr	B	60 - 90	up to 300 mL up to 400 mL	22 months 18 months provided rainfall + irrigation exceeds 2000 mm
Intervix®	33 g/L imazamox + 15 g/L imazapyr	B + B	20 – 30 + 25 – 142	375 – 750 ml	34 months
MCPA (various names)	500 g/L MCPA	I	5-6	0.2 – 2.1 L	No re-cropping intervals specified
metribuzin (various names)	750 g/kg metribuzin	C	30 - 60	up to 960 g above 960 g	6 months 12 months
metsulfuron (various names)	600 g/kg metsulfuron methyl	B	30	5 - 7 g	Cotton should not be planted on land previously treated with metsulfuron. Tolerance of cotton grown through to maturity should be determined on a small scale before sowing into larger areas
oxyfluorfen (various names)	240 g/L oxyfluorfen	G	30 - 40	up to 75 mL	7 days
paraquat (various names)	250 g/L paraquat	L	1000	1.6 – 2.4 L	1 hour
paraquat + diquat (various names)	135 g/L paraquat + 115 g/L diquat	L + L	1000	0.8 – 3.2 L	None
Raptor® WG	700 g/kg imazamox	B	20 - 30	45 – 50 g	10 months with 800 mm rainfall + irrigation
Sakura® 850 WG	850 g/kg pyroxasulfone			118 g	5 months with a minimum of 150 mm rainfall
Sharpen® WG	700 g/kg saflufenacil	G	20	9 – 26 g	6 weeks
simazine (various names)	900 g/kg simazine	C	149	up to 2.5 kg above 2.5 kg	9 months more than 9 months
sulfosulfuron (various names)	750 g/kg sulfosulfuron	B	24	20 – 25 g	No re-cropping intervals specified, but likely to be extended
terbutryn (various names)	500 g/L terbutryn	C	52 – 74	0.3 – 1 L	14 months where the soil pH is above 7.5
Tordon 75-D® (various names)	300 g/L 2,4-D + 75 g/L picloram	I + I	10 + 90	0.3 – 1 L	12 months
Tordon 242® (various names)	420 g/L MCPA + 26 g/L picloram	I + I	5 – 6 + 90	1.0 L	12 months
triasulfuron (various names)	750 g/kg triasulfuron	B	20 – 25	10 - 35 g	15 months where soil pH is up to 7.5 with 700 mm of rain 18 months where soil pH is 8.5 with 700 mm of rain 24 months where soil pH is above 8.6 with 700 mm of rain
Tribenuron methyl (various names)	750 g/kg tribenuron methyl	B	10 days	15 – 30 g	Not to be followed by cotton
trichlopyr (various names)	600 g/L triclopyr	I	30	80 - 160 mL	14 days
Valor®	500 g/kg flumioxazin	G	15	30 - 90 g	1 day

Pre-planting residual herbicides

A range of residual and non-residual herbicides is available for use in cotton, as shown in Tables 3, 4 and 5.

Pre-planting residual herbicides have the advantage that they can be applied anywhere from several weeks before planting, up to immediately prior to planting or even at planting for some herbicides, and remain effective for weeks to months after application. They can be applied in anticipation of a known weed problem and they control weeds before the weeds emerge. They can be less expensive than many of their non-residual alternatives, particularly when multiple non-residual applications are required to replace a single residual herbicide application.

Residual herbicides have a very important role in the Roundup Ready Flex® system, of reducing the selection pressure on glyphosate. Growers are strongly advised to include residual herbicides on any Roundup Ready Flex fields expected to have heavy weed pressure or where the presence of weeds resistant to glyphosate is suspected or known.

However, residual herbicides have three major drawbacks

1. they must be applied in anticipation of a weed problem, whether or not a problem actually occurs,
2. they can damage cotton seedlings and in extreme conditions, can kill a large percentage of the plant stand. In situations of low weed pressure, their use may result in damage to cotton plants without any real benefit, and
3. 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 which may conflict with other farming practices such as minimum tillage and stubble retention.

In addition, when applied at planting, the application of residual herbicides slows and complicates the planting process, making it more difficult for growers to achieve ideal planting conditions.

Residual herbicides also have the potential to contaminate the environment if they move out of the target area. This potential is greater than that of most non-residual herbicides simply because they persist for longer in the environment and so are exposed to more opportunities for off-site movement. Their subsequent affect is also likely to be more significant because of their persistence.

Herbicide movement may occur through leaching of the herbicide following irrigation or rainfall. However, many residual herbicides are strongly attracted to soil particles and so have little potential to leach. These herbicides may still move off-site, carried on blown dust, or on suspended soil particles following irrigation or rainfall. This risk can be greatly reduced by good irrigation design, where run off and irrigation tail-water are captured and recirculated, remaining on-farm.

Cotton can be damaged by herbicides used on rotation crops. This damage (distorted growth) was caused by phenoxy drift from a neighbouring fallow.

Special care must be taken to ensure that the herbicides used in a rotation crop will not damage the subsequent cotton crop.

Table 3. *A guide to the weeds controlled by soil residual herbicides. This information is a guide only, always refer to the product label for up-to-date information.*

Active ingredient Typical use rate Herbicide group	diuron[1] 900 g/kg 1-2 kg/ha C	fluometuron 900 g/kg 1.5-3.1 kg/ha C	fluometuron + prometryn 880 g/kg 1.4-2.9 kg/ha C	metolachlor 720 g/L 2 L/ha K	pendimethalin 440 g/L 2.25 L/ha D	prometryn 900 g/kg 1.8-2.5 kg/ha C	trifluralin 480 g/L 1.2-2.3 L/ha D
Grass weeds							
Annual grasses general	MS	MS	MS	S	S	MS	S
Awnless barnyard grass	MS	MS	MS	S	S	MS	S
Johnson grass seedlings	T	PS	T	MS	MS	T	S
Liverseed grass	MS	MS	MS	S	S	MS	S
Volunteer cereals	S	S	S	MS	MS	S	MS
Volunteer sorghum	MS	S	S	S	S	S	S
Nutgrass	T	T	T	T	T	T	T
Broad-leaf weeds							
Anoda weed	-	-	-	T	T	-	T
Australian bind weed	-	T	T	T	T	T	T
Bathurst burr *	S[2]	S	S	T	T	S	T
Bellvine	MS[2]	MS	S	T	T	S	T
Blackberry nightshade	S	S	S	PS	MS	S	T
Black bindweed	-	-	MS	T	T	S	MS
Bladder ketmia	MS	S	S	T	T	S	T
Cathead	MS	S	S	PS	MS	S	S
Caustic weed	MS	S	S	T	T	S	T
Common sowthistle	S	S	S	T	T	S	T
Cowvine (peachvine)	T[2]	MS	S	T	T	S	T
Deadnettle	S	S	S	PS	T	S	MS
Devils claw	-	T	S	T	T	MS	T
Dwarf amaranth	S	S	S	PS	S	S	S
Emu-foot	-	T	T	T	T	T	T
Fierce thornapple *	S[2]	S	S	T	T	S	T
Grey rattlepod	S	S	S	T	T	S	T
Mintweed	MS	MS	S	MS	MS	S	MS
Mung bean *	MS	MS	MS	T	T	T	T
Native jute	PS	MS	MS	PS	-	MS	PS
Native rosella	-	S	S	T	T	-	T
Noogoora burr *	S[2]	S	S	T	T	S	T
Parthenium weed	S	S	S	T	T	S	T
Pigweed	S	S	S	T	S	S	S
Polymeria takeall seedlings	T	-	-	T	T	-	T
Prickly paddymelon	S	S	S	T	T	S	T
Raspweed	-	-	-	T	T	-	T
Ryncho	-	-	-	T	T	-	T
Sesbania	MS	MS	MS	T	T	MS	T
Small-flowered mallow	T	T	T	T	T	T	T
Sunflower *	MS	S	MS	T	T	MS	T
Turnip weed	S	-	-	T	T	S	T
Vigna takeall	-	-	-	T	T	-	T
Wireweed	MS	-	MS	PS	S	S	S
Wild gooseberry	MS	S	S	T	T	S	T
Wild melon *	S	S	S	T	T	S	T
Yellow vine	MS	S	S	PS	MS	S	S

S = Susceptible MS = Moderately susceptible PS = Some activity T = Tolerant - = Not known

[1] = Diuron can only be applied on fields where tail water and runoff is retained on-farm.

[2] = These weeds have large seeds and may germinate below the herbicide band, reducing the level of control.

** = Because of their large seed size, these weeds may germinate below the herbicide band, reducing the level of control.*

Table 4. *A guide to the weeds controlled by contact and residual (Zoliar) herbicides. This information is a guide only, always refer to the product label for up-to-date information.*

Active ingredient	glufosinate	glyphosate	MSMA	norflurazon	pyrithiobac sodium	trifloxysulfuron sodium
Registered trade name	Liberty® 200 g/L	various[1] 450 g/L	various 720 g/L	Zoliar® 800 g/kg	Staple® 800 g/kg	Envoke® 750 g/kg
Typical use rate	3.75 L/ha	0.4-2.4 L/ha	3.1 L/ha	1-4 kg/ha	30-120 g/ha	15-30 g/ha
Herbicide group	N	M	Z	F	B	B
Grass weeds						
Annual grasses general	MS	S	S	MS	T	MS
Awnless barnyard grass	MS	S[2]	S	MS	T	MS
Johnson grass from seed	MS	S	MS	MS	T	-
Liverseed grass	MS	S[2]	S	MS	T	-
Volunteer Cereals	MS	S	-	MS	T	-
Volunteer sorghum	MS	S	MS	MS	S	-
Nutgrass	T	MS	MS	MS	T	MS
Broad-leaf weeds						
Anoda weed	S	MS	T	T	S	S
Australian bind weed	-	MS	T	T	T	-
Bathurst burr	S	S	S	T	S	S
Bellvine	S	PS	T	T	S	-
Blackberry nightshade	-	MS	T	T	-	-
Black bindweed	S	MS	T	T	T	MS
Bladder ketmia	S	MS	T	T	T	MS
Cathead	S	S	T	T	T	S
Caustic weed	S	S	T	T	T	-
Common sowthistle	S	S	T	T	T	-
Cowvine (peachvine)	S	MS	T	T	S	MS
Deadnettle	S	S	T	T	T	-
Devil's claw	S	S	T	MS	T	-
Dwarf amaranth	S	S	T	T	S	-
Emu-foot	-	MS	T	T	T	-
Fierce thornapple	S	S	T	T	S	T
Grey rattlepod	S	MS	T	T	T	-
Mintweed	S	S	T	T	T	-
Mung bean	S	S	T	T	T	-
Native jute	-	S	T	T	T	-
Native rosella	S	MS	T	T	T	-
Noogoora burr	MS	S	S	T	S	S
Parthenium weed	-	MS	T	T	T	-
Pigweed	S	S	T	T	T	-
Polymeria takeall seedlings	-	PS	T	T	T	-
Prickly paddymelon	S	PS	T	T	T	-
Raspweed	-	PS	T	T	T	-
Ryncho	S	MS	T	T	T	T
Sesbania pea	S	MS	T	T	S	S
Small-flowered mallow	-	PS	T	T	T	-
Sunflower	S	S	T	T	S	-
Turnip weed	S	S	T	T	T	MS
Vigna takeall	-	S	T	T	T	-
Wireweed	S	S	T	T	T	-
Wild gooseberry	MS	S	T	T	S	MS
Wild melon	S	S	T	T	S	-
Yellow vine	S	S	T	S	S	S

S = Susceptible MS = Moderately susceptible PS = Some activity T = Tolerant - = Not known

[1] = Glyphosate can only be safely applied over-the-top of cotton varies with Roundup Ready Flex® technology. In non-Roundup Ready varieties, it can only be safely applied post-emergence through a well-constructed shielded sprayer, under suitable operating conditions with regard to wind, nozzle pressure, shield design, ground speed etc.

[2] = Glyphosate resistant populations of awnless barnyard grass, liverseed grass and windmill grass are becoming common throughout the cotton area. These populations are unlikely to be controlled by the registered rates of glyphosate.

***Table 5.** A guide to weeds controlled by the post-emergence, over-the-top, grass herbicides.*

Active ingredient Registered trade name Typical use rate (/ha) Herbicide group	butroxydim Factor® 120-180 ml A	clethodim various 250-375 ml A	fluazifop-butyl various 750 ml A	haloxyfop various 100-150 ml A	propaquizafop Shogun® 200 – 900 ml A
Grass weeds					
Annual grasses general	S	S	S	S	-
Awnless barnyard grass	S	S	S	S	S
Johnson grass from seed	S	S	S	S	S
Liverseed grass	S	S	S	S	S
Volunteer cereals	S	MS	S	S	S

S = Susceptible *MS = Moderately susceptible* *- = Not known*

Young cotton in a well-managed seedbed, free of weeds.

Residual grass herbicides

The most commonly used residual grass herbicide in cotton is pendimethalin, applied at planting, in a band behind the planter and incorporated with finger harrows positioned behind the planter boxes. It has activity on most grass weeds, and some broad-leaf weeds such as dwarf amaranth, caltrop, caustic weed and mintweed, but requires only the minimal incorporation of finger harrows or a chain. A residual grass herbicide, such as pendimethalin, should be used in conjunction with the Liberty Link® system to strengthen grass control in this system.

Trifluralin was traditionally the herbicide of choice due to its low cost and flexibility of application, with the application window stretching from 6 weeks prior to planting to immediately pre-planting. However, trifluralin has the drawbacks that it can inhibit the development of surface roots of emerging cotton seedlings, it requires thorough soil incorporation to be effective, and its application requires an additional machinery pass. Soil incorporation at, or immediately after application is necessary because trifluralin is degraded by sunlight and is slightly volatile, leading to significant losses if it is left on the soil surface. Trifluralin is degraded by microorganisms in the soil.

When trifluralin was used prior to planting, it was also common to apply a band of pendimethalin as a 'top-up' behind the planter, even though trifluralin had previously been applied. This most often occurred on fields that were pre-irrigated, where a layer of dry soil was skimmed off the top of the irrigation hill at planting to allow cotton seed to be planted into moist soil. Consequently, the trifluralin treated soil from the top of the hill often ended up in the furrow, leaving the plant-row prone to weed problems. To overcome this problem, a band of pendimethalin was applied to the area disturbed by planting, replacing any trifluralin that may have been removed.

Metolachlor is an alternative residual grass herbicide option to trifluralin and pendimethalin and can be readily substituted for pendimethalin. It has similar activity on grass and broad-leaf weeds, but has a different mode of herbicidal action, with added value for herbicide resistance management. Alternatively, growers may consider using pendimetahlin with cotton but using metolachlor with rotation crops, such as cereals, maize or sorghum, to broaden their residual grass spectrum.

The main advantages of pendimethalin and metolachlor are that they don't need as much soil incorporation as trifluralin, can be applied at planting, and don't cause surface root pruning. However, they are more expensive than trifluralin, and although they don't inhibit surface root development, they can still cause serious injury to cotton seedlings if they are poorly applied or subject to adverse weather conditions after application. Damage is most commonly seen when rain occurs soon after planting, washing herbicide into the cotton seed zone, most commonly occurring when the cotton beds are not well formed or the planter has left a furrow in the top of the beds, effectively concentrating the herbicide in the seed zone. Both herbicides require some incorporation, with finger harrows behind the planter, or either by rainfall or irrigation. Both herbicides also have some volatility (metolachlor less than pendimethalin), and are degraded by sunlight (metolachlor more than pendimethalin).

While many growers have had excellent results with both pendimethalin and metolachlor over many years, there have been numerous instances where metolachlor has proved more injurious to cotton than pendimethalin, resulting in this herbicide going out of favour with most cotton growers.

An alternative to these herbicides is Zoliar®, a highly residual, soil applied herbicide with activity against most grass weeds and some broad-leaf. Zoliar is particularly useful in fields infested with nutgrass or anoda weed, but can be very expensive if required at the maximum use rates. It needs to be thoroughly incorporated into the soil, and can be applied in autumn or winter before cotton planting. For nutgrass control, Zoliar needs to be applied over several consecutive seasons and should be used in conjunction with other management tools such as glyphosate. Zoliar is only active at high soil moisture contents. It acts on plant chlorophyll and membrane lipids, rapidly turning affected tissue white. This will kill the affected plant if the soil remains wet and the herbicide remains active for long enough. Frequently, however, under Australian conditions, the soil dries and the affected plant recovers. In this situation, Zoliar does give effective suppression of the weed but will not eliminate the problem.

Zoliar has a major advantage in that it is highly active in wet conditions when it is most needed and has a long half-life in the soil. Its disadvantages include relatively high cost (at the rates required for use in nutgrass), a lack of activity under dry conditions, and toxicity to most rotation crops. High rates of Zoliar should not be used with the last cotton crop before planting a rotation crop. Plant back periods should be carefully considered before choosing a rotation crop. Most rotation crops can't be safely grown for several seasons following high rates of Zoliar applied to consecutive cotton crops.

Residual broad-leaf herbicides

The residual broad-leaf herbicides commonly used in cotton are diuron, fluometuron and prometryn singularly, and a 50:50 fluometuron/prometryn mixture. These herbicides can be applied pre-planting, at planting, or post-planting, and have pre-emergence and post-emergence activity on many broad-leaf and some grass weeds. They are most effective when incorporated into the soil, but are also effective when applied to the soil surface or sprayed on small weeds, with the addition of a wetting agent.

Application timing and technique is important with these herbicides. While they can, and often are applied before cotton emergence, with no adverse effects, these herbicides have the potential to kill or severely damage cotton seedlings, resulting in the need to re-plant the crop. Damage, when it does occur, generally follows rainfall soon after planting which washes the herbicide into the seed zone. This problem is most likely where the hills are poorly formed or the planter has left a furrow in the top of the hill. Rain can concentrate herbicide from the top of the hill into this furrow, and into the root or shoot zone of emerging cotton seedlings. Prometryn is not commonly applied prior to crop emergence, due to the risk of injury to cotton from this herbicide, although the prometryn-fluometuron mixture is often used. Injury from diuron, fluometuron, and the prometryn/fluometuron mixture can be widespread when rain occurs at planting. As these herbicides are water-activated, they are most effective under wet conditions, when weeds are most active.

Although listed earlier as a negative characteristic, the tendency of trifluralin to prune the surface roots of cotton seedlings may add some additional degree of product safety when trifluralin is included with one of these products in a weed management program. While pruning of the surface roots reduces the cotton's ability to absorb nutrients and water from the soil surface (a negative aspect), it also reduces the likelihood of cotton seedlings absorbing high concentrations of other herbicides from the soil surface (a positive aspect). Consequently, injury to cotton seedlings from herbicides like diuron is less likely when trifluralin has been applied pre-planting.

Prometryn damage from a layby application. The herbicide was directed to the base of the plant, but poor application resulted in damage to these lower leaves.

Cotton seedlings are initially small, emerge slowly from spring planting and compete poorly with weeds.

Generally, cotton can be successfully re-established from re-sowing after cotton seedlings are killed by herbicides, as these herbicides have relatively short half-lives, and so break down relatively quickly.

Because they do also have foliar activity, it is important that the residual broad-leaf herbicides are applied as directed sprays when used after cotton emergence (the spray nozzle positioned to direct herbicide away from cotton foliage). It is common to observe some leaf damage to cotton after a directed spray application even when these herbicides are correctly applied. The damage is seen as yellowing of the cotton leaf, but should not cause leaf death or a reduction in cotton yield.

Residual herbicides for dryland cotton

Problems can occur for growers of dryland cotton where residual herbicides are used early in the season. Residual herbicides can give more cost-effective weed control than many of the post-emergence options and are a must when glyphosate resistant or tolerant weeds are suspected or known to be present, but for optimum performance, they must be applied prior to or at planting. If a planting opportunity fails to eventuate, or the crop fails, residual herbicide already applied may preclude later planting of an alternate crop.

Minimum re-cropping intervals for cotton herbicides are shown in Tables 6 and 7. Judicious use of soil residual herbicides enables growers to consider other crop options for a December-January planting, such as sorghum, sunflower and mung beans.

One strategy to avoid problems with pre-planting residual herbicides is to band the herbicide so that herbicide is applied to the cotton row, and a band of untreated soil remains in the inter-row area. Weeds that emerge in this area can be managed with cultivation or a shielded sprayer, and a residual herbicide may be applied to this area later in the season. However, should the cotton establishment fail, an alternative crop can be safely planted in the untreated area. This strategy is ideally suited to cotton grown with permanent wheel tacks, where the cotton-row and inter-row areas are well defined, and is particularly suitable for skip-row cotton which has a wide inter-row area.

Another strategy is to use a Roundup Ready Flex® cotton variety with no early-season residual herbicides. This strategy can be very cost effective in relatively clean fields, but the total number of glyphosate applications and the presence of resistant and tolerant weeds will be of concern over time. Reliance on glyphosate as the primary weed control tool has resulted in a shift in the weed spectrum to those weeds that are more tolerant of glyphosate and to the development of glyphosate resistant weeds.

Residual herbicides applied after planting may still cause problems in the event of the cotton crop failing or being hailed-out. All residual herbicides have the potential to cause problems for the crop following cotton, as indicated in Tables 6 and 7. These data have been developed in consultation with the agrochemical industry and are intended only as a guide.

ALWAYS CHECK THE PRODUCT LABEL.

The re-cropping intervals listed can be modified to suit local seasonal conditions and soil type variations.

Dryland cotton sown in a skip-row configuration (two cotton rows 1 m apart, separated by a 2 m gap). The cotton is sown into sorghum stubble.

Table 6. *Minimum re-cropping interval (months) to rotation crops after residual herbicide application in cotton. Products are sold under a variety of trade names.*

	diuron	fluometuron	fluometuron + prometryn	metolachlor	pendimethalin	prometryn	trifluralin
Barley	24	-	6	6	0	6	0
Canola	24	-	6	6	0	6	0
Chickpea	24	-	6	6	0	0	0
Cotton	12	-	0	0	0	0	0
Cowpea	24	-	6	6	0	6	0
Faba Bean	24	-	6	6	0	6	0
Lablab	24	-	6	6	0	6	0
Linseed	24	-	6	6	0	6	0
Lucerne	24	-	6	6	0	6	0
Maize	12	-	6	0	0*	6	0
Millet	24	-	6	6	12	0	12
Mung Bean	24	-	6	6	0	6	0
Oats	24	-	6	6	0	6	12
Sorghum	24	-	6	0**	12	6	12
Soybean	24	-	6	0	0	6	0
Sunflower	24	-	6	0	0	6	0
Triticale	24	-	6	6	0	6	0
Wheat	24	-	6	6	0	6	12

** = Maize can be re-sown immediately after use in a failed crop provided the seed is sown below the treated band of soil*
*** = Concept® treated sorghum seed*
- = No information provided on the label.

Table 7. *Minimum re-cropping interval (months) to rotation crops after contact and residual (Zoliar) herbicide application in cotton. Some products are sold under a variety of trade names.*

	glufosinate	glyphosate	MSMA	norflurazon Zoliar®	pyrithiobac sodium Staple®	trifloxysulfuron sodium Envoke®
Barley	1	0	-	30	5	6
Canola	1	0	-	-	-	22
Chickpea	1	0	-	9	-	18
Cotton	1	0	-	0	0	9
Cowpea	1	0	-	-	-	22
Faba Bean	1	0	-	30	-	7
Lablab	1	0	-	-	-	22
Linseed	1	0	-	9	-	22
Lucerne	1	0	-	-	-	22
Maize	1	0	-	27	22	22
Millet	1	0	-	-	-	22
Mung Bean	1	0	-	27	11	9
Oats	1	0	-	30	5	6
Sorghum	1	0	-	27	22	22
Soybean	1	0	-	9	22	15
Sunflower	1	0	-	27	22	22
Triticale	1	0	-	30	-	22
Wheat	1	0	-	30	5	6

Pre-emergence, post-irrigation herbicides

In irrigated cotton production, the crop is established on moisture whenever possible, but most commonly is established either by irrigating before planting, planting cotton into a drying soil (pre-irrigation), or by irrigating after planting (watering-up). An additional light irrigation (termed 'flushing') may be necessary soon after planting pre-irrigated cotton if hot, dry condition follow planting and the surface soil dries too rapidly for the emerging cotton seedling.

Where pre-irrigation occurs, it is common to get a rapid emergence of weeds, particularly grasses, before the cotton seedlings emerge from the soil. When this happens, opportunity exists to apply a herbicide such as glyphosate or Spray.Seed® to control these weeds without damaging the cotton. If no rain or irrigation occurs after this herbicide application, there may be no further weed emergence and the cotton will be able to establish into a relatively weed-free situation. This strategy can also be valuable for managing problem weeds that emerge before the cotton, and so can be controlled at this stage.

However, this strategy is not always reliable and should only be used in conjunction with other weed management tools, as wet or windy weather can prevent herbicide application in this narrow window between planting and crop emergence.

Post-emergence, non-residual herbicides

Residual herbicides have the advantage that they are present and are active from the time of application, but have the disadvantage that they may damage cotton, and they are normally applied in anticipation of a problem, and thus may not actually be necessary. Non-residual herbicides have the advantage that they can be applied as needed, always achieving value for money, but will only control weeds present at the time of application and so are unable to control weeds from later germinations. This can be a major issue in wetter seasons when successive, staggered germinations of weeds may occur following rain. Controlling successive germinations with a non-residual herbicide may require 6 or more applications to be made over a summer, inevitably often leading to escapes and a mess by the end of the summer.

A range of non-residual grass herbicides is shown in Table 5. These herbicides can be safely applied over-the-top of cotton and are effective in controlling small, actively growing grass weeds. However, they have no effect on broad-leaf weeds and are much less effective on stressed grass weeds. They are also largely ineffective in controlling larger grass weeds that escape earlier treatment. These herbicides are all in herbicide Group A. There is a high likelihood of weeds developing resistance to these herbicides if they are used repeatedly within or over seasons and any survivors are not controlled using an alternative management tool before they can set seed. Experience with other weeds has shown that spray failures due to resistance to these herbicides can emerge after as few as 3 – 5 applications where they are used as the only weed management tool.

Glyphosate has been the herbicide of choice over the last decade, especially when used in conjunction with cotton varieties including Roundup Ready Flex® technology, giving these varieties a high level of tolerance to glyphosate. Glyphosate is a relatively inexpensive herbicide, it is effective on a wide range of grass and broadleaf weeds, and it is effective on both small and medium-sized weeds. Glyphosate is not so effective on many of the leguminous weeds and the vine weeds. Over-use of this herbicide has resulted in species shift to weeds that are tolerant of or resistant to glyphosate, diminishing its value.

Over-use has resulted in species shift to weeds that are tolerant of or resistant to glyphosate. Failure to manage the feathertop Rhodes grass in this dryland field will result in years of problems with this weed.

Glufosinate is an alternative to glyphosate, used in conjunction with cotton varieties including Liberty Link® technology, giving these varieties a high level of tolerance to glufosinate. Glufosinate is a more expensive herbicide than glyphosate, effective on a wide range of broadleaf weeds, but with poor efficacy on all but very small grass weeds. Nevertheless, glufosinate is effective on many of the weeds that glyphosate is less effective on, including the vine weeds and when used in conjunction with residual grass herbicides, these give it a broad range of efficacy. It has the huge advantage that it has a little-used mode of action, Group N, and it is unlikely that resistance to this mode of action will develop in the foreseeable future. The regular use of glufosinate in the system is a good option to manage species shift and glyphosate resistance issues, although there are several examples in the world of ryegrass which has developed resistance to glyphosate and is cross-resistant to glufosinate.

Envoke® herbicide (Table 4) is active at relatively low rates. It controls a range of broad-leaf weeds, can be applied over-the-top of cotton, and has some residual activity. Envoke is relatively expensive and can cause significant damage to following rotation crops. Re-cropping intervals are shown in Table 7. However, Envoke has activity on some of the weeds that glyphosate is weak on, and so can have value in complementing a glyphosate-based weed management strategy.

Staple® (Table 4) is also active at relatively low rates. It controls a range of broad-leaf weeds and can be applied over-the-top of cotton, although it does cause some injury to cotton and may suppress cotton growth for up to 14 days. This growth suppression should not result in a yield reduction. Staple® is relatively expensive and is often applied in a band to reduce overall cost. While it has little residual activity against weeds, it can cause significant damage to following rotation crops. Re-cropping intervals are shown in Table 7.

Unlike the older broad-leaf herbicides (diuron, fluometuron and prometryn), Staple® has activity against a very specific range of weeds and so accurate weed identification is very important when using this herbicide. For example, Staple® is effective in controlling spineless caltrop (*Tribulus micrococcus*) but will not control caltrop (*T. terrestris*); these two weeds are similar in appearance and often grow together. Similarly, Staple® is effective for controlling sesbania pea (*Sesbania cannabina*) but less effective on budda pea (*Aeschynomene indica*). These plants are difficult to distinguish in early growth.

Both Envoke and Staple are Group B herbicides. There is a high likelihood of weeds developing resistance to these herbicides if they are used repeatedly within or over seasons and any survivors are not controlled using an alternative management tool before they can set seed. Experience with other weeds has shown that spray failures due to resistance to this mode of action can emerge after as few as 3 – 5 applications where they are used as the only weed management tool.

Watering-up cotton planted into a dry seedbed following an application of residual herbicide.

MSMA is another herbicide with activity against most grass weeds, as well as nutgrass and many broad-leaf weeds. It can be applied over-the-top of cotton, but can damage cotton and may result in significant reductions in yield, particularly from sequential applications.

Consequently, MSMA should only be applied over-the-top of cotton in situations of heavy weed infestation, where the potential for damage from the herbicide is far less than the potential for damage from the weeds. MSMA should be applied as a directed spray where possible, minimising contact with the crop. MSMA is rarely, if ever, used in the modern cotton system.

In hot, wet conditions, a weed control program based on non-residual herbicides may need to be repeated at 3- to 4-weekly intervals. Such a program may be impractical due to high cost, time and labour constraints. A period of wet or windy weather could be a disaster for a weed control program based solely on non-residual herbicides.

Inter-row cultivation can be used through the season to control weeds in the inter-row area and to maintain irrigation hills. Herbicides and fertiliser may also be applied through the cultivation rig.

Post-emergence & lay-by herbicides

The residual broad-leaf herbicides discussed earlier (diuron, fluometuron and prometryn) can also be applied post-crop emergence, often in combination with inter-row cultivation. They may be applied as 'lay-by' herbicides with the final inter-row cultivation, just prior to the crop closing over the inter-row area. When used in this way, they are normally sprayed in front of a cultivator, which is set to throw some of the herbicide treated soil up under the cotton plants. Consequently, the herbicide is incorporated into the soil and kept away from the cotton foliage, but some treated soil still ends up over-the-top of the hill. This herbicide application is intended to control weeds that germinate after it is no longer practical to cultivate or apply directed herbicides in the cotton crop.

Shielded herbicide applications

Some herbicides that can't be safely applied over-the-top of cotton can be used to control weeds in the inter-crop fallow area between the rows when applied through a well-constructed shielded sprayer that prevents herbicide making contact with the cotton foliage. These sprayers must be operated under suitable conditions. This strategy is more commonly used in dryland cotton, where large inter-crop fallow strips may be present, but where stubble destruction and soil moisture losses resulting from cultivation are undesirable (inter-row cultivation is another inexpensive option for controlling inter-row weed populations).

Shielded sprayers have gone out of fashion with the widespread adoption of Roundup Ready Flex® cotton, but can play a vital role in protecting the Roundup Ready® system into the future. Shielded sprayers allow the use of a range of alternative herbicides to control weeds that survived a glyphosate application before they set seed, allowing herbicides such as Alliance®, AmitroleT, Spray.Seed® and Valor® to be used to manage survivors from glyphosate sprays.

The use of herbicides such as glyphosate, Alliance, Amitrole T, Spray.Seed or Valor applied to the inter-crop fallow area through a shielded sprayer is relatively safe, but extensive crop damage can occur if the herbicide makes contact with cotton foliage. Damage is most likely to arise from herbicide drift from within the shield due to windy conditions, excessive ground speed, poor shield construction or set up, excessive nozzle pressure, or poorly positioned spray nozzles. Problems can be reduced by using appropriate nozzles, producing large droplets at low pressure, within well-constructed shields and ensuring that nozzles remain well positioned. It is also essential to ensure that there are no herbicide leaks from tanks or fittings. Due to the risk of damage to cotton, shielded sprayers should only be used where weeds can't easily or economically be controlled by other methods. Over the years, there have been all to many examples of shielded spraying operations that have been used highly successfully, often over multiple seasons, that have then led to major issues of crop damage, often due to a minor, undetected problem, such as a leaking fitting or hose.

A purpose-built, high clearance sprayer set up for shielded spraying.

A purpose-built shielded sprayer being to used to inter-row spray a troublesome weed, polymeria takeall, in young cotton.

Spot-spraying

Spot-spraying is ideally suited to situations where large weeds are present at low densities. Herbicides such as glyphosate and Amitrole T may be applied to small areas of weed within a field, where the damage caused by the herbicide is confined to a small area and is negligible over the entire field. Alternatively, a more expensive herbicide, such as Envoke®, and the post-emergence grass herbicides may be spot-applied to greatly reduce the overall cost. Spot-spraying may involve a 'normal' boom spray, with the operator switching on boom-sections as required, but more commonly involves a purpose built, self-propelled, spot-spraying unit, designed to go through cotton rows with a minimum of disturbance. These units may have multiple operators, each of whom can spot-spray weeds in several rows in a single pass, using special applicators which limit spray drift.

Herbicide Guide

A guide to the weeds controlled by the herbicides most commonly used in cotton is provided in Tables 3, 4 and 5. This information is provided as a general guide only.

SPECIFIC DIRECTIONS FOR PESTICIDE USE IS PROVIDED ON THE PRODUCT LABEL AND MUST BE COMPLIED WITH.

Further information on specific herbicides, application rates, and application details is provided in the Cotton Pest Management Guide, published each year.

Spot spraying and hand hoeing are efficient and effective ways of controlling low densities of large weeds such as these velvetleaf plants.

Crop agronomy & management

A cotton grower aims to establish a strong, healthy cotton stand that produces a profitable cotton crop. To achieve this aim, the grower will try to produce a favourable seedbed with optimum levels of nutrients and water. Unfortunately these conditions are also ideal for weed establishment and growth, enabling weeds to out-grow and out-compete cotton seedlings. A dense population of weeds can easily out-compete and shade cotton, but the converse is also true, that a well established cotton crop can, in time, out-compete and shade most weeds.

The opportunities for weeds can be reduced and managed by attention to crop agronomy and management, making the crop more competitive. Once established, a well grown cotton plant will develop a thick leaf canopy, shading both the row and furrow area, and an extensive and deep root system, extracting water from the soil surface and deeper in the soil profile. In contrast, poor cotton establishment may result in large gaps between cotton plants, allowing opportunities for weeds to establish and grow. Re-planting of 'gappy' cotton stands is essential in weedy fields. Poorly growing cotton can also be out-competed by weeds, with weeds growing more rapidly than cotton in spring, shading the cotton and competing strongly for nutrients and water.

For best results, cotton should be given the best chance for establishment and vigorous growth. Where a grower has both clean and weedy fields, the weedy fields should be planted last. If the opportunity arises, a herbicide such as glyphosate should be applied to weeds after cotton planting but before crop emergence (this can occur after emergence in Roundup Ready Flex crops). Operations such as cultivation, hand hoeing, and side banding of fertilizer, should be timed to give the crop the best chance to out-compete weeds. Taller cotton varieties, with good seedling vigour, are best suited to weedy fields.

A purpose-built, spot-spraying rig set up for four operators, spraying weeds in 8 rows at a time.

Transgenic cotton varieties

Transgenic, herbicide tolerant cotton varieties are commonly growing, with around 98% of Australian cotton production using the glyphosate tolerance, Roundup Ready Flex® trait in the last few seasons. Varieties with glufosinate tolerance are also available, using the Liberty Link® technology.

Herbicide tolerant varieties have been genetically modified to enhance their tolerance of these specific herbicides. The herbicides can't be safely used over-the-top of conventional cotton varieties, nor can Liberty® Herbicide be safely applied to varieties with Roundup Ready Flex technology, not Roundup Ready® Herbicide be safely applied to varieties with Liberty Link technology. The use of transgenic varieties provides opportunities to use a new range of herbicides in cotton with improved crop safety and allows cotton growers to substitute non-residual herbicides for residual herbicides, reducing potential re-cropping problems and environmental issues. These herbicides can also be valuable for managing weeds that are difficult to control in conventional cotton.

Irrigation management

Irrigation management is an important aspect of crop agronomy. Weeds generally emerge after irrigation and rainfall events, so the timing of irrigation affects the emergence of weeds.

While cotton may be sown into soil moisture following rainfall, sowing generally occurs as the soil dries after pre-irrigation, or cotton is sown into a dry seedbed and then irrigated. Both practices result in a flush of weeds, but pre-watering is generally preferred in weedy fields as it allows a better opportunity for weed emergence and control with cultivation or herbicides before crop emergence.

Later in the season, irrigation, hand hoeing, cultivation and herbicide applications must be coordinated to minimise stress to the cotton crop but maximise weed control and weed control opportunities.

Irrigation water can be a source of weed infestation, with weed seeds carried in the water. While it is not practical to filter these seeds from the irrigation water, growers should always be on the lookout for new weeds that may have been introduced in irrigation water. Growers should give special consideration to water pumped during floods, as this water has the greatest potential to carry new seeds. If possible, flood water should be first pumped into storage to allow weed seeds to settle out of the water, reducing the risk of these seeds being carried into fields.

Poorly maintained irrigation structures can be a major source of weed seeds.

Irrigation is often timed to follow inter-row cultivation, as in this field.

Inter-row cultivation

Inter-row cultivation is a relatively cheap and effective method of removing weeds from the inter-row area, potentially controlling weeds that are resistant to, or tolerant of the commonly used herbicides. In irrigated cotton, cultivation is also an important tool for re-delving and maintaining the irrigation furrow, to ensure even and efficient water flow throughout the field.

To be effective, inter-row cultivation should occur before weeds become too large, and be timed to occur as fields are drying. Cultivation should be delayed for a few days after rain or irrigation, as many weeds will not be killed but simply transplanted by cultivating in damp soil. Soil compaction is another undesirable outcome of cultivating wet soil. However, cultivating in dry conditions is expensive and may cause excessive damage to young cotton seedlings, particularly in a blocky or compacted soil. Inter-row cultivation can be timed to occur just prior to an irrigation, provided that the soil is easily friable, allowing sufficient time between cultivation and irrigation for weeds to be killed (approximately 1 day), but minimising the stress to cotton which may be damaged during the cultivation pass.

Inter-row cultivation is particularly valuable for managing dryland, skip row cotton. However, some soil moisture is lost with every cultivation pass, and some pruning of cotton roots occurs, damaging the crop. This root pruning may contribute to problems with fusarium wilt, where this disease is present. Inter-row cultivation also exposes the soil surface, leaving the soil more vulnerable to erosion. Ideally, cultivation should cause minimal surface soil disturbance, leaving surface residues largely undisturbed. This is particularly important on sloping, erosion prone fields.

Inter-row cultivation rig set up for one-pass cultivation and cold-flow nitrogen application.

A homemade flame weeder for controlling weeds in the inter-row area.

Flame & other weeders

Flame weeders, infra-red weeders, steam weeders and electro-static weeders have been developed as alternatives to cultivation and herbicides and are especially useful in organically grown cotton where herbicides can't be used. They are effective in controlling small annual weeds in the inter-crop area and can control small weeds in the cotton plant line in older cotton with minimal damage to the crop. They have the drawback that they require large inputs of energy and are therefore expensive to use.

Machinery hygiene

Weeds are spread through a variety of mechanisms, but most commonly through the dispersion of seeds by wind and water. Most weeds produce large numbers of seeds, each of which is capable of producing a new plant. Some weeds are also capable of reproducing vegetatively, spreading through tubers, rhizomes or stolons, and some are capable of regrowing from a piece of leaf or stem.

Apart from the natural means of weed dispersion, one of the principle villains for spreading problem weeds is the cotton grower himself. This spread normally occurs on contaminated machinery such as cultivation equipment, pickers and farm vehicles. Good machinery hygiene is essential to avoid introducing new weeds and diseases from other contaminated fields, or other areas. Machinery from off-farm should always be thoroughly cleaned before use.

Hand hoeing

Manual weeding using hand hoeing is a valuable tool for removing low densities of weeds from the cotton plant line. Hoeing can also help prevent the build up of herbicide resistant and herbicide tolerant weeds, removing weeds that survive the other weed management practices.

However, hand hoeing can be extremely expensive. Hoeing should be used in conjunction with inter-row cultivation, so that the majority of weeds are removed by the cultivator, at much lower cost than hoeing. Care should be taken to ensure that the cost of hoeing does not become excessive.

Row configurations for cotton

A range of planting configurations, including the ultra-narrow row configuration have been trialled over the past decade or so. These configurations all have advantages and disadvantages in terms of weed control. Irrigated, ultra-narrow row cotton is more competitive than conventionally planted cotton on 1 m beds, due to a much increased cotton plant density. However, the narrow-row configuration precludes normal in-crop, inter-row cultivation, and limits in-crop herbicide applications to those herbicides that can be applied over-the-top of the crop. Ultra-narrow row is best suited to transgenic herbicide tolerant cotton varieties and fields that are relatively free of weeds.

Managing weeds on non-cropping areas

Weeds present on areas surrounding cotton fields can contribute significant weed seed loads to cotton fields. If poorly managed, these areas can contribute large seed loads of many of the more difficult to control weeds such as noogoora and Bathurst burr, fierce thornapple, sesbania and cowvine.

Roadways and irrigation structures can be particularly important in spreading weeds, as rain run-off from these areas often flows directly into irrigation channels and onto cotton fields. Weed seeds are readily transported in this water.

Weeds on irrigation channels and structures are most commonly managed using a combination of residual and knockdown herbicides and mechanical means. Regular mechanical maintenance of irrigation structures also contributes to weed management, removing many of the more difficult to control weeds. Cotton growers who pump irrigation water from a river or whose land is flood susceptible, have little control over weed input from these sources, but the management of seeds from all sources within a growers control can make a big difference to the level of in-crop weed competition.

Hand hoeing is an important tool in an integrated weed management program.

Weeds around channels, roads and water storages can contribute significant quantities of weed seeds to cotton fields.

The skip-row configuration often used in dry-land cotton can leave inter-row areas open to infestation by weeds.

Ultra-narrow row cotton. A range of planting configurations can be used.

Susceptibility of weeds to herbicides

The weeds listed in Tables 3, 4 and 5 have been rated according to their susceptibility to the various herbicides under average to good conditions. Since the level of control is influenced by plant size, rainfall, seedbed soil conditions, and other environmental factors, there is no guarantee that a treatment will give the result indicated in the tables.

ALWAYS REFER TO THE PRODUCT LABEL BEFORE USE.

The information supplied here is only a guide. Product registrations vary between states and can vary between formulations and suppliers, but the label information must be complied with. Products labels supply additional information on product safety and use constraints, application rates and timing, the use of surfactants, soil incorporation, water rates, nozzle pressure and configuration, product compatibilities, and equipment decontamination, as well as other information pertaining to the product and its use.

Herbicide resistance

Overuse of glyphosate in the farming system is increasingly leading to species shift (to species more tolerant of glyphosate) and herbicide resistance (to glyphosate resistant species). In practice, this means that more and more in-crop weeds are not being controlled by glyphosate and a 2nd weed management tool must be used following each glyphosate application to achieve acceptable levels of in-crop weed control.

Not only does this greatly increase the cost of managing weeds in cotton, but it places strong selection pressure on the 2nd tool and it is likely that species shift and/or resistance to the 2nd tool will soon occur. Given the very limited number of weed management tools available in cotton, growers need to carefully consider their options before just reaching for the same backup tool every time. For example, the current tendency in the farming system to use paraquat and/or diquat as the herbicide of choice for double knocking in fallows is a good short-term strategy, but in the long-term, is guaranteed to lead to the emergence of resistance to paraquat and diquat, with the loss of a 2nd mode of action in fallows. The loss of 3rd and 4th modes of action are likely to follow quite quickly, with the costs of fallow weed control mounting every time.

Ultimately, the only sustainable solution to species shift and herbicide resistance is to develop and adopt an integrated approach to weed control in the farming system. Central to a sustainable integrated weed management system must be:

Scout after every herbicide application and control survivors with an alternative control tool before they set seed – EVERY TIME!!

More detailed information on managing herbicide resistance is given in Section C of WEEDpak, Managing Herbicide Resistance in Cotton.

Modes of action of herbicides

There are many different modes of herbicidal action and a single herbicide may act on more than one plant process. Nevertheless, similar herbicides often have similar modes of action. For example, the post-emergence grass herbicides (Table 5) are all group A herbicides which act through inhibiting acetyl-coA carboxylase, leading to membrane disruption in the plant. Consequently, although five chemically distinct herbicides are listed in Table 5, they all act on the same plant pathway and a weed that develops resistance to one of these herbicides will almost certainly have some resistant to all five herbicides. However, apparently similar herbicides do not always have similar modes of action. Of the pre-emergent grass herbicides (Table 3) for example, trifluralin and pendimethalin are both group D herbicides, which inhibit tubulin formation, effectively inhibiting plant growth, whereas metolachlor is a group K herbicide, with multiple modes of action inhibiting growth and root elongation.

Where herbicides with similar weed spectrums have different modes of action, opportunity exists to rotate herbicides, thereby reducing the risk of selecting weeds resistant to any one herbicidal mode of action.

Development of herbicide resistance

When applied correctly, a herbicide will effectively control its target weed. Nevertheless, within any weed population there will be weed species that are more tolerant of the herbicide, and within a species there may be individual plants that are more resistant to the herbicide than the remainder of the population.

Repeated use of a herbicide will have two effects. Firstly, the herbicide will select for the more tolerant weed species, probably resulting in a shift in favour of those tolerant species. That is, the density of the more herbicide susceptible species will decline, while there will be a relative increase in the density of the herbicide tolerant species. Secondly, the herbicide will select the more herbicide resistant individuals from within a species and the frequency of these individuals will increase within the population, leading to the development of herbicide resistance.

The rate at which these changes occur depends on a number of factors, including:

- herbicide efficacy, the frequency of herbicide application, the degree of tolerance to the herbicide, the frequency of herbicide resistant individuals within the population, and the nature of the weed's reproductive mechanism,
- dilution of the population from external sources, and
- use of other management tools that reduce the population of tolerant and resistant individuals.

While all herbicides have the potential to cause a species shift in the weed population, they do not all have the same risk of developing a resistant weed population. Within the herbicide groups, there are two broad categories.

1. herbicides with high risk (groups A and B). Repeated use of herbicides from groups A and B has a high risk of selecting out herbicide resistant weeds, and
2. herbicides with moderate risk (groups C - Z).

Nevertheless, these risks are relative. Repeated use of a single herbicide from any herbicide group may eventually lead to the development of herbicide resistance. That is, the selection from a previously susceptible population, of a new population that is resistant to the herbicide at the rates used. Once this happens, the herbicide is no longer of any use for controlling that weed.

Rotating herbicide groups

One approach to reducing the likelihood of herbicide resistance developing is to rotate the use of the herbicide groups, using different herbicide groups over time, so that weeds are exposed to a range of different herbicidal modes of action. This strategy is difficult to implement in cotton, as many of the herbicides that could be readily substituted are from the same mode of action group.

For example, as discussed earlier, although a range of post-emergence grass herbicides are registered for use in cotton and are all chemically different, they are all group A herbicides with similar modes of action. A weed that develops resistance to one of these herbicides will probably have some cross-resistant to all of them, even though the weed had not been exposed to the other herbicides.

Similarly, the residual, broad-leaf herbicides most commonly used with cotton production (diuron, prometryn and fluometuron) are all group C herbicides, with the same mode of action.

However, the pre-emergent grass herbicides belong to groups D (trifluralin and pendimethalin) and K (metolachlor). Use of these herbicides in rotation allows the opportunity to expose weeds to totally different herbicidal modes of action, greatly reducing the risk of developing resistance to a single mode of action.

Overall, the most effective approach to reducing the development of herbicide resistance and species shift to herbicide tolerant individuals, is to:

- ensure that herbicides are used correctly,
- use an integrated approach to weed management, using a range of the weed management tools,
- maintain low weed pressure and not allow weeds to set seed at any stage in the cropping cycle, and
- drive down the weed seed bank.

Special care needs to be taken when making repeated use of Group A or Group B herbicides.

Control every survivor every time. This single glyphosate resistant awnless barnyard grass plant could be the source of year's of heartache if not controlled before it sets seed.

Re-cropping interval after cotton

The minimum re-cropping intervals following herbicide applications in cotton are presented as a guide in Tables 6 and 7 to assist in planning crop rotations.

ALWAYS READ THE PRODUCT LABEL.

Planting a crop too soon after a previous crop in which residual herbicides were used is likely to result in crop failure, or crop damage, which may not be apparent in initial crop establishment. A 20% or 30% yield reduction due to herbicide residues can be a very costly mistake.

An integrated weed management approach is the simplest way to ensure that all weed management tools remain available into the future. Some weeds (such as the nutgrass in this photo) will be very difficult to manage if they develop resistance to herbicides.

C. Putting it together

An historical perspective of weed management

Weeds have been a major issue since the birth of the modern Australian cotton industry in the early 1960s.

Over the 70s and 80s, a robust weed management system evolved based on the use of residual broadleaf and grass herbicides both before- and at-planting, in-crop inter-row cultivation and hand hoeing, and a mid-season (layby) residual herbicide. This system effectively controlled almost all weeds, with weed densities declining over time, but:

- could be extremely expensive,
- caused some crop damage (unacceptable levels of damage occurred on some occasions),
- was prone to environmental damage from off-field herbicide movement, and
- didn't control all weeds. Nutgrass was the worst example of a highly competitive weed that was not well controlled in the system.

By the late 90s, the weed seed bank had been driven down on many older cotton fields and these growers had dropped the use of the pre-planting residual herbicides on cleaner fields, just using an at-planting band of residual herbicide. Shielded in-crop applications of glyphosate were being increasingly commonly used on the dirtier fields, especially where weeds such as nutgrass were problematic. However, instances of crop damage from glyphosate were all too common. Hand hoeing was still being used on many fields, but growers were increasingly replacing hoeing with spot spraying, and were using the newer post-emergent, over-the-top broadleaf herbicides, Staple® and Envoke®, to minimise the need for hand hoeing.

The 2000/2001 season saw the first commercial release of cotton varieties with the Roundup Ready® technology, allowing Roundup Ready® Herbicide (glyphosate) to be applied over-the-top of cotton during early crop growth, and later shielded applications to be made with much better crop safety. These varieties supported the change to fewer residual herbicides and largely eliminated the need for hand hoeing. There were also some reductions in the use of inter-row cultivation and the layby residual herbicide, with laybys only applied where they were needed.

The later part of the decade saw cotton varieties with Roundup Ready technology replaced by varieties with Roundup Ready Flex® technology, which allows glyphosate to be applied over-the-top of cotton from emergence through to 22 nodes of crop growth, by which stage the crop is large and highly competitive. By 2011/2012, around 98% of Australian cotton used the Roundup Ready Flex® technology.

With this technology, many growers have greatly simplified their management system, using glyphosate to ensure a clean seedbed at planting, and again using glyphosate to manage weeds that emerge in the crop, with up to 4 in-crop applications permitted. Inter-row cultivation is still used in furrow irrigated cotton crops to ensure the flow of water, but other management tools are only used as required.

The Crop Management Plan

One of the requirements when growing varieties with Roundup Ready or Roundup Ready Flex technology (or varieties with Liberty Link® technology) is that a grower adheres to the Crop Management Plan for that technology.

These Crop Management Plans were developed prior to the commercial release of the technologies after consultation between growers, researchers and the technology provider, using the vehicle of the Herbicide Tolerant Crop Technical Panel of the TIMS (Transgenic and Insect Management Strategies) committee, originally set up to deal with issues around insect resistance in Australian cotton. The underlying philosophy of the Crop Management Plans was to promote preventative resistance management strategies, maintaining the value and sustainability of the technologies as long as possible.

These Crop Management Plans cover a range of topics, but generally include requirements that:

- the crop is planted into fields with low weed pressure,
- weeds that survive an in-crop spay be controlled using an alternative management tool before they set seed, and
- an in-crop audit to record the target weed species and assess the weeds remaining 10 - 14 days after a glyphosate (or Liberty®) application

These requirements are consistent with good crop management and reinforce the need to manage weeds at all stages during the crop and non-crop phases. Controlling weed survivors before they set seed is a simple and effective way of preventing the development of herbicide resistance and species shift to herbicide tolerant weeds.

The requirements of the Crop Management Plans are reviewed annually and adjusted as necessary to ensure an efficient and robust approach to weed management in transgenic cotton, taking into account any issues or observed changes in the weed spectrum. Local and regional information from the weed audits is used to assess trends in the weed spectrum and determine the need for changes in the system or targeted information to assist growers.

Developing an IWM system

Each of the weed management tools has advantages and disadvantages, and needs to be integrated with the other tools to form an effective and efficient weed management system. The weed management system must be balanced with the needs of the other components of cotton production, such as insect management and disease control.

A weed management system must be flexible and able to respond to the changing needs of each field. One of the most significant factors affecting weed management is the prevailing seasonal conditions, and in particular, rainfall.

An effective weed management system must be able to respond to a range of seasonal conditions. Rainfall affects both weed germination and herbicide efficacy. All plants need moisture to germinate and grow. Generally, weeds will germinate only after a rainfall or irrigation event, and are not normally much of a problem in dry seasons. However, residual herbicides are water activated. They are relatively inactive in a dry soil and become active after rain or irrigation. In addition, most of the translocated, non-residual herbicides are much more effective on plants that are not moisture stressed. Residual herbicides should work well in a wet season, when maximum weed pressure will occur, but may not work well in a relatively dry season, when light rain may be sufficient to stimulate weed germination, but not sufficient to activate the herbicides. In this situation, non-residual herbicides and cultivation may be needed to supplement residual herbicides.

An integrated weed management approach is the simplest way to ensure that all weed management tools remain available into the future. Some weeds, such as the nutgrass in this photo, will be almost unmanageable if they develop resistance to glyphosate.

The inevitable downside of the almost universal adoption of the glyphosate centric approach to weed management has been the strong selection pressure on weeds for species shift to weeds that are naturally more tolerant of glyphosate and the emergence of individuals that are resistant to glyphosate. Many fields remain relatively weed free, well managed by glyphosate in a Roundup Ready Flex system. However, there is an increasing number of fields where problematic weeds, such as flaxleaf fleabane, feathertop Rhodes grass, windmill grass, bindweed and cowvine, are challenging a glyphosate centric system.

To address these problem weed issues, cotton growers need to re-introduce some of the older weed management tools that they have discarded over the past decade, such as residual herbicides and inter-row cultivation, returning to a more integrated approach to weed management. Consequently, management needs to continue to be a dynamic approach, both pre-emptive and responsive, field by field and year by year. Both best management practice and the Crop Management Plans require that weeds that are not controlled by the primary herbicide must be controlled using an alternative management tool and it is only by maintaining an integrated approach that weeds will be successfully managed in the long-term.

With the increasing weed problems in fallows, a cotton crop can now be seen as a valuable weed management opportunity in itself, as a cotton crop which brings with it the ability to use a wide range of management tools and drive down the weed seed bank, reducing the weed pressure on the other stages of the farming system.
Using a glyphosate-centric approach to weed management has been a viable strategy for the past decade. It has been very cost-effective, is consistent with high production efficiency, causes minimal environmental problems, and has given a high level of control for most weeds, reducing most weed issues over time. However, it has also led to species shift and the emergence of a range of glyphosate resistant weeds.

Continuing to use a glyphosate centric approach to weed control in fields with low weed pressure is still a viable approach, provided there is close attention to detail to manage species shift and any emerging resistance issues. Any weeds that survive a glyphosate application must be controlled using an alternative weed management tool before they set seed – EVERY TIME. Failure to do this will result in the whole system failing within 1 or 2 seasons. Failure to respond in a timely fashion to emerging problems is a recipe for disaster.

If fields where there has been species shift to glyphosate tolerant weeds or where glyphosate resistant weeds are present, growers need to rethink their approach to weed management and develop an integrated approach to weed management that is tailored to deal with the specific weed issues with which they are faced.

Waiting till the system fails and then trying to patch it by adding an alternative herbicide is a recipe for disaster. It is an approach which has been used elsewhere in the world and it fails, usually quite quickly and quite disastrously.

To return to the example of managing glyphosate resistant flaxleaf fleabane. Adding a pre-plant diuron into the glyphosate system to manage this weed will result in resistance to diuron and potentially the other Group C herbicides within a few seasons. However, reintroducing a winter cultivation of sufficient robustness to control any over-wintering plants, adding a pre-planting diuron and including an in-crop spot-spraying pass should be adequate to manage fleabane in the cotton phase. In addition, similar changes need to be added to manage fleabane in the cereal phase and also to manage fleabane on channels, roadways etc. It all sounds like overkill, but failure to adopt a comprehensive, integrated approach to managing resistant weeds will result in the whole system failing. The examples from other countries are numerous. Failure to return to an integrated approach to weed management has resulted in complete failure of the system and it will happen here if we don't change our approach.

This fleabane in emerging Roundup Ready Flex cotton will need to be controlled with inter-row cultivation and hand hoeing as plants of this size will not be susceptible to glyphosate at label rates. The presence of these plants indicates a major failure in the system that requires a total rethink to weed management on this farm, before its too late.

Summary

Weeds can compete strongly with cotton, potentially reducing cotton lint yields and lint quality. Weeds can act as hosts for diseases and pests of cotton. Uncontrolled weeds can also produce large numbers of seeds, creating far bigger weed problem in future years.

A range of management tools is available for weed control in cotton. These tools are best used in combination, in an integrated weed management system. The management tools include residual and contact herbicides, cultivation, hand hoeing, cropping rotations, transgenic, herbicide resistant cotton varieties and crop agronomy. Herbicides can be used in a variety of ways, including in fallows, pre-crop planting, post-planting, post-emergence, and as directed or spot applications. Even inputs such as irrigation, fertilizers, and crop variety selection have some impact on weed management.

However, over the last decade, glyphosate has been substituted for most of the other weed management tools. The glyphosate centred system which has evolved have been highly effective for controlling most weeds, is relatively inexpensive, can be targeted to growing weeds and can be rapidly applied to large areas. It has been an important part of achieving the very high yields that have become the normal in the Australian cotton industry of the new century, valuable both for weed control in-crop, and for managing weeds in fallows, facilitating the development of moisture conservation and stubble retention systems.

Unfortunately, resistance to glyphosate has developed, and to more than just one species. The system is rapidly falling apart. The system is no longer sustainable in the long-term or even the medium-term and failure to change our approach to weed management now will result in Australia joining a growing list of countries where glyphosate technology has already been effectively lost for many of their most troublesome weeds.

However, it doesn’t just stop there. The loss of glyphosate for managing the worst weeds in these countries has been followed by the successive loss of the most useful alternative chemistries, with these herbicides also falling to resistance in rapid succession.

To avoid a looming glyphosate resistance disaster, the weed management tools need to be integrated into a cost effective, sustainable management system. Attention to weed management in fallows and rotation crops, and on irrigation structures and roads is critical to the whole farm system. Movement of weed seeds on equipment and in the irrigation system must also be taken into account.

The cotton crop has the potential to be used to drive down the weed seed bank, reducing weed pressure in other components of the farming system. Cotton growers need to grasp this opportunity to protect the use of glyphosate and their whole farm enterprise.

This document discusses in detail the tools available to develop a sustainable weed management system. Cotton growers need to use these tools and redevelop their systems before it is too late.