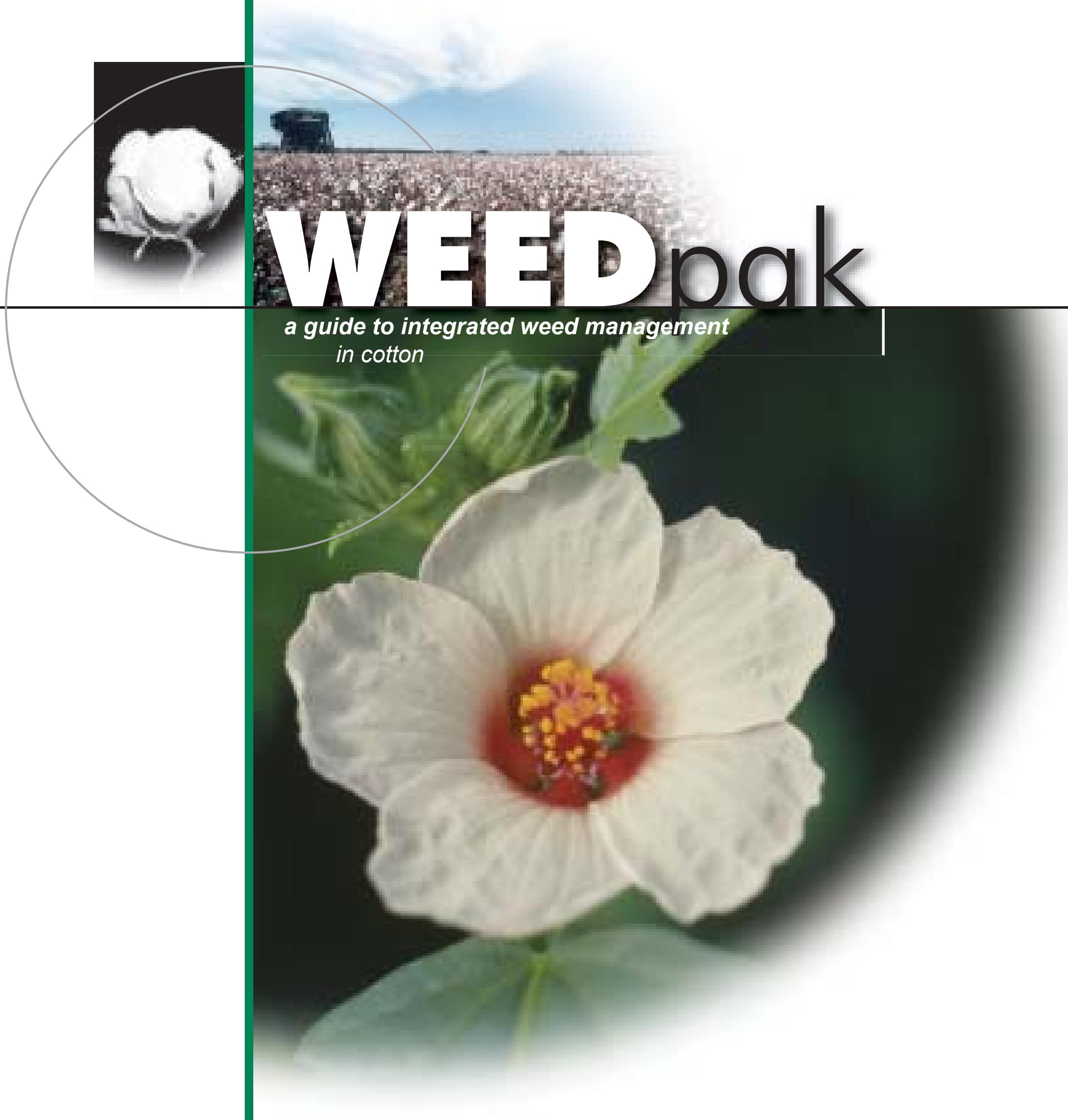
October 2013 Revision



WEEDpak

a guide to integrated weed management in cotton

Australian Government
Cotton Research and Development Corporation

Cover image:
Wide-leaf bladder ketmia
Hibiscus trionum var. *vesicarius*

DISCLAIMER

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The manual does not claim to be complete and all-inclusive, but it aims to grow with the input of all who use and report on it.

Where trade names or products and equipment are used, no endorsement is intended nor is criticism implied of products not mentioned. Label information provided with chemicals regarding chemical use must be adhered to.

This manual does not contain a complete statement of all relevant legal obligations. You should seek your own legal advice as to both legislative and general legal obligations, in particular those legal obligations rising under environmental laws and the general laws of negligence.

FOREWORD

Andrew and John Watson (l to r) in a cotton crop on their property 'Kilmarnock', near Boggabri.

Foreword

At last! The publication of this weed management guide, 'WEEDpak', will meet a real need in the cotton industry. Many growers feel that weeds are becoming more expensive, and more difficult, to control. The weed spectrum seems to be changing for the worst and it is now appropriate that the many investigations of the weed scientists, and some grower experiences, are documented in the one publication as a practical management guide

With this information there will still need to be a more disciplined approach to weed control to achieve growers' aims of reduced costs for weed-free cotton fields. This will entail better documentation of weeds in the previous crops in each field, planning for the control measures in the coming crop by using this guide, and a commitment to timeliness of operations.

WEEDpak covers quite a number of topics related to improving our knowledge and thus the control of our weeds. It highlights an integrated approach to weed control, stressing the need to use a range of management tools to achieve the cotton managers' aims in a modern cotton farming system. The main part of the book will deal with individual weeds, a 'best bet' management guide, the use of Roundup Ready cotton, and the potential development of resistant weeds by overuse of various herbicides including glyphosate.

Growers planning more rotations to control difficult weeds, or as a response to low cotton prices, will find sections containing weed lists, herbicide groups, plant back periods, and other important aspects of weed management.

The environmental risks of pollution by leaching and runoff will need to be understood by growers and allowed for on their farms. More structured scouting and counting of weed densities will help manage the need to reduce dependence on herbicides, particularly residuals with leaching potential.

As an important part of weed management, an identification guide will be published separately and is also available on the internet. This will complement the range of identification guides that already exist to provide one guide covering all weeds of significance to cotton. As with WEEDpak itself, further information can be incorporated when available. The format will allow new sections to be added where relevant. Needless to say the authors will welcome comments and new information.

I have been pleased to be associated with this project through the ACGRA with funding by the CRDC. The development of this publication has drawn on the considerable expertise of the weeds researchers with support from the National Cotton Extension Network.

Although cotton researchers may be contacted directly, there may be benefits to be gained by contacting your agronomist or your Cotton Industry Development Officer, to relate local knowledge and practices to this guide.

John Watson

ACGRA Weeds and Diseases Committee,
June 2002

INTRODUCING WEEDpak

Weeds are a major problem in Australian cotton farming systems. Weeds directly impact on cotton production by competing for water, nutrients and light, they contaminate cotton fibre and cotton seed production, they act as hosts for both insects and pathogenic organisms that have adverse impacts on cotton production, they reduce the efficiency of various operations like picking and they may cause injury to field staff. The management of weeds imposes a significant cost burden on growers particularly as they aim for environmental sensitivity while reducing the risk of weeds developing herbicide resistance.

Integrated weed management (IWM) seeks to deal with these issues by combining a number of different approaches to achieve sustainable, cost effective and environmentally sensitive weed management. The WEEDpak manual has been designed to provide growers, agronomists, consultants and others with information on IWM, why IWM is so important and the tools that are available to implement an IWM strategy.

WEEDpak synthesizes the results of extensive research on IWM in Australian cotton farming systems from research over the past 13 years. The WEEDpak manual includes extensive reference material to help identify weeds, an important first step in IWM. WEEDpak then discusses a number of other issues involved with IWM including herbicide resistance, herbicides and their application, farm hygiene, the control of volunteer cotton, and weed control in rotation crops. Since the main thrust of IWM is management, WEEDpak contains sections on Roundup Ready cotton management, the management of specific problem weeds and a species-specific best bet management guide, sourced from industry consultation.

As further information becomes available, registered users of WEEDpak will receive updates, research reviews and other publications from the Australian Cotton Cooperative Research Centre's Technology Resource Centre. Sections in WEEDpak are complimentary and cross-referenced to other Australian Cotton CRC information packages such as ENTOpak, SPRAYpak, SOILpak and MACHINEpak. Growers and industry personnel are encouraged to register with the Australian Cotton CRC to ensure that they receive WEEDpak updates and other information packages.

A number of partners have sponsored the research contained in WEEDpak. These include the Cotton Research and Development Corporation (CRDC) and the Australian Cotton Cooperative Research Centre (CRC), NSW Agriculture, the University of New England (UNE), CSIRO Plant Industries and the Queensland Department of Primary Industries (DPI). This research continues as part of an on-going program to ensure that IWM continues to achieve sustainable cost-effective and environmentally responsible weed management outcomes.

Dr. Stephen Johnson

Coordinator

The following people have helped produce WEEDpak

WEEDpak Researchers:

Graham Charles,
NSW Agriculture,
Australian Cotton CRC,
Narrabri.
Graham.Charles@agric.nsw.gov.au

Stephen Johnson,
University of New England,
Australian Cotton CRC,
Narrabri.
StephenJ@mv.pi.csiro.au
Coordinator

Grant Roberts,
CSIRO Plant Industry,
Australian Cotton CRC,
Narrabri.
Grant.Roberts@csiro.au

Ian Taylor,
NSW Agriculture,
Australian Cotton CRC,
Narrabri.
Ian.Taylor@agric.nsw.gov.au

Cotton CRC WEEDpak Production Coordinator:

Leah MacKinnon

Cotton CRC WEEDpak Team: Cathy Charles, Susan Hazlewood, Leanne Smith, Benita Inchbold, John Watson, David Larsen, Nicky Schick, Stewart Whiteside, Paul Grundy and Tracey Farrell.

Cotton CRC Extension Coordinator: Ingrid Christiansen (QDPI, Toowoomba).

Cotton CRC Extension Team: Mark Hickman (NSWAg Gunnedah), Leigh Jenkins (NSWAg Warren), David Kelly (QDPI Emerald), Sarah Kerlin (previously QDPI St.George), Julie O'Halloran (NSWAg Moree), Klara Schulze (NSWAg Narrabri), Annie Spora (NSWAg Narrabri), Anne Sullivan (QDPI, Goondiwindi).

Cotton Consultants & Growers in the Macquarie, Namoi, Gwydir, Macintyre, St. George, Dawson/Callide and Emerald cotton growing areas.

WEEDpak Reviewers: Anne Tuart, John Watson, Lewis Wilson and Gary Fitt.

WEEDpak Layout and Production: Visual Resources Unit, CSIRO Plant Industry

CONTENTS

WEED IDENTIFICATION AND INFORMATION GUIDE

Introduction

The cotton farm can be home to a wide range of weed species. Many of these weeds are native and were present before cotton was first grown in these areas. Many more weed species, however, are introduced and have successfully established in the farming system.

Some of these weeds are of little importance, but most compete with cotton and are routinely controlled on cotton farms. When these weeds are not controlled, they may act as hosts for pests and diseases, may reduce crop yields, may impede irrigation, cultivation and harvesting operations, and may contaminate or discolour cotton lint.

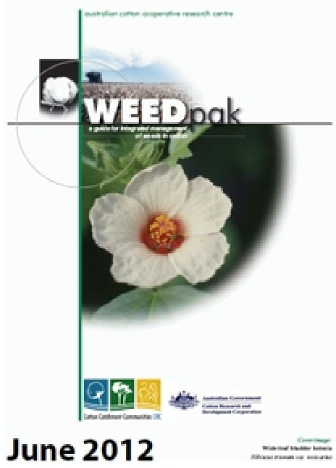
Commonly, around 60 to 70 different weed species are found in cotton fields, although the weed spectrum may vary from field to field. Over 200 weed species are currently considered to be weeds of significance on cotton farms.

Positive identification and an understanding of the life cycles of these weeds is an important step in their management. Positive identification is especially important when using an integrated weed management system that includes herbicides. It is essential that herbicides are matched to their target species, matching label information on the control of specific species with a clear understanding of the weed spectrum present in a field.

Traditionally, plants have been primarily identified from their floral structure. Identification of adult plants is well covered in a host of publications. However, positive identification of weed seedlings is particularly difficult and is not covered in most publications. The **Weed Identification and Information Guide** has been designed with this difficulty in mind. A range of photographs has been included for all weeds, including pictures of cotyledon and young seedling plants. In addition, descriptions of the plants are given. These descriptions will help clarify any difficulties with identification.

NB This chapter of WEEDpak exists as a standalone document. This document is not complete as yet. More weed species will be added to the list as these become available. The guide is also available on the internet at http://www.cotton.crc.org.au and may include additional material. Just follow the links through the cotton site to **WEEDpak** and the **Weed Identification and Information Guide**.

Section A1
Weed ID and Information



WEED GROWTH & DEVELOPMENT GUIDE

Graham Charles
(NSW Dept of Primary Industries)

Introduction

The data in this guide is a combination of growth cabinet, glasshouse and field observations on a range of weeds, recording characteristics such as growth rate, time to flowering and time to first mature seeds. The data set is not complete, but gives the best information currently available. Additional data will be added as it becomes available.

This data may be used as a guide to how quickly these weeds can grow and set seed in the field, giving an indication to the timing of weed management operations to prevent seed set. However, the data is a indication only, weeds may grow more or less quickly than shown in this guide, depending on environmental conditions such as temperature, soil moisture and soil nutrition. Generally, weeds will grow more slowly in cooler spring conditions and most quickly over mid-summer, provided soil moisture is not limiting. Also, weeds can be expected to grow more quickly in the northern-cotton areas and less quickly in the southern areas.

Differences in growth rate can be easily adjusted for by using the plant height as an indicator of growth stage. For example, in a field with a low density of anoda, the weed pressure might not be sufficient to require these weeds to be controlled (as indicated by the Critical Period for Weed Control, WEEDpak section B4). However, the information on the following page shows that the anoda is likely to start flowering about 25 days after emergence and will have mature seed around 16 days later. If the plants in the field are already around 20 – 30 cm high, then it is likely that they are already flowering and may have as many as 500 mature seeds per plant. They will need to be controlled as soon as possible. This estimation can be made even though the date of the anoda emergence is unknown and without considering the rate of growth.

Plant height may often be a better indicator of weed maturity than the time since weed emergence. However, stressed weeds may flower and set seeds while much smaller than is indicated in this guide. If in doubt, check some plants to determine their stage of growth.

Acknowledgements

I gratefully acknowledge the input of Dr. Stephen Johnson (NSW DPI), whose research produced much of the data used to develop this guide. Thanks also go to Todd Green for the fleabane data.

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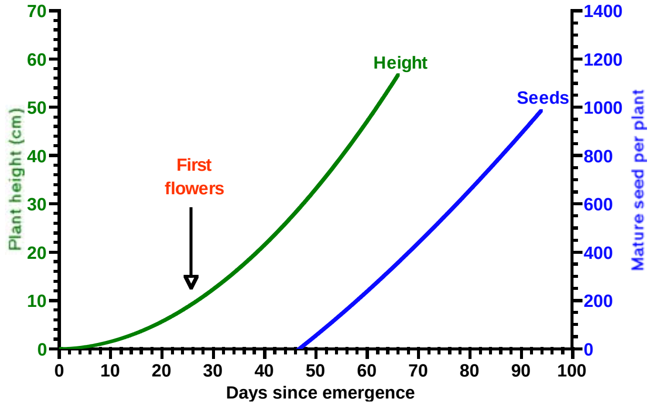
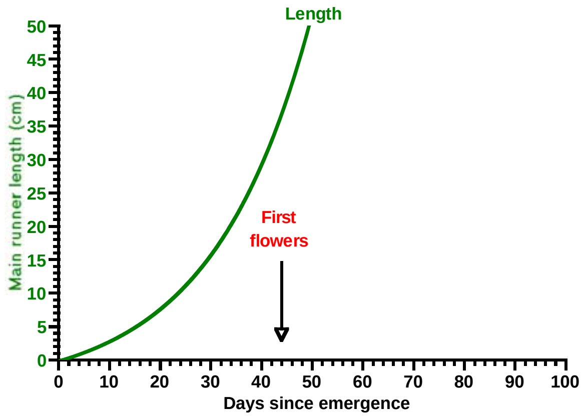
Anoda (*Anoda cristata*)



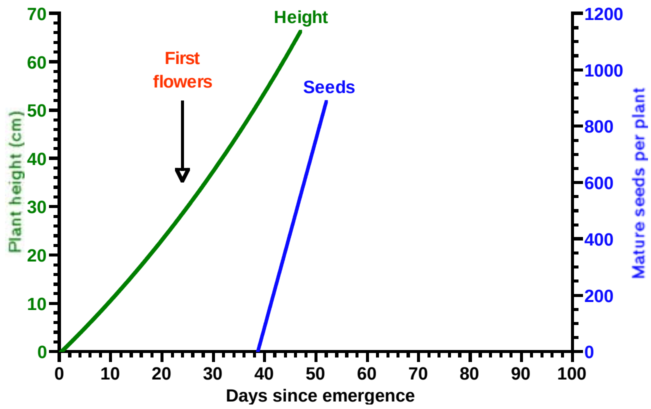
Annual ☒	
Frost sensitive ☒	
Emergence	Spring - autumn
Days to emerge	4 - 12
Typical emergence	20%
Depth of emergence	
First flowers	25 days
Mature pods	41 days
Seeds per pod	11 - 14
Seeds per medium plant	4000
Mature plant height	2 m
An introduced weed ☒	

Australian bindweed (*Convolvulus erubescens*)



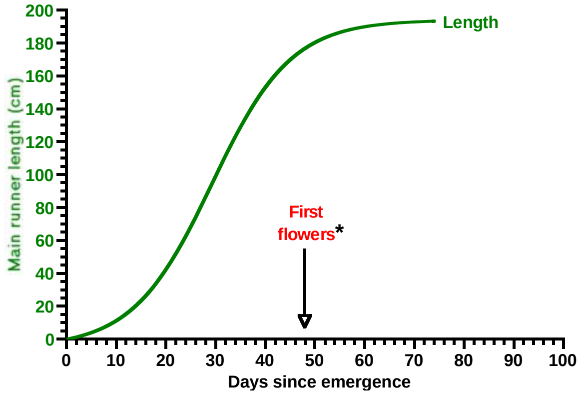
Perennial ☒	
Frost tolerant ☒	
Emergence	Autumn - spring
Days to emerge	4 - 9
Typical emergence	2%
Depth of emergence	
First flowers	44 days
Mature pods	
Seeds per pod	4
Seeds per medium plant	100
Mature plant diameter	2 m
A native plant ☒	

Awnless barnyard grass (*Echinochloa colona*)



Annual ☒	
Frost sensitive ☒	
Emergence	Spring - autumn
Days to emerge	5 - 7
Typical emergence	20 - 30%
Depth of emergence	0 -7 cm
First flowers	24 days
Mature seeds	39 days
Seeds per stem	75
Seeds per medium plant	
Mature plant height	0.6 m

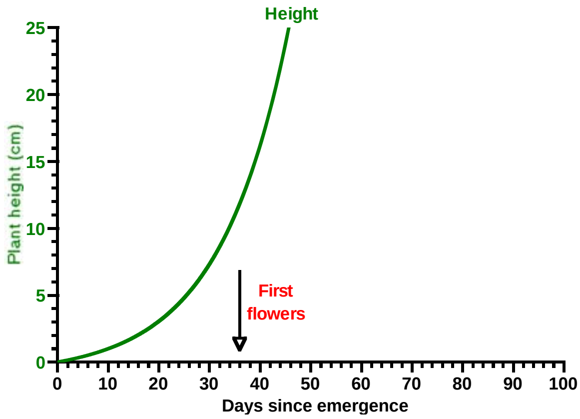
Bellvine (*Ipomoea plebeia*)



Annual ☒	
Frost sensitive ☒	
Emergence	Spring & summer
Days to emerge	4
Typical emergence	60 - 90%
Depth of emergence	2 - 4 cm
First flowers*	48 days*
Mature pods	
Seeds per pod	4
Seeds per medium plant	
Mature plant diameter	2 - 3 m
A native plant ☒	

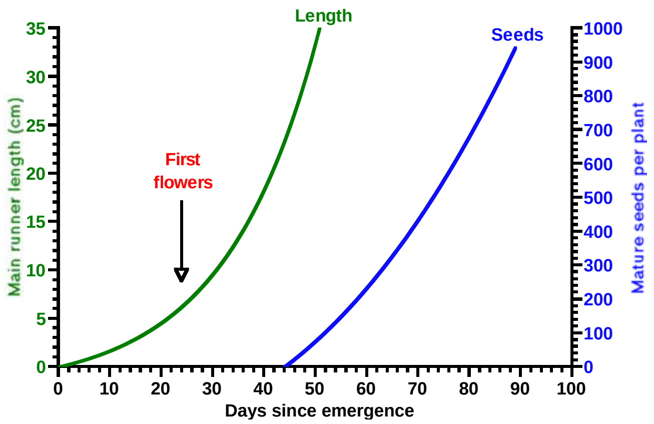
Note* Plants respond to day length and mostly flower in autumn, regardless of plant size.

Blackberry nightshade (*Solanum nigrum*)



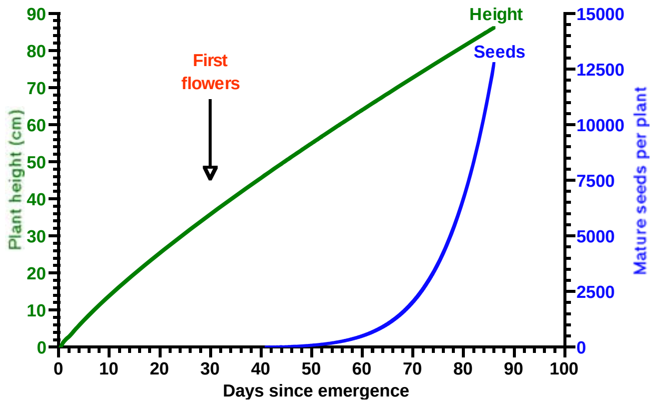
Annual ☒ or short-lived perennial ☒	
Frost tolerant ☒	
Emergence	Winter - summer
Days to emerge	6 - 7
Typical emergence	30 - 90%
Depth of emergence	
First flowers	36 days
Mature pods	
Seeds per stem	
Seeds per medium plant	
Mature plant height	0.6 - 1.2 m
An introduced weed ☒	

Black pigweed (*Trianthema portulactastrum*)



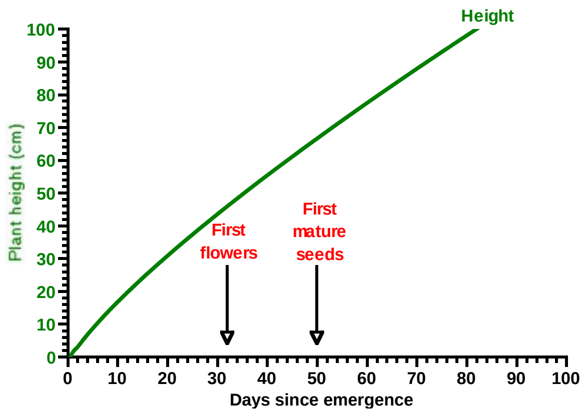
Annual ☒	
Frost sensitive ☒	
Emergence	Spring - summer
Days to emerge	4 - 8
Typical emergence	30 - 50%
Depth of emergence	to 7 cm
First flowers	24 days
Mature pods	43 days
Seeds per pod	3 - 15
Seeds per medium plant	7000
Mature plant diameter	0.6 - 1 m
An introduced weed ☒	

Bladder ketmia – narrow leaf (*Hibiscus tridactylites*)



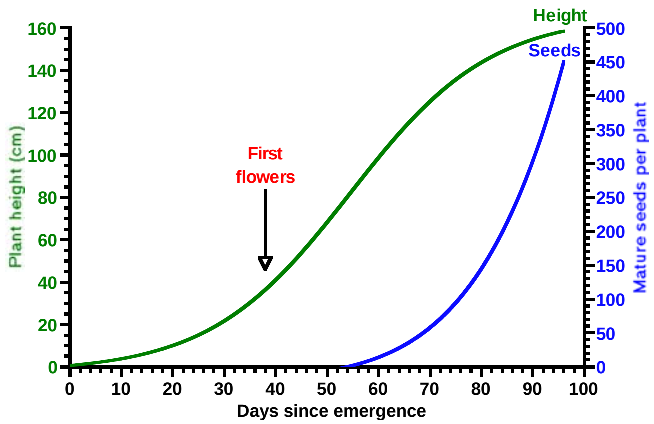
Annual ☒	
Frost sensitive ☒	
Emergence	Spring - autumn
Days to emerge	3 - 6
Typical emergence	1 - 10%
Depth of emergence	
First flowers	30 days
Mature seed pods	40 days
Seeds per pod	33
Seeds per medium plant	15 000
Mature plant height	1.3 m

Bladder ketmia – wide leaf (*Hibiscus verdcourtii*)



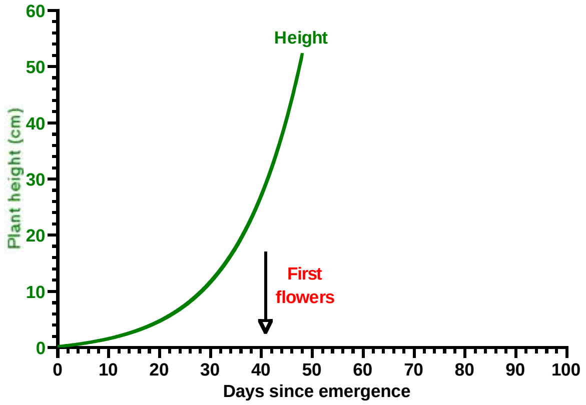
Annual ☒	
Frost sensitive ☒	
Emergence	Spring - autumn
Days to emerge	4 - 7
Typical emergence	1 - 10%
Depth of emergence	
First flowers	32 days
Mature seed pods	50 days
Seeds per pod	33
Seeds per medium plant	8000
Mature plant height	1.5 m

Budda pea (*Aeschynomene indica*)



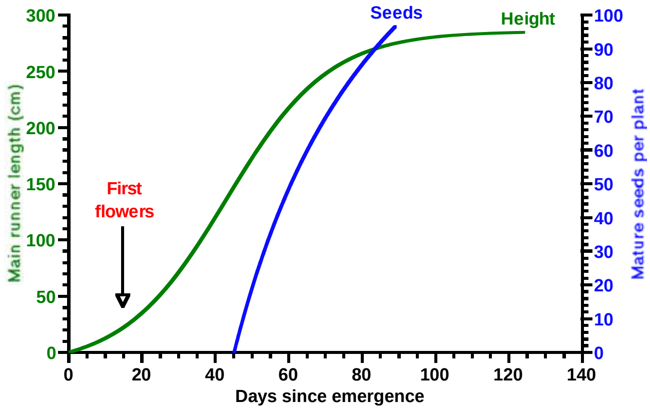
Annual ☒ or short-lived perennial ☒	
Frost sensitive ☒	
Emergence	Spring & summer
Days to emerge	11
Typical emergence	20%
Depth of emergence	
First flowers	40 days
Mature seed pods	55 days
Seeds per pod	3 - 9
Seeds per medium plant	1000
Mature plant height	2 m
A native plant ☒	

Cobbler's pegs (*Bidens pilosa*)



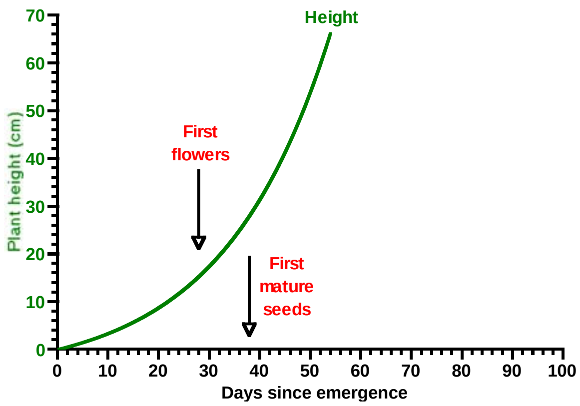
Annual ☒	
Frost sensitive ☒	
Emergence	Spring - autumn
Days to emerge	3 - 6
Typical emergence	70 %
Depth of emergence	
First flowers	41 days
Mature seeds	
Seeds per head	
Seeds per medium plant	
Mature plant height	1 m
An introduced weed ☒	

Cowvine - peachvine (*Ipomoea lonchophylla*)



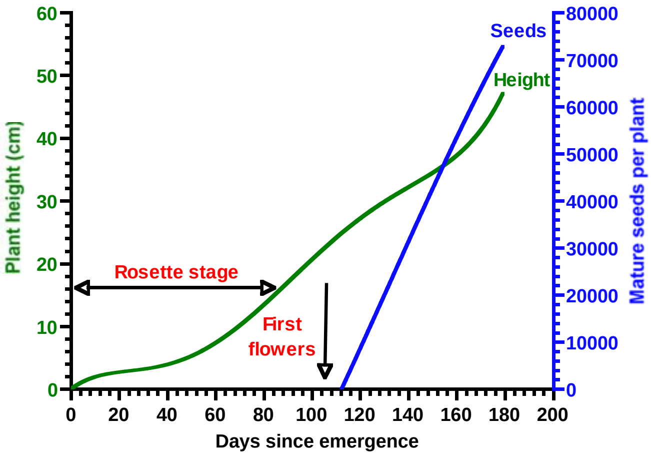
Annual ☒ or short-lived perennial ☒	
Frost sensitive ☒	
Emergence	Spring - autumn
Days to emerge	4
Typical emergence	1 - 10%
Depth of emergence	5 cm
First flowers	16 days
Mature seed pods	50 days
Seeds per pod	3 - 4
Seeds per medium plant	1000
Mature plant diameter	2 - 3 m
A native plant ☒	

Dwarf amaranth (*Amaranthus macrocarpus*)



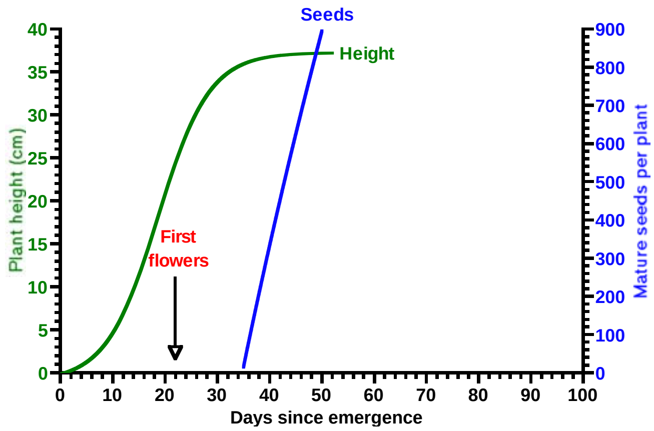
Annual ☒	
Frost sensitive ☒	
Emergence	Spring - autumn
Days to emerge	3 - 7
Typical emergence	10 - 50%
Depth of emergence	
First flowers	28 days
Mature seed pods	35 days
Seeds per pod	
Seeds per medium plant	
Mature plant height	0.3 m
A native plant ☒	

Flaxleaf fleabane (*Conyza bonariensis*)



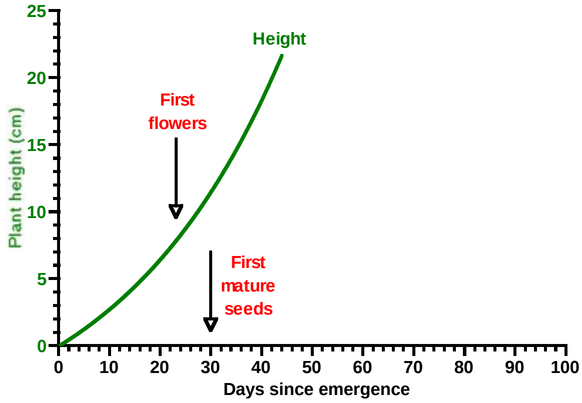
Annual ☒	
Frost tolerant ☒	
Emergence	Spring - autumn
Days to emerge	2 - 3
Typical emergence	10 - 60%
Depth of emergence	Surface only
First flowers	106 days
Mature seeds	124 days
Seeds per head	180 - 240
Seeds per medium plant	60 000 - 85 000
Mature plant height	0.4 - 1 m
Seedbank decay (50%)	3 - 9 months
An introduced weed ☒	

Liverseed grass (*Urochloa panicoides*)



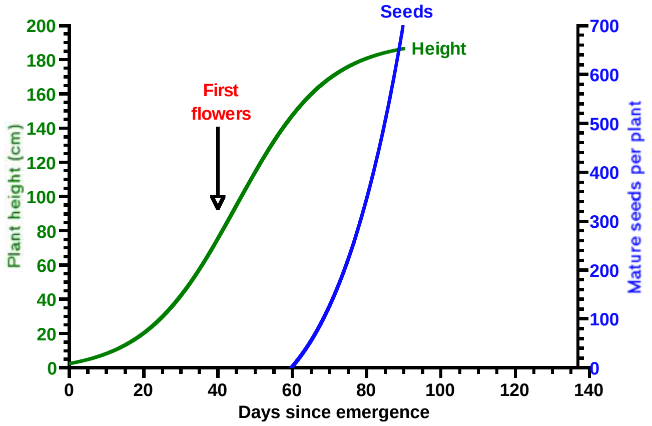
Annual ☒	
Frost sensitive ☒	
Emergence	Spring
Days to emerge	5 - 7
Typical emergence	1 - 40%
Depth of emergence	
First flowers	22 days
Mature seeds	38 days
Seeds per stem	20 - 30
Seeds per medium plant	
Mature plant height	0.6 m
An introduced grass ☒	

Mintweed (*Salvia reflexa*)



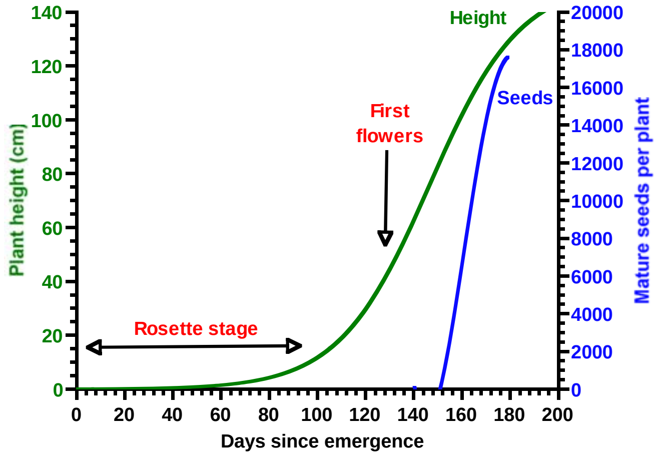
Annual ☒	
Frost tolerant ☒	
Emergence	Winter - summer
Days to emerge	7 - 15
Typical emergence	6%
Depth of emergence	
First flowers	23 days
Mature seed pods	30 days
Seeds per pod	2 - 4
Seeds per medium plant	
Mature plant height	0.7 m
An introduced weed ☒	

Sesbania (*Sesbania canabina*)



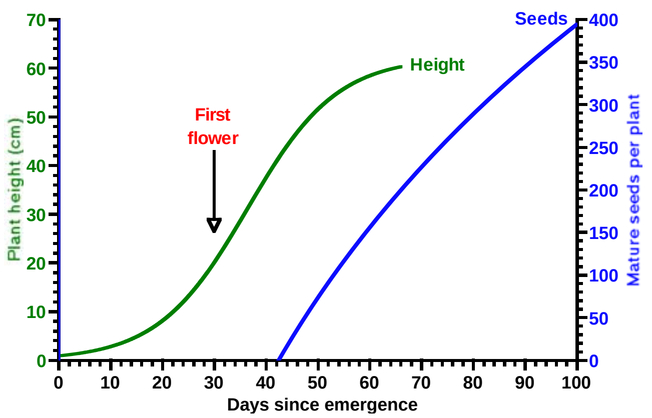
Annual ☒	
Frost sensitive ☒	
Emergence	Spring - autumn
Days to emerge	4 - 9
Typical emergence	5%
Depth of emergence	
First flowers	40 days
Mature seed pods	60 days
Seeds per pod	20 - 30
Seeds per medium plant	10 000 - 20 000
Mature plant height	2 - 3.5 m
A native plant ☒	

Tall fleabane (*Conyza sumatrensis*)



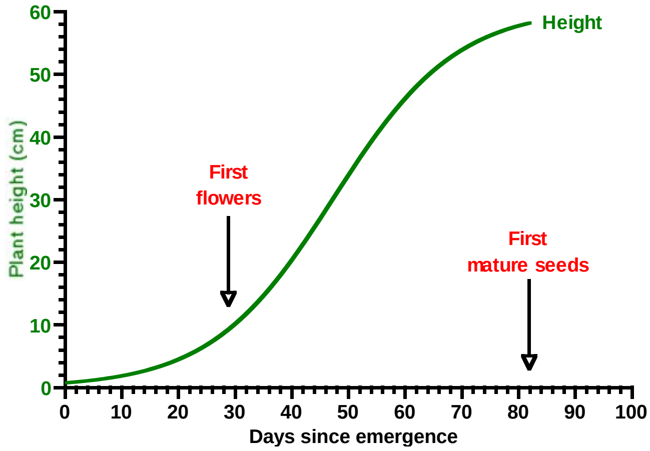
Annual ☒ or biennial ☒	
Frost tolerant ☒	
Emergence	Spring - autumn
Days to emerge	2 - 3
Typical emergence	10 - 80%
Depth of emergence	Surface only
First flowers	129 days
Mature seed pods	148 days
Seeds per head	120 - 170
Seeds per medium plant	14 000 - 21 000
Mature plant height	1.2 - 2 m
Seedbank decay (50%)	3 - 8 months
An introduced weed ☒	

Velvet leaf (*Abutilon theophrasti*)



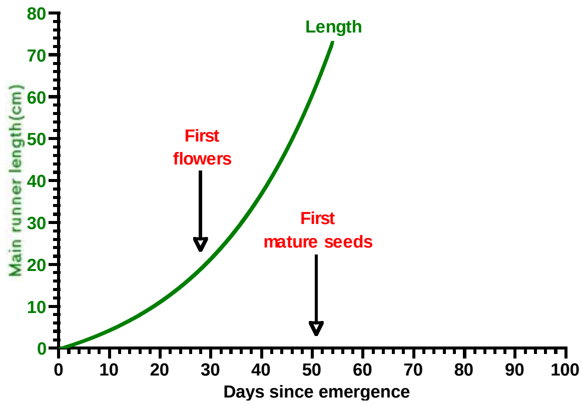
Annual ☒	
Frost sensitive ☒	
Emergence	Spring - autumn
Days to emerge	3 - 7
Typical emergence	5%
Depth of emergence	
First flowers	30 days
Mature seed pods	45 days
Seeds per pod	2 - 3
Seeds per medium plant	1000 - 12 000
Mature plant height	1.4 m
An introduced weed ☒	

Wild gooseberry (*Physalis minima*)



Annual ☒	
Frost sensitive ☒	
Emergence	Spring - summer
Days to emerge	7
Typical emergence	50 - 90%
Depth of emergence	
First flowers	29 days
Mature seed pods	82 days
Seeds per pod	
Seeds per medium plant	
Mature plant height	05 - 0.8 m
A native plant ☒	

Yellow vine (*Tribulus micrococcus*)



Annual ☒	
Frost sensitive ☒	
Emergence	Spring - autumn
Days to emerge	4 - 5
Typical emergence	1 - 10%
Depth of emergence	
First flowers	28 days
Mature seed pods	51 days
Seeds per pod	10
Seeds per medium plant	10 000 - 15 000
Mature plant diameter	2 - 3 m
A native plant ☒	

INTEGRATED WEED MANAGEMENT

Introduction

The advent of insecticide resistance precipitated a radical change in insect management for Australian cotton growers. A major change was the adoption of an Integrated Pest Management (IPM) approach to managing insects. Similarly, an Integrated Weed Management (IWM) approach will need to be adopted if growers are to prevent herbicide resistance becoming a major issue in cotton. However, IWM is about more than just preventing herbicide resistance developing, it is about using multiple methods of weed control in synergy to achieve a superior outcome. The results of implementing IWM will be to reduce the reliance on herbicides, minimise the development of species shift and herbicide resistance, and reduce the impact of herbicides on the environment. An overriding theme throughout WEEDpak is the concept of IWM and how important this approach will be in the future.

The aim of this section is to introduce the concepts of IWM in detail and provide an overview of the weed management principles available for cotton production.

Contents:

B2 Managing Weeds in Cotton

A comprehensive overview of the management of weeds in cotton. This document describes the impact of weeds on the crop, common problems with weed identification and a description of the management tools that might be used for weeds in the Australian cotton system. There are summary tables on:

- Re-cropping intervals for many of the herbicides used in rotation crops,
- Residual herbicides and the weeds they control,
- Post-emergent grass herbicides, and
- Re-cropping intervals for the cotton herbicides.

A range of non-chemical management tools are also discussed. The article leads into the issue of herbicide resistance, while reiterating the importance of developing an integrated weed management system for cotton farms.

B3 Integrated Weed Management (IWM) Guidelines

This document introduces the concept of managing weeds in the cotton production system using an Integrated Weed Management (IWM) approach. It provides an understanding of why IWM will be important for the future management of weeds in Australian cotton and the importance of this concept with herbicide tolerant cotton. A summary table of weeds that have developed herbicide resistance is included, along with a table of the weeds that have developed resistance to the herbicide glyphosate. A description of the components of IWM is provided. This document will encourage cotton growers to evaluate their farm practices, review these practices in light of the IWM principles and adapt their systems to achieve improved outcomes.

B4.1 The Critical Period Weed Sampling Sheet

This sampling sheet is used to estimate weed density in the field and determine the optimum timing of weed control using the weed control threshold developed from the critical period for weed control concept. The table of weed control thresholds and examples of weeds in the "large broad-leaf" group are shown on the reverse side. An explanation of how to use the sheet is given in section B4.7.

B4.2 Understanding the Critical Period for Weed Control

This document explains the theory behind the weed control threshold developed using the Critical Period for Weed control. It discusses the establishment of the economic threshold and the approach used to quantify the yield loss caused by the weeds.

A strength of the critical period for weed control concept is that it clearly defines the period during which weed control is required, and conversely, the periods during which weeds cause insufficient yield loss to justify their control. However, weeds might still need to be controlled to avoid seed production, harvesting difficulties and weed problems in later seasons.

This information is especially important for the management of relatively clean fields where weed control decisions can be difficult to make, as it may be unclear whether a weed density is sufficient to justify control.

B4.3 Applying the Critical Period for Weed Control in the Field

The critical period for weed control is a concept that relates the yield reduction caused by weed competition to an economic threshold. It establishes a period at the start of the season when weeds do not need to be controlled as they cause no economic loss, and a period at the end of the season when weeds again cause no economic loss. These periods define the middle, critical period for weed control, in which weeds must be controlled to reduce yield losses.

The relationships which define the critical period are affected by weed species, weed density and the economic threshold chosen.

This document develops this concept in the field, using real data and establishes a preliminary weed control threshold for cotton. It goes on to discuss the need to ensure that all weed control management inputs are focussed not only on maximizing crop yields but also on avoiding species shift and herbicide resistance.

B4.4 Using the Critical Period for Weed Control in Roundup Ready Flex® Cotton

The weed control threshold developed using the critical period for weed control approach were tested on relative dirty cotton fields at Narrabri using climatic data from the 2004/5, 2005/6 and 2006/7 seasons, using both fully irrigated and dryland scenarios. The findings from this analysis were:

- Applying the CPWC and controlling weeds within a few days of germination will minimize yield losses from weeds, while not leading to excessive herbicide use.
- Weeds that emerge after the CPWC still have to be controlled, but timing is not critical provided they are controlled before they set seed.
- Fields that have significant populations of troublesome weeds should always be treated with residual herbicides before or at planting.
- Alternative weed management tools such as inter-row cultivation and chipping can reduce the pressure on Roundup applications.
- Include a directed layby residual herbicide, incorporated with inter-row cultivation in the system.
- Consider an early layby herbicide application if seasonal conditions lead to excessive early season weed pressure.

B4.5 Using the Critical Period for Weed Control in the 2007/8 Season

The weed control threshold developed using the critical period for weed control approach were tested on clean, average and dirty cotton fields at Narrabri in the 2007/8 season, using fully irrigated and dryland scenarios. The conclusions from this analysis were:

- Using Roundup Ready Flex cotton without pre- or at-planting residual herbicides can be a sound weed management strategy in low weed pressure fields.
- Including alternative weed management tools in the system, such as inter-row cultivation, can reduce the pressure on Roundup applications.
- Including a directed layby residual herbicide, incorporated with inter-row cultivation, in the system can assist with the management of later emerging weeds and reduce the risk of species shift and herbicide resistance.
- If seasonal conditions lead to excessive early season weed pressure, an early layby herbicide application may be a valuable investment for reducing the pressure on glyphosate.
- Fields with significant populations of glyphosate tolerant or hard-to-control weeds should always be treated with residual herbicides before or at planting.

B4.6 Managing Weeds Using the Critical Period for Weed Control

This document explores the same data set as the previous document, but with an updated threshold. The threshold was changed in response to a large jump in herbicide and fuel costs during the season, necessitating the adoption of a higher economic threshold.

Data from the 2007/8 season was used to test the practicality of applying the critical period for weed control for irrigated (higher yielding) and dryland (lower yielding) cotton crops. The critical period was applied to weedy, average and clean Roundup Ready Flex® fields.

Applying the spraying threshold required that weed control began soon after crop emergence, while weeds were still small. A lighter herbicide rate would be appropriate for these weeds. The threshold was reached later in the dryland crop. The duration of the critical period depended on the density of weeds present.

All weed flushes were controlled using Roundup during the critical period within the constraints of the Roundup Ready Herbicide label, with an inter-row cultivation or early layby available as an additional management tool.

The results show that ensuring weeds are controlled soon after emergence is a practical approach to weed control which will help maximize crop yields. The approach can be equally applied to irrigated and dryland crops using Roundup Ready Flex, Liberty Link® or conventional cotton varieties.

B4.7 Sampling Methods for the Critical Period for Weed Control

A sampling method to estimate the weed population in a field is described and the system for using the sampling sheet is explained. In summary, the system is:

- Use a drive-by survey to identify patches of heavier weeds in the field
- Assess weeds in 3 - 5 of the more weedy areas (depending on field size)
- Estimate the weed type and density on a 250 m strip into the field at each assessment point
- Use these assessments to determine the Critical Period for Weed Control for this crop.
- Organise to control weeds as soon as practical if the weed flush is within the Critical Period
- If not, monitor the weeds and control them before they set seed.

INTEGRATED WEED MANAGEMENT (IWM)

Guidelines for Australian Cotton Production

Graham Charles

(NSW Dept. Primary Industries)

Contents Page

IWM is best practice in weed management

The impact of weeds

Weeds adversely impact cotton in many ways. Weeds compete for nutrients, water and light. They can also directly impact cotton quality through contamination of cotton fibre and seed. Weeds may act as sources 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 thornapple by hand-hoeing is less than one plant per 100 m of cotton row, based purely on cotton yield reductions through competition. In addition, thornapples can host Heliothis, mites and verticillium wilt, they can block cultivation and harvesting equipment, and they can cause serious injury to field workers. Thornapple seeds may also contaminate cotton seed.

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

Weeds also impact cotton production indirectly, as many of the tools used to manage weeds are expensive and can adversely affect cotton to some extent. Most herbicides cause some degree of leaf or root damage to cotton. Many of the more commonly used residual herbicides can and on occasions do kill cotton plants if they are incorrectly applied, or if adverse weather conditions occur soon after application.

What is integrated weed management (IWM)?

IWM is about NOT relying on only one or two methods of weed control alone, and particularly not relying on a herbicide or a single herbicide group alone. To use a quote from Prof. Stephen Powles, Director of the Australian Herbicide Resistance Initiative, "When you are on a good thing, don't stick to it!"

An IWM program uses a range of weed control tools in combination so that all weeds are controlled by at least one component of the weed management system. IWM also recognises and incorporates as far as possible, the other aspects of crop production, all of which have some effect on crop and weed growth. Some of these effects may be small, but they can combine to make an important difference to both crop and weeds.

Ultimately, the aim of IWM is to prevent weeds setting seeds, or vegetatively reproducing, so that the weed population is reduced over time, reducing weed competition and improving crop productivity. This aim must apply to all phases of the cropping phase, not just the cotton crop.

Weed management approaches that rely on a limited number of tools often end up with uncontrolled weeds. The most common example of this is the repeated reliance on one or two groups of herbicides to control a target weed population. Within a weed population there is likely to be individual plants that are naturally resistant to any single herbicide. The frequency of these resistant individuals in the population is usually very low.

However, repeated exposure of the weed population to a limited range of herbicides results in these resistant individuals being selected out, so that eventually a large proportion of the population is resistant to the herbicides. Once herbicide resistance develops, the herbicide no longer controls the target weed. In addition, there may be cross-resistance to other herbicides in the same herbicide group, so that the weeds are resistant to all herbicides in the group, even though they have never been exposed to some of these herbicides.

As well as selecting for herbicide resistant weeds, the repeated use of a small number of weed management tools causes a species shift in the weed population. Weed species that are not controlled by these management tools soon come to dominate the weed population, and the weed spectrum shifts towards these weeds. This species shift can result in new weed problems, with weed species that are much more difficult to control than were the original weeds.

The risk of developing these problems can be greatly reduced by using an IWM program. An IWM program may be conceptualised as shown above (Figure 1), where all the individual components of the system contribute to a total weed management system.

Why Use IWM?

Using an IWM program throughout the entire cotton rotation, including rotation crops and fallows, will:

- reduce the reliance on herbicides,
- reduce the risk of herbicide resistance developing in the weed spectrum and prolong the usefulness of the available herbicides,
- reduce the rate of shift in the weed spectrum towards more herbicide tolerant weeds,
- reduce the risk of herbicides accumulating in the soil and riverine systems, and
- reduce the total weed control costs in the future by reducing the weed seed bank (the number of weed seeds in the soil).

Although all these outcomes are important, the evolution of weeds resistance to glyphosate has become the number 1 weed threat to the cotton system, with a rapidly increasing range of glyphosate resistant grass and broadleaf weeds already present on many cotton properties. The presence of glyphosate resistant weeds is a serious threat to the conservation farming system and it is vital that growers address this issue before it is too late.

Failure to prevent glyphosate resistant and tolerant weeds such as this feathertop Rhodes grass setting seed are a very real threat to the long-term viability of the cotton industry..

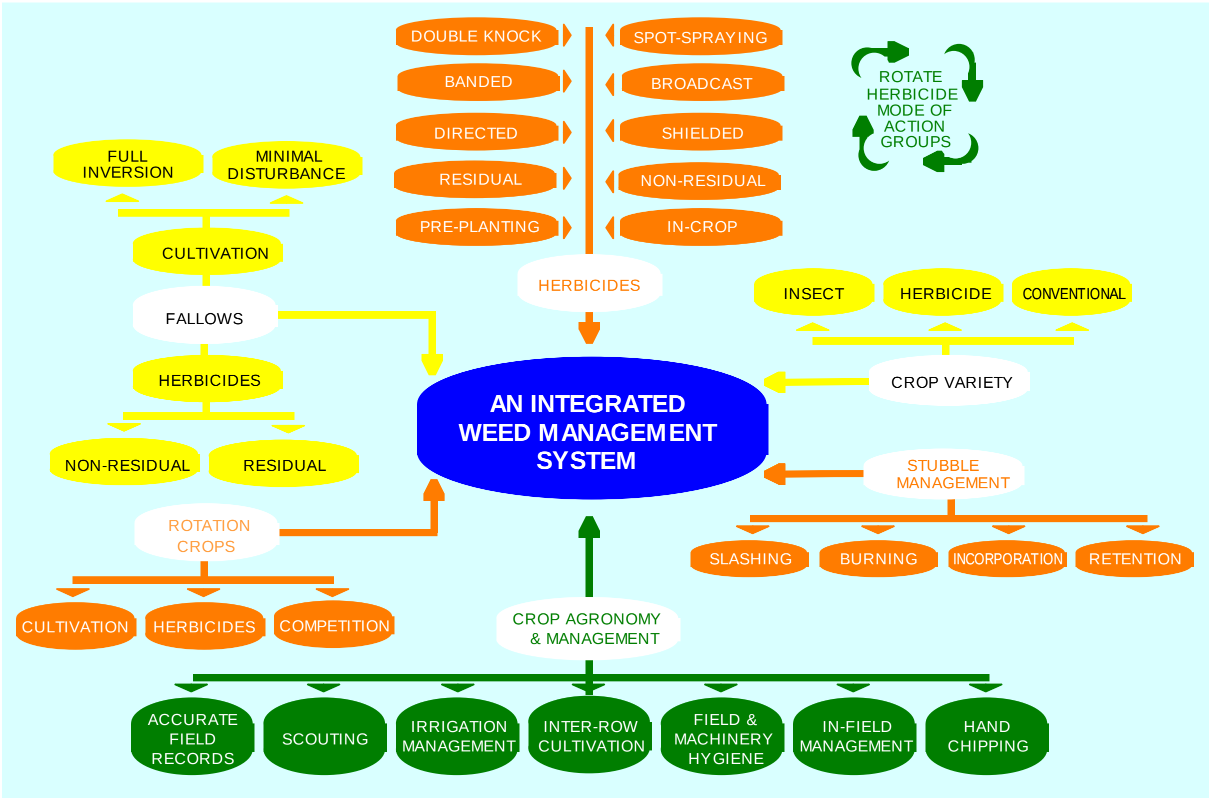


Figure 1. *An integrated weed management system uses a large number of interrelated, complimentary components, so that the combination of the components achieves the best possible outcome.*

Herbicide resistant weeds

In 2013 there were 220 weed species and 404 documented unique cases of weeds that have developed resistance to herbicides worldwide, with resistance identified in 60 different countries.

A total of 37 weed species have developed resistance to a range of herbicides in Australia, as shown in Table 1. Many of these weeds are cross-resistant to a range of herbicides. Cross-resistance occurs when a weed develops a mechanism of resistance to one herbicide that makes it resistant to other herbicides within the same or a different herbicide group.

For some of these weeds, such as ryegrass, there are individuals that have resistance to a large number of different herbicide groups, although any individual plant will not be resistant to every one of these herbicides. Nevertheless, there are instances of multiple resistance, with a single plant containing more than one resistance mechanism, making it resistant to more than one herbicide and herbicide mode of action group. Weeds with multiple resistance can be very difficult to control with herbicides.

Twenty four weed species have developed resistance to glyphosate around the world as shown in Table 2. Many more weeds can be expected to develop resistance to glyphosate if it continues to be the primary method of weed control in the farming system.

Why we don't have herbicide resistant weeds in Australian cotton fields

We do!! Most cotton farms have glyphosate resistant flaxleaf fleabane and glyphosate resistant awnless barnyard grass. Many properties also have resistant annual ryegrass and resistant windmill grass. On top of this, the annual surveys show an ever increasing problem with species shift in the cotton system to glyphosate tolerant weeds such as Feathertop Rhodes grass, bindweed, rhyncho, emu foot and pigweed.

Adherence to the Crop Management Plan (managing glyphosate survivors) and the use of a combination of different weed control methods in Australian cotton fields has up to this point limited the appearance of resistant weeds as in-crop issues, but they are becoming increasingly common in the farming system. Cultivation and particularly hand hoeing have been excellent practices for preventing herbicide resistant survivors from setting seed and so preventing herbicide resistance building up. Complacency and continued over reliance on glyphosate for weed control will quickly change this situation.

Table 1. *Important weeds that have developed resistance to herbicides in Australia.*

Weed	Species	Herbicide mode of action	Herbicide Group	Examples[1]
Capeweed	*Arctotheca calendula*	Inhibitors of photosystem I	L	Spray.Seed
Wild oats	*Avena fatua* and *sterilis*	Inhibitors of acetyl coA carboxylase	A	Hoegrass
		Inhibitors of acetolactate synthase	B	Hussar
		Unknown	Z	Mataven
Wild turnip	*Brassica tournefortii*	Inhibitors of acetolactate synthase	B	Glean
Brome grass	*Bromus diandrus* and *rigidus*	Inhibitors of acetyl coA carboxylase	A	Nugrass
		Inhibitors of acetolactate synthase	B	Monza
		Inhibitors of photosystem II	C	simazine
		Inhibitors of EPSP synthase	M	glyphosate
Windmill grass	*Chloris truncata*	Inhibitors of EPSP synthase	M	glyphosate
Flaxleaf fleabane	*Conyza bonarienses*	Inhibitors of EPSP synthase	M	glyphosate
Dirty dora	*Cyperus difformis*	Inhibitors of acetolactate synthase	B	Londax
Starfruit	*Damasonium minus*	Inhibitors of acetolactate synthase	B	Londax
Crabgrass	*Digitaria sanguinalis*	Inhibitors of acetyl coA carboxylase	A	Hoegrass
		Inhibitors of acetolactate synthase	B	Glean
Sand rocket	*Diplotaxis tenuifolia*	Inhibitors of acetolactate synthase	B	Glean
Awnless barnyard grass	*Echinochloa colona*	Inhibitors of photosystem II	C	atrazine
		Inhibitors of EPSP synthase	M	glyphosate
Paterson's curse	*Echium plantagineum*	Inhibitors of acetolactate synthase	B	Logran
Climbing buckwheat	*Fallopia convolvulus*	Inhibitors of acetolactate synthase	B	Glean
Dense flowered fumitory	*Fumaria densiflora*	Inhibitors of microtubule assembly	D	Trifluralin
Northern barley grass	*Hordeum glaucum*	Inhibitors of acetyl coA carboxylase	A	Hoegrass
		Inhibitors of acetolactate synthase	B	Glean
		Inhibitors of photosystem I	L	Spray.Seed
Barley grass	*Hordeum leporinum*	Inhibitors of acetyl coA carboxylase	A	Hoegrass
		Inhibitors of photosystem I	L	Spray.Seed
Prickly lettuce	*Lactuca serriola*	Inhibitors of acetolactate synthase	B	Ally
Wimmera ryegrass	*Lolium rigidum*	Inhibitors of acetyl coA carboxylase	A	Hoegrass
		Inhibitors of acetolactate synthase	B	Glean
		Inhibitors of photosystem II	C	diuron
		Inhibitors of microtubule assembly	D	trifluralin
		Inhibitors of mitosis/microtubule organisation	E	Carbetamex
		Inhibitors of fat synthesis	J	Avadex
		Inhibitors of cell division/VLCFA	K	Dual
		Inhibitors of EPSP synthase	M	glyphosate
		Bleachers: inhibitors of carotenoid biosynthesis	Q	Director
Iceplant	*Mesembryanthemum*	Inhibitors of acetolactate synthase	B	Glean
Small square weed	*Mitracarpus hirtus*	Inhibitors of photosystem I	L	Spray.Seed
Serrated tussock	*Nassella trichotoma*	Inhibitors of fat synthesis	J	Taskforce
Calomba daisy	*Pentzia suffruticosa*	Inhibitors of acetolactate synthase	B	Glean
Paradoxa grass	*Phalaris paradoxa*	Inhibitors of acetyl coA carboxylase	A	Wildcat
Annual poa	*Poa annua*	Unknown	Z	Mataven
Wild radish	*Raphanus raphanistrum*	Inhibitors of acetolactate synthase	B	Glean
		Inhibitors of photosystem II	C	atrazine
		Bleachers: inhibitors of carotenoid biosynthesis	F	Brodal
		Disruptors of plant cell growth	I	2,4-D
Turnip weed	*Rapistrum rugosum*	Inhibitors of acetolactate synthase	B	Ally
Arrowhead	*Sagittaria montevidensis*	Inhibitors of acetolactate synthase	B	Glean
Charlock	*Sinapis arvensis*	Inhibitors of acetolactate synthase	B	Glean
Indian hedge mustard	*Sisymbrium orientale*	Inhibitors of acetolactate synthase	B	Glean
		Bleachers: inhibitors of carotenoid biosynthesis	F	Brodal
		Disruptors of plant cell growth	I	2,4-D
African turnip weed	*Sisymbrium thellungii*	Inhibitors of acetolactate synthase	B	Glean
Common sowthistle	*Sonchus oleraceus*	Inhibitors of acetolactate synthase	B	Glean
Liverseed grass	*Urochloa panicoides*	Inhibitors of photosystem II	C	atrazine
		Inhibitors of EPSP synthase	M	glyphosate
Dwarf nettle	*Urtica urens*	Inhibitors of photosystem II	C	atrazine
Squirrel-tailed fescue	*Vulpia bromoides*	Inhibitors of photosystem II	C	atrazine
		Inhibitors of photosystem I	L	Spray.Seed

List compiled from Heap I.,The International Survey of Herbicide Resistant Weeds. Online. Internet.2013.

Note[1]. A complete list of product trade names is listed in the ***Herbicide and formulation list****, section D1 in* ***WEEDpak****.*

Table 2. Weeds that are resistant to glyphosate around the world (Group M).

Weed	Species	Country
Palmer amaranth	*Amaranthus palmeri*	USA
Needleburr	*Amaranthus spinosus*	USA (Mississippi)
Common waterhemp	*Amaranthus tuberculatus*	USA
Annual ragweed	*Ambrosia artemisiifolia*	Canada & USA
Giant ragweed	*Ambrosia trifida*	Canada & USA
Brome grass	*Bromus diandrus*	Australia (SA)
Windmill grass	*Chloris truncata*	Australia (NSW)
Flaxleaf fleabane	*Conyza bonariensis*	Australia, Brazil, Colombia, Greece, Israel, Portugal, South Africa, Spain & USA
Canadian fleabane	*Conyza canadensis*	Brazil, Canada, China, Czech Republic, Greece, Italy, Poland, Spain & USA
Tall fleabane	*Conyza sumatrensis*	Brazil, Greece, & Spain
Gramilla mansa	*Cynodon hirsutus*	Argentina
Sourgrass	*Digitaria insularis*	Brazil & Paraguay
Awnless barnyard grass	*Echinochloa colona*	Argentina, Australia & USA
Crowsfoot grass	*Eleusine indica*	Argentina, Chine, Colombia, Malaysia & USA
Summer cyprus	*Kochia scoparia*	Canada & USA
Tropical spangletop	*Leptochloa virgata*	Mexico
Italian ryegrass	*Lolium multiflorum*	Argentina, Brazil, Chile, New Zealand, Spain & USA
Perennial ryegrass	*Lolium perenne*	Argentina & New Zealand
Annual ryegrass	*Lolium rigidum*	Australia, France, Israel, Italy, South Africa, Spain & USA (California)
Parthenium	*Parthenium hysterophorus*	Colombia
Ribwort	*Plantago lanceolata*	South Africa
Winter grass	*Poa annua*	USA
Johnsongrass	*Sorghum halapense*	Argentina & USA
Liverseed grass	*Urochloa panicoides*	Australia (NSW)

Adapted from: Heap I.,The International Survey of Herbicide Resistant Weeds. Online. Internet.2013.

Choosing your farming future

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.

Now is the water-shed moment when Australian cotton growers get to choose their future. They can continue to enjoy the advantages of a glyphosate centred system and join the rest of the world on a down-hill spiral to out-of-control herbicide resistance and huge input costs. Or, they can walk away from the glyphosate centred system, returning to an integrated approach to weed management and a future with a full compliment of valuable herbicides.

Returning to an integrated weed management system doesn’t necessarily mean going back to the full spectrum of conventional herbicides, inter-row cultivation and hand hoeing, but it does mean going away from a glyphosate centred approach in all aspects of the farming system and it means ensuring that any survivors of a glyphosate application are controlled using an alternative management tool before they set seed, in every part of the farming system, every time.

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.

Components of Integrated Weed

Management in cotton:

To develop an integrated approach to weed management, growers need to move away from relying on glyphosate to solve all weed issues and redevelop weed management systems that employ multiple management tools. Some of the tools they have available to them include:

1. Scouting
   Regularly check fields (cotton, rotations and fallows), roadways, channels, irrigation storages and unused land (grazing area, areas around sheds etc.) for weeds. Ensure that areas where herbicides are used are checked soon after application. Weeds which survive a herbicide must be controlled using an alternative tool before they set seed. Weeds may need to be closely examined, as some are capable of setting seed while still very small.

   Identify and closely monitor areas where machinery such as pickers and headers breakdown, as weed seeds are often inadvertently released when panels are removed from machines during repairs.

2. Field records
   Maintain records of crops and weed control methods, and effectiveness after each operation in each field, each year. This allows field rotations and the effectiveness of methods of weed control to be compared. In addition, fields with low weed pressure can be identified. Herbicide rates may be able to be reduced on these fields, and some herbicides may not be needed. Remember that glyphosate will be ineffective for controlling volunteer Roundup Ready Flex® cotton seedlings that may emerge on fallows, roadways, etc.

3. Accurate weed identification
   Ensure that weeds are correctly identified. Always be on the lookout for new weeds and if necessary seek help to get these identified.

4. Follow label recommendations
   No herbicide controls every weed. Ensure that the herbicide you use control the target weeds at the rates you are using.

   Most herbicide labels include information on surfactants, water rates, correct nozzles, nozzle pressure droplet size, etc. These are the parameters that will give the best result from the herbicide. Always follow the recommendations. Achieving a great result from a slow job with a high water rate makes much more sense than a quick but poor result from taking short cuts such as cutting the water rate.

   Always consider weather conditions and never spray when there is a risk of off-target movement.

5. Timeliness of operations
   Often the timeliness of a weed control operation has the largest single influence on the effectiveness of the operation. Herbicides are far more effective on rapidly growing weeds, and may be quite ineffective in controlling stressed weeds. Weeds must always be controlled before they set seed. Cultivation may be a more cost effective option than herbicides for controlling stressed weeds.

6. Growing conditions
   Herbicides are most effective in controlling small, rapidly growing weeds. Weeds that are larger than the recommended application window are unlikely to be controlled by the herbicide, even at the highest rate. Even going above label rates will not be effective for controlling most weeds, so if weeds are too big, look at other options, such as cultivation.

7. Herbicide rates
   Always use the recommended rate of a herbicide. Using lower than label rates leads to poor results and selects for non-target site resistance mechanisms. Using higher than label rates is wasteful, is more likely to cause off-target issues, generally will not improve weed control and creates very high selection pressure that leads to target site resistance. Doubling herbicide rates is not the answer to weeds that are too big or stressed!

8. Herbicide combinations and rotations
   Regular use of a small range of herbicides will result in a species shift to those weeds tolerant of the herbicides used. Using several herbicides in combination, or in rotation, can be an effective way of increasing the spectrum of weeds controlled. Always adjust herbicide rates when using combinations to reflect the overall amount of herbicide used. Always ensure that the herbicides are compatible before tank-mixing.

9. Rotating herbicide groups
   All herbicides are classified into groups, ranging from A to Z, based on their mode of action in killing weeds. The ratings are on the label and outside of each herbicide container. Weeds repeatedly exposed to herbicide groups A and B are at high risk of developing herbicide resistance. Groups C to Z have a moderate risk level, and resistant weeds already exist for many of these herbicide groups. Rotate herbicide groups whenever possible to avoid repeated resistance selection. If this is unavoidable, then other methods of weed control must be used in combination with the herbicides. Refer to Managing Herbicide Resistance in Cotton, section C1 in WEEDpak for more information.

10. Double knocking
The control of many of the more difficult to manage weeds can be improved by using the double knock strategy, applying a 2nd herbicide 7 – 14 days after the first herbicide. To be effective, the herbicides should have different modes of action and must both be applied at label rates that will kill the target weeds. Although this strategy is often employed to manage resistant weeds, it is not really effective once resistance has already occurred. Using cultivation as the 2nd knock is a valuable alternative practice, giving better levels of weed control than either herbicide or cultivation would alone.

11. Ensure optimum spraying conditions
There are a set of parameters to achieve the maximum on-target contact from a herbicide and minimise off-target movement (drift). These include:

- nozzles should be 0.5 m from the target,
- air movement should be between 3 and 15 km/h, and
- use as large a droplet size as practical.

Rushing around a paddock at high speed, with the booms flapping in the wind and using a low water volume that necessitates small droplets is a recipe for poor results. For more information on spray application refer to the Cotton Pest Management Guide.

12. Reducing herbicide use
Select fields with low weed pressure and reduce herbicide rates or remove some herbicide applications on these fields. Reducing the exposure of weeds to herbicides is one method of reducing the selection pressure on potentially herbicide resistant weeds. Limiting the use of residual herbicides will reduce the number of successive weed generations controlled by the same herbicide. Identify major weed species and use the herbicides most appropriate for these target weeds. Avoid blanket approaches without thinking about the weeds you are trying to control.

13. Herbicide tolerant cotton varieties
Consider using herbicide tolerant cotton varieties to reduce the need for some residual herbicides. Substituting post-emergent herbicides for some residual herbicides allows weed management to be more responsive, only controlling weeds when they are present. Follow the label crop management guidelines for herbicide tolerant cotton, ensuring that if weed escapes are detected, these weeds are controlled using an alternative tool before setting seed. **Herbicide resistance MUST be prevented.** Detailed information on the use of Roundup tolerant, Roundup Ready Flex cotton, is given in Monsanto's "Roundup Ready® Cotton technical Manual" and in Managing Roundup Ready Cotton, in WEEDpak.

14. Shielded spraying
Utilise shielded sprayers with non-selective herbicides, such as Spray.Seed® (a mixture of paraquat+diquat), to control herbicide tolerant weeds and reduce the need for hand hoeing and blanket herbicide applications. Weed detecting sprayers are available that can improve spray selectivity and can greatly reduce overall herbicide usage and cost, as well as reducing the risk of spray damage to the crop. This same technology can be used to great advantage in fallow spraying, making the strategic use of very high rates of two and three way herbicide mixes efficient and cost effective.

15. Spot spraying
Spot sprayers may be used as a cheaper alternative to hand hoeing for controlling low densities of weeds in crop. Ideally, weeds should be sprayed with a relatively high rate of a herbicide from a different herbicide group to the herbicides previously used to ensure that any herbicide resistant and herbicide tolerant weeds are still controlled.

16. Cultivation
Complete broad-acre cultivation is an effective, non-herbicide, weed control strategy in fallows. Ensure all weed escapes are controlled. Tactically use in-crop inter-row cultivation to control furrow weeds. Tractor guidance systems can improve the accuracy of cultivation next to the plant line. Cultivating when the soil is drying out is the most successful strategy for killing weeds and will reduce the damage caused by tractor compaction and soil smearing from tillage implements. Aggressive cultivation of dry soils can be effective for controlling perennial weeds

17. Hand hoeing
Hand hoeing is one of the most effective weed management tools for preventing the development of herbicide resistant weeds. Hand hoeing is ideally suited to dealing with low densities of weeds, especially those that occur within the crop row. However, it can be prohibitively expensive if used as a main form of weed control, and is normally used to supplement inter-row cultivation or spraying. Hand hoeing may be delayed until late in the season (before canopy closure) to reduce costs. This strategy relies on good scouting to ensure that weed escapes do not set seed

before they are controlled.

18. Cropping rotations
Strategically use rotations to help control weeds by selecting crops and/or fallows that enhance weed control in cotton. It may be useful to pick crops that allow different herbicides or methods of weed control.

Fallows provide opportunities to use different herbicide groups and non-herbicide methods of control.

19. Farm hygiene
Minimise new weeds entering fields. Clean down boots, vehicles, and equipment between fields and between properties. Pickers and headers are worthy of special attention. Eradicate any new weeds that appear while they are still in small patches; monitor frequently for new weeds. Weed patches should be monitored over a number of seasons, as weed seeds may remain dormant in the soil for many years.

Refer to Managing Weeds with Farm Hygiene in WEEDpak for additional information.

20. Cotton variety selection
Established cotton competes strongly with weeds, shading the soil surface and extracting water and nutrients from deeper in the soil profile than is available to emerging weeds. More vigorous, taller cotton varieties are better able to compete with weeds and better suited to weedy fields.

21. Planting time
Cotton seedlings grow slowly in cool spring conditions and do not compete well with weeds at this stage. Delaying planting on weedy fields until last, gives more opportunity to control weeds that emerge prior to planting and better conditions for cotton emergence and early growth.

22. Irrigation management
Weed emergence is often stimulated by rainfall and irrigation events. Irrigation should be planned to reduce the impact of weeds by coordinating irrigation with planting, cultivation and herbicide events. Pre-irrigation allows a flush of weeds to emerge and be controlled before cotton emergence. Irrigation during the season will cause another weed flush which will need to be controlled, but will also reduce moisture stress for existing weeds, making these more easily controlled by herbicide applications.

Irrigation must be sufficiently delayed after in-crop cultivation to allow all weeds to be killed by the cultivation, but should occur soon after cultivation to reduce stress to the crop.

23. Crop competition
An evenly established, vigorously growing cotton crop can compete strongly with weeds. Factors such as uneven establishment (gappy stands) and seedling diseases reduce crop vigour, and increase the susceptibility of the crop to competition from weeds. Close attention to crop agronomy will increase crop yields and can help reduce weed problems.

24. Canopy closure
Row closure in irrigated cotton is important to maximise light interception for optimum cotton yield but also provides a very important method of minimising light for weeds growing below the crop canopy. Many weeds will fail to germinate once row closure occurs, and many small weeds will not receive enough light to compete with cotton plants.

25. Defoliation
Additional opportunities for weed control can exist at defoliation where small numbers of large weeds, such as Noogoora burrs, emerge above the crop plants later in the season. If uncontrolled, these weeds can damage or block pickers and can reduce lint quality and contribute large numbers of seeds to the soil seed-bank. Hand removal of large weeds may be worthwhile. Alternatively, weeds can be controlled at defoliation with glyphosate or Spray.Seed (ground-rig application only). Drop-Ultra can also assist with defoliation and subsequent weed control.

26. Consider the total management system
Most inputs into cotton production have some impact on weed management and should be considered as part of the IWM program. Inputs such as fertilizer applications (type, amount, position and timing), stubble retention, and even insecticide applications all impact on weed growth and management. Remember, weeds and cotton are both plants.

All inputs that affect cotton also affect weeds.

Inputs such as in-furrow insecticides, fungicides and fertilizer placement can have a large impact on the early season vigour of cotton, which in turn affects its ability to compete with weeds

27. Silver bullets
There are no “silver” bullets for weed control. Glyphosate was the closest to a silver bullet to come along, and the silver is rapidly wearing off. It is now over 30 years since the last new herbicidal mode of action was discovered, and there is no reason to expect a new mode of action in the next decade. The critical thing is to keep the system as sustainable as possible, using a variety of weed management tools to ensure the longevity of every product.

Herbicide Tolerant Crops – WARNING!

A range of herbicide tolerant crops is being developed throughout the world. Australia may see more of these crops over the next decade. Glyphosate and glufosinate tolerant cotton and canola varieteies are available and triazine and imazapic + imazapyr tolerant (Clearfield®) canola are already widely grown in Australia.

Whatever the technology, it is critical that growers adhere to the respective crop management plans and ensure that any survivors of a herbicide spray are controlled using an alternative technology before they can set seed.

Always utilise the IWM principles when growing GM crops.

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

Summary

Integrated Weed Management (IWM) is about managing weed problems now and reducing problems for the future.

The main principle behind IWM is to manage weeds by integrating different management tools together such that each tool compliments the others. In short, it is the principle of NOT relying on one method of weed control alone, particularly herbicides.

The three steps involved in implementing IWM are:

- **Education.** Understanding the principles of IWM, the range of control options available, and how to use them in an appropriate combination.
- **Evaluation.** Knowing the weed spectrum on each field and developing targeted economic and sustainable management strategies
- **Implementation.** Implementing an appropriate IWM strategy.

Preventing seed set and vegetative propagation is the most effective long-term method of managing and reducing weed problems. To develop an IWM program you need to think strategically about how you as a cotton grower can best utilise all available weed control methods in combination to give the best overall result, both in-crop and in rotations and fallows. Always avoid relying on one or two methods alone. Complacency with IWM may appear to save you money in the short term but will inevitably lead to expensive problems such as herbicide resistant weeds.

IWM is best practice in weed management

Table 3. Integrated weed management calendar for back-to-back cotton. The timing of operations will vary between seasons and regions.

	Sep	Oct	Nov	Dec	Jan	Feb	Mch	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mch	Apr
		Cotton							Fallow					Cotton						
Pre-emergent herbicides	eg. diuron, trifluralin	Cotogard, Stomp											eg. diuron, trifluralin	Cotogard, Stomp						
Selective post-emergent herbicides			eg. Envoke, Staple, Factor, Select												eg. Envoke, Staple, Factor, Select					
Broadacre cultivation																				
Fallow herbicides									eg. Amitrole T, glyphosate, Spray.Seed											
Fallow broadleaf herbicides									eg. 2,4-D, Garlon, Sharpen, Starane											
Inter-row cultivation																				
In-crop directed herbicides (layby)				eg. gesagard												eg. gesagard				
Shielded spraying of non-selective herbicides			eg. Alliance, Amitrole T, Spray.Seed												eg. Alliance, Amitrole T, Spray.Seed					
Non-selective post-emergent herbicide (Roundup Ready Flex & Liberty Link cotton only)[1]		Roundup Ready Herbicide or Liberty Herbicide												Roundup Ready Herbicide or Liberty Herbicide						
Hand hoeing																				
Spot spraying – non-selective herbicides		eg. Alliance, Amitrole T, Spray.Seed												eg. Alliance, Amitrole T, Spray.Seed						
Cotton canopy closure																				
Defoliation							eg. glyphosate												eg. glyphosate	
Scouting (key times)																				
Field hygiene (key times for equipment)		Planting equipment	Cultivation equipment					Transport equipment	Cultivation equipment					Planting equipment	Cultivation equipment					

Non-herbicide options

Herbicide options

Note1. Roundup Ready Herbicide can only be safely used over-the-top of varieties including the Roundup Ready Flex trait, and Liberty Herbicide on varieties including the Liberty Link trait.

Table 4. Integrated weed management calendar for a cotton/rotation farming system. The timing of operations will vary between seasons and regions.

	Sep	Oct	Nov	Dec	Jan	Feb	Mch	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mch	Apr
		Cotton							Rotation crop such as wheat							Fallow prior to cotton				
Pre-emergent herbicides	eg. diuron, trifluralin	Cotogard, Stomp							eg. Dual, trifluralin											
Selective post-emergent herbicides			eg. Envoke, Staple, Factor, Select							eg. dciamba, Hotshot, Hussar, MCPA, Sakura, 2,4-D										
Broadacre cultivation																				
Fallow herbicides																Eg. Amitrole T, Balance,, Garlon, glyphosate, Sharpen, Spray.Seed				
Inter-row cultivation																				
In-crop directed herbicides (layby)				eg. gesagard																
Shielded spraying of non-selective herbicides			eg. Alliance, Amitrole T, Spray.Seed																	
Non-selective post-emergent herbicide (Roundup Ready Flex & Liberty Link cotton only)[1]		Roundup Ready Herbicide & Liberty Herbicide																		
Hand hoeing																				
Spot spraying – non-selective herbicides		eg. Alliance, Amitrole T, Spray.Seed										eg. bromoxxynil, dicamba,, MCPA, Starane, 2,4-D								
Cotton canopy closure																				
Defoliation						eg. glyphosate														
Scouting (key times)																				
Field hygiene (key times for equipment)		Planting equipment	Cultivation equipment					Transport equipment	Planting equipment							Cultivation equipment				

Non-herbicide options — Herbicide options

Note1. Roundup Ready Herbicide can only be safely used over-the-top of varieties including the Roundup Ready Flex trait, and Liberty Herbicide on varieties including the Liberty Link trait.

MANAGING WEEDS IN COTTON

Graham Charles[1] and Grant Roberts
([1]NSW Dept. Primary Industries)

Contents

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

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.

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.

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.

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.

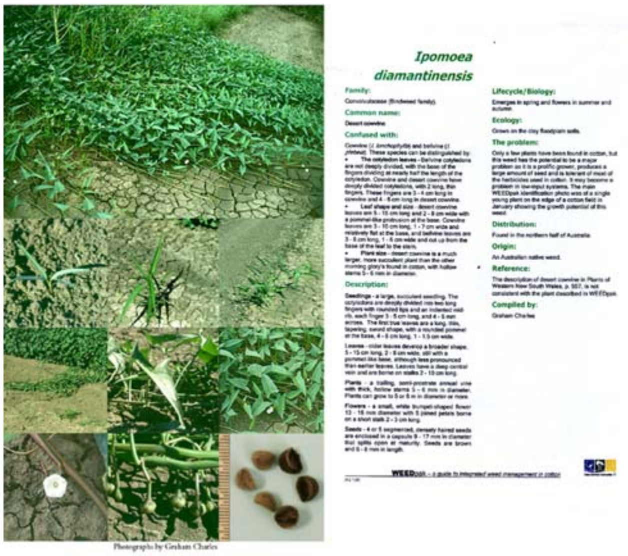
Weeds and volunteer cotton can also be hosts to aphids that are implicated with cotton bunchy top.

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.

The Critical Period Weed Sampling Sheet

Date: Recorder:

Property: Field: Assessment:

Large broadleaf – Noogoora burrs, thornapples, sesbania & budda pea

Medium broadleaf – all other broadleaf weeds

Grasses – grasses and all grass like weeds

Number per 50 m of row

Large broadleaf weeds	<5 1	5 - 50 2	50 - 500 3	>500 4	
0-50 m					
50-100 m					
100-150 m					
150-200 m					
200-250 m					
250-200 m					
200-150 m					
150-100 m					
100-50 m					
50 - 0 m					Total
Sum	___	___	___	___	

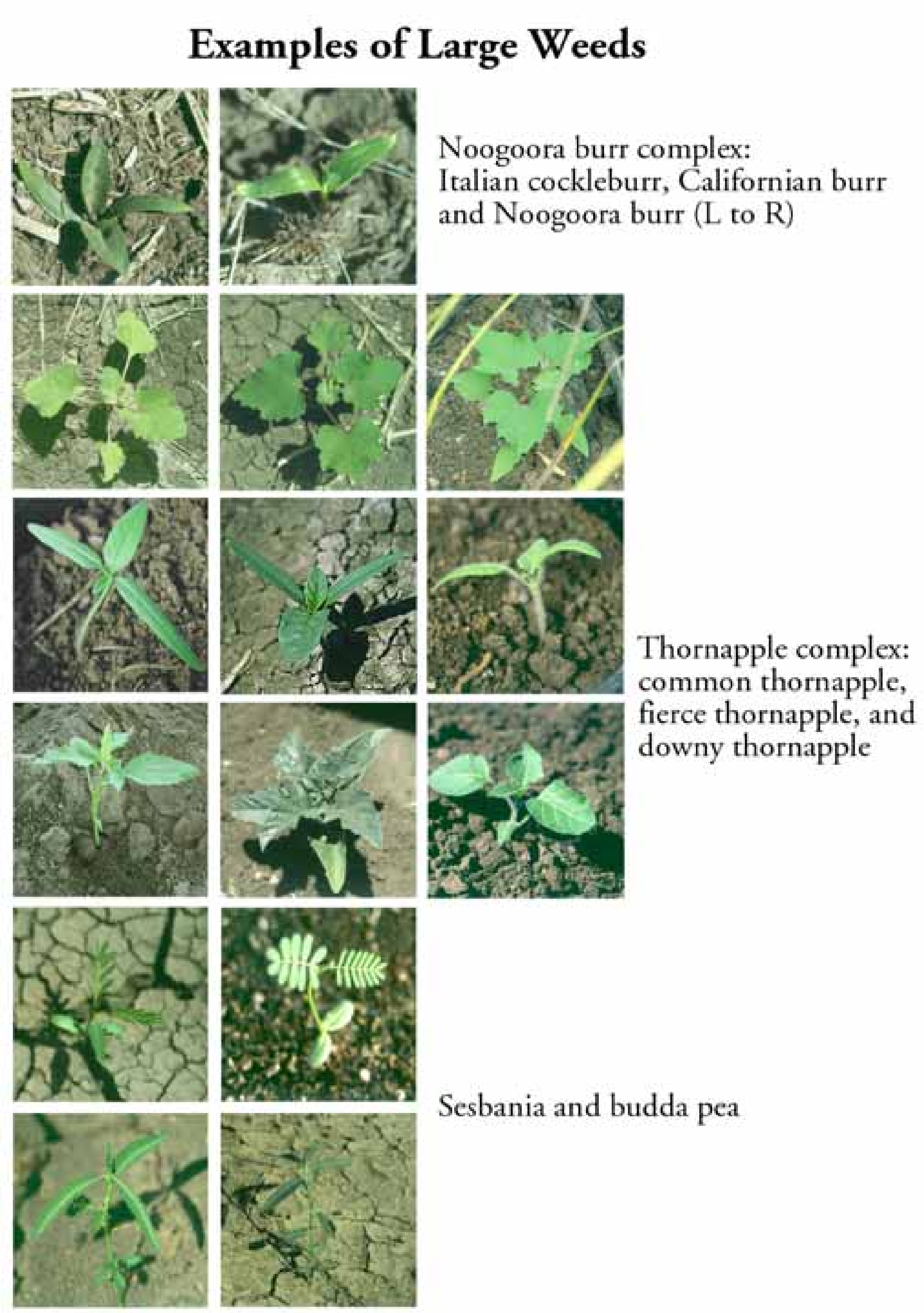
Medium broadleaf weeds	<5 1	5 - 50 2	50 - 500 3	>500 4	
0-50 m					
50-100 m					
100-150 m					
150-200 m					
200-250 m					
250-200 m					
200-150 m					
150-100 m					
100-50 m					
50 - 0 m					Total
Sum	___	___	___	___	

Grasses	<5 1	5 - 50 2	50 - 500 3	>500 4	
0-50 m					
50-100 m					
100-150 m					
150-200 m					
200-250 m					
250-200 m					
200-150 m					
150-100 m					
100-50 m					
50 - 0 m					Total
Sum	___	___	___	___	

Assessment score	1	2	3	4	5
Large broadleaf					
Medium broadleaf					
Grasses					

Assessment summary	1	2	3	4	5	Average
Large broadleaf						___
Medium broadleaf						___
Grasses						___

Assessment score	Weed density
1	0.006
2	0.008
3	0.010
4	0.013
5	0.016
6	0.020
7	0.025
8	0.032
9	0.040
10	0.05
11	0.063
12	0.079
13	0.10
14	0.13
15	0.16
16	0.20
17	0.25
18	0.32
19	0.40
20	0.5
21	0.63
22	0.79
23	1.00
24	1.26
25	1.58
26	1.99
27	2.51
28	3.15
29	3.97
30	5
31	6.29
32	7.92
33	10
34	12.6
35	15.8
36	19.9
37	25.1
38	31.5
39	39.7
40	50



The Critical Period for Weed Control in cotton (day degrees since planting)

Weed density (no./m^2)	High yielding cotton crops: Broad-leaf weeds: Large Start	End	Medium Start	End	Grasses Start	End	Low yielding cotton crops: Broad-leaf weeds: Large Start	End	Medium Start	End	Grasses Start	End
0.1	145	189	145	172	-	-	-	-	-	-	-	-
0.2	144	275	144	244	-	-	254	229	-	-	-	-
0.5	143	447	143	387	-	-	251	368	-	-	-	-
1	141	600	141	514	-	-	246	498	246	319	-	-
2	139	738	139	627	-	-	238	620	238	421	-	-
5	131	862	131	729	129	174	215	735	215	537	-	-
10	121	915	121	771	127	248	184	785	184	595	152	206
20	106	944	106	795	125	357	142	812	142	631	147	290
50	87	962	87	810	119	531	93	830	93	654	134	431
Min. density	0.06		0.07		2.5		0.24		0.59		5.4	

UNDERSTANDING THE CRITICAL PERIOD FOR WEED CONTROL

Graham Charles and Ian Taylor
(NSW Dept of Primary Industries)

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Introduction

The last few years have brought new innovations in weed management in the Australian cotton industry. These include the transgenic herbicide tolerance options of Roundup Ready®, Roundup Ready Flex® and Liberty Link® cottons, the post-emergence, over-the-top herbicides Staple® and Envoke®, and more accurate inter-row cultivation, with additional options likely over the next decade.

These new options allow growers to develop more effective and flexible weed management programs, but the old dilemmas still remain. Growers have to answer the questions; should I use multiple pre-emergent herbicide applications, with pre-planting as well as at-planting herbicides? Or maybe just one of the options, but if so, which herbicide/s and at what rates, broadcast or banded? When should I inter-row cultivate or chip, or should I just apply another herbicide? Should I use a layby?

Using more and more herbicides gives better weed control, but pre-emergence residual herbicides can contribute to establishment problems and additional post-emergence herbicides will not necessarily result in better yields, or improved returns. In fact, controlling weeds in a fairly clean field may just reduce profits. Conversely, inadequate weed control can be costly to remedy, and can result in lost yield and weed problems for years to come. So the question is, what herbicide/ cultivation/ chipping combinations will give optimal weed control, and maximise yields and returns?

The answers are complex and vary from field to field and season to season.

A weed control threshold

Post-emergence herbicides, such as glyphosate, bring the advantage that they are applied to a known weed population. This allows the choice of herbicide, rate and application timing to be targeted to the weed population. These herbicides can substitute for pre-emergent residual herbicides, cultivation and chipping inputs to maximise weed control and minimise costs.

However, the application timing of post-emergent herbicides remains an issue. Growers must balance spraying too often, which provides good weed control, but increases cost and selection pressure for herbicide resistance and species shift, against spraying too little. Delaying control may save costs by reducing the number of applications needed over the season, but increases the risk of weed escapes that can be costly to control, and may lead to yield losses and a build up of weeds over time.

A weed control threshold is needed to help balance the pressures of spray efficacy and cost. The threshold must take into account the characteristics of the weeds, their density and the control options available, to provide guidelines on if and when a weed population should be controlled.

Determining the economic threshold for weed control

The decision to control a weed is influenced by crop growth stage, the availability of suitable herbicides, labor and equipment, the weather, and financial aspects such as lint price, expected yield, and the cost of weed control. The actual level of the economic threshold (the critical number of weeds that triggers a grower to control a weed infestation) is a personal choice reflecting how much loss a grower is willing to tolerate before deciding to control the weed.

For example, a grower may consider using a Roundup Ready Herbicide® application costing around $23/ha, including application. The grower will probably not use the herbicide unless the weeds will cause at least a $23 per ha yield loss, with additional benefit expected in harvest efficiency, lint quality and reduced weed problems in later years. At a bale price of $380 and an expected yield of 8 bales per ha, this establishes an economic threshold for applying Roundup Ready Herbicide at around 0.8% yield loss. That is, **the economic threshold is the 0.8% level of yield loss.**

The economic threshold is easily established. The trick is in being able to quantify the yield loss caused by the weeds.

Understanding the impact of weeds

A weed control threshold must take into account the characteristics of the weeds, their density and the control options available. Competitive ability is one of the more important characteristics of a weed, but other features, such as the ability to host insect pests and diseases, seed production, and lint contamination potential are also important.

The competitive ability of a weed relates to its growth rate and architecture (height, shape, leaf size, branching characteristics, root structure, rooting depth, etc.), and varies with each weed species. Generally, smaller weeds are less competitive, and large weeds, such as noogoora burrs, are highly competitive.

The competitive impact on a crop is also affected by the time the weed emerges and the time of the weed's removal. Weeds that emerge late in the season may have little impact on the crop's yield, whereas even relatively uncompetitive weeds that emerge with the crop are likely to impact on yields if not controlled.

Determining the yield loss from weeds

The impact of weed competition on crop yield is demonstrated in Figure 1, generated from a field population of 4 thornapples per meter of cotton row.

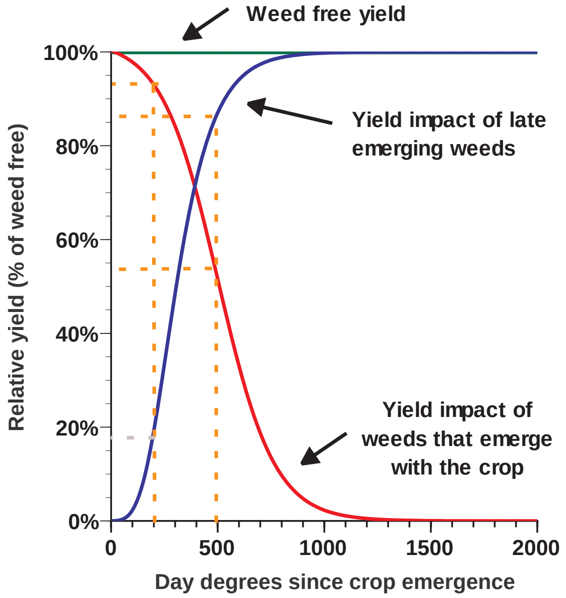

Figure 1. *The impact of 4 thornapples/m on crop yield. The orange lines demonstrate the impact of control 200 and 500 day degrees after crop emergence.*

In Figure 1, the green line across the top is the yield if there were no weeds in the field (the weed free yield).

The red line is the yield loss from a thornapple infestation where the weeds emerged with the crop and were removed some time after emergence. For example, if the thornapples were controlled at 200 day degrees, crop yield would be reduced to 93%, a 7% yield reduction (indicated by where the orange line at 200 day degrees hits the red line). If the thornapples were removed at 500 day degrees, the yield would be reduced to 54%, a 46% yield reduction (500 degrees days orange line). Yield would be reduced by 100% if the thornapples were not controlled before 1300 day degrees.

The blue line is the yield loss from a thornapple infestation where the weeds emerged after the crop and were not subsequently controlled. If, for example, thornapples emerged at 200 day degrees and were not controlled, yield would be reduced to 18%, an 82% yield reduction (where the orange line at 200 day degree hits the blue line). However, if the thornapples didn't emerge till 500 day degrees and were not controlled, the yield would only be reduced to 86%, a 14% yield loss.

Although a single red line is shown for simplicity in Figure 1, there would actually be a family of red lines, representing thornapples that emerged after each weed control input (inter-row cultivation, herbicide etc.), as shown in Figure 2.

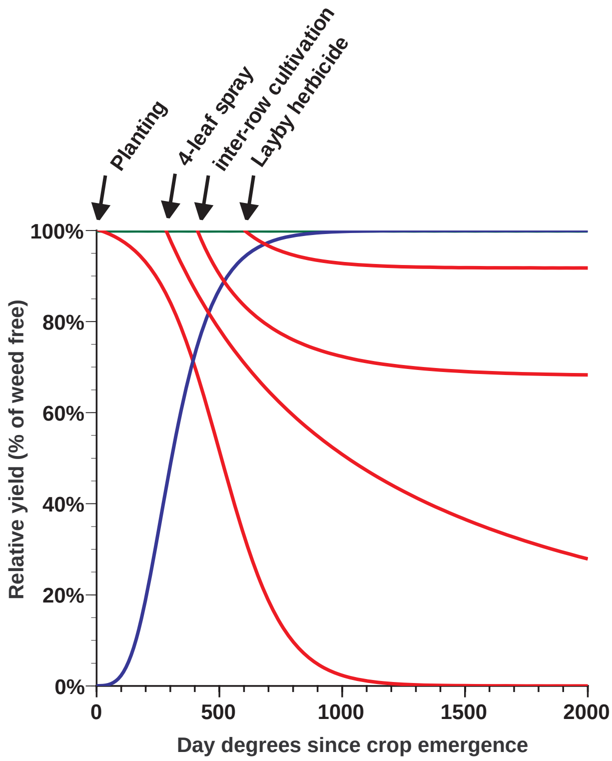

Figure 2. *The impact of weed competition on crop yield following weed control inputs.*

A further set of lines would be needed to show the impact of thornapples at another density, and still more sets of curves to show the impact of other weeds, as the curves are different for each species and density.

The critical period for weed control

A concept known as the 'critical period for weed control', can be derived from the interaction of these relationships with the economic threshold for weed control.

The critical period for weed control starts at the intersection of the first red line with the economic threshold (yellow line), and ends with the intersection of the blue line with the economic threshold, as shown in Figure 3. A new critical period for weed control is defined after each weed control input, beginning where each subsequent red line intersects with the economic threshold. The end of the critical period does not change.

The critical period for weed control is defined by the economic threshold chosen, the weed species and the weed density. In this example, the critical period for weed control for 4 thornapples/m of cotton row is 166 to 621 day degrees at a 5% economic threshold. Thornapples not controlled during this period will cause economic yield loss.

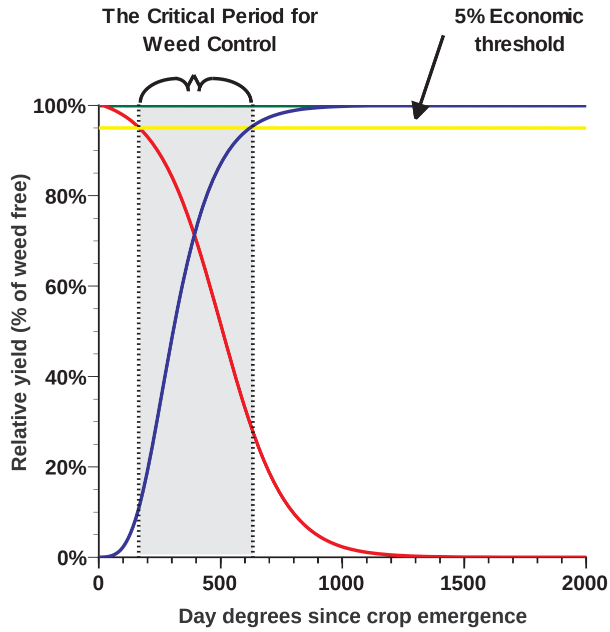

Figure 3. *Deriving the critical period for weed control (the blue shaded area).*

Beyond the critical period for weed control

A strength of the critical period for weed control concept is that it clearly defines the period during which weed control is required, and conversely, the periods during which weeds cause insufficient yield loss to justify their control. Figure 3, for example, shows that where thornapples emerged with the cotton crop at 4 plants/m, there is no justification for controlling them before 166 day degrees of crop development.

Conversely, if up to 4 thornapples/m establish after 621 day degrees, they would not cause an economic yield loss (using a 5% yield loss threshold). However, they might still need to be controlled to avoid seed production, harvesting difficulties and thornapple problems in later seasons.

This information is especially important for the management of relatively clean fields where weed control decisions can be difficult to make, as it may be unclear whether a weed density is sufficient to justify control.

However, the critical period for weed control concept has several weaknesses. It assumes that weeds are equally easily controlled at all growth stages, that the cotton grower has the capacity to control all weeds at the required time, and that the weeds have no negative impact except on crop yield. Weed control decisions may also be justified for irrigation and harvesting efficiency, to reduce pest and disease carryover, to prevent lint contamination, and to prevent weed seed set, reducing future weed burdens.

Also, the critical period for weed control is affected by the economic threshold adopted. At a 1% yield loss (economic) threshold, compared to a 5% economic threshold, for example, the critical period in Figure 3 extends from 61 to 818 day degrees after crop emergence. At this threshold, the first-post-emergence treatment would occur while the crop was at the 1 node stage, and subsequent treatments would need to occur within a week or so of weed emergence to avoid reductions in crop yield.

Timing of herbicide applications

Application timing is critical to achieving good results with post-emergent herbicides. Herbicides should be applied when they will provide effective control and before weeds begin to reduce crop yield potential, ideally at the start of the critical period for weed control (Figure 3). Best control with herbicides is obtained when weeds are small, when there is adequate soil moisture and when temperatures are ideal.

However, the germination of weed seeds is mainly governed by temperature and soil moisture conditions, (it may also be influenced by seed dormancy). Consequently, there are normally a number of weed flushes throughout a season following rainfall and irrigation events. Cotton growers must take into account the likely number of germination events, the cost of weed control, the capacity to cover a number of fields with the application equipment available, and possible yield reductions due to weed pressure when making a weed control decision. Control of very small weeds prior to the weed removal time would be efficient in terms of herbicide, as lower rates are required to control smaller weeds, but may be very inefficient if subsequent germinations quickly replace the previous weed population, requiring repeated treatments.

Preventing weed seed set

The aim of weed management is to minimise economic loss in the current crop, but also to protect future crops by preventing weeds from setting seeds and adding to future weed problems. To achieve this, weed management strategies may need to continue beyond the critical period for weed control.

However, rather than focusing on controlling the weeds, emphasis needs to be placed on preventing those weeds from setting seed. This may be achieved using a lay-by herbicide, or with spray topping, where a sub-lethal dose of herbicides is applied to cause weeds to abort seed or to set non-viable seed. Defoliants or Roundup applied at or prior to defoliation may also help to reduce seed set. Further research is needed to confirm the value of these options.

APPLYING THE CRITICAL PERIOD FOR WEED CONTROL IN THE FIELD

Graham Charles and Ian Taylor
(NSW Dept of Primary Industries)

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Sunflowers in cotton at the start of November mimicking an infestation of large broad-leaf weeds.

Introduction

The critical period for weed control is a concept that relates the yield reduction caused by weed competition to an economic threshold. It establishes a period at the start of the season when weeds do not need to be controlled as they cause no economic loss, and a period at the end of the season when weeds again cause no economic loss. These periods define the middle, critical period for weed control, in which weeds must be controlled to reduce yield losses.

The relationships which define the critical period are affected by weed species, weed density and the economic threshold chosen.

The critical period for weed control

Experiments were conducted at the ACRI at Narrabri over the past 4 seasons to define the critical period for weed control for irrigated cotton in Australia. These experiments used sunflowers, mung beans and Japanese millet to mimic the competition from a large broad-leaf weed such as thornapple, a medium sized broad-leaf weed such as bladder ketmia and a grass weed such as barnyard grass.

Relationships for these weeds at two densities are shown in Figure 1. The curves show the competitive effects of weeds that emerge with the crop and are subsequently controlled (maroon line) and weeds that emerge after the crop and are not subsequently controlled (brown line).

At the densities shown, the large broad-leaf weeds had the greatest effect on the crop, suppressing yield by up to 100% when not controlled. The medium broad-leaf and grass weeds had less effect, with 79% yield reduction from season-long competition of 40 grass plants per metre of cotton row.

Japanese millet at 40/m row in cotton at the end of December mimicking a heavy infestation of a grass weed.

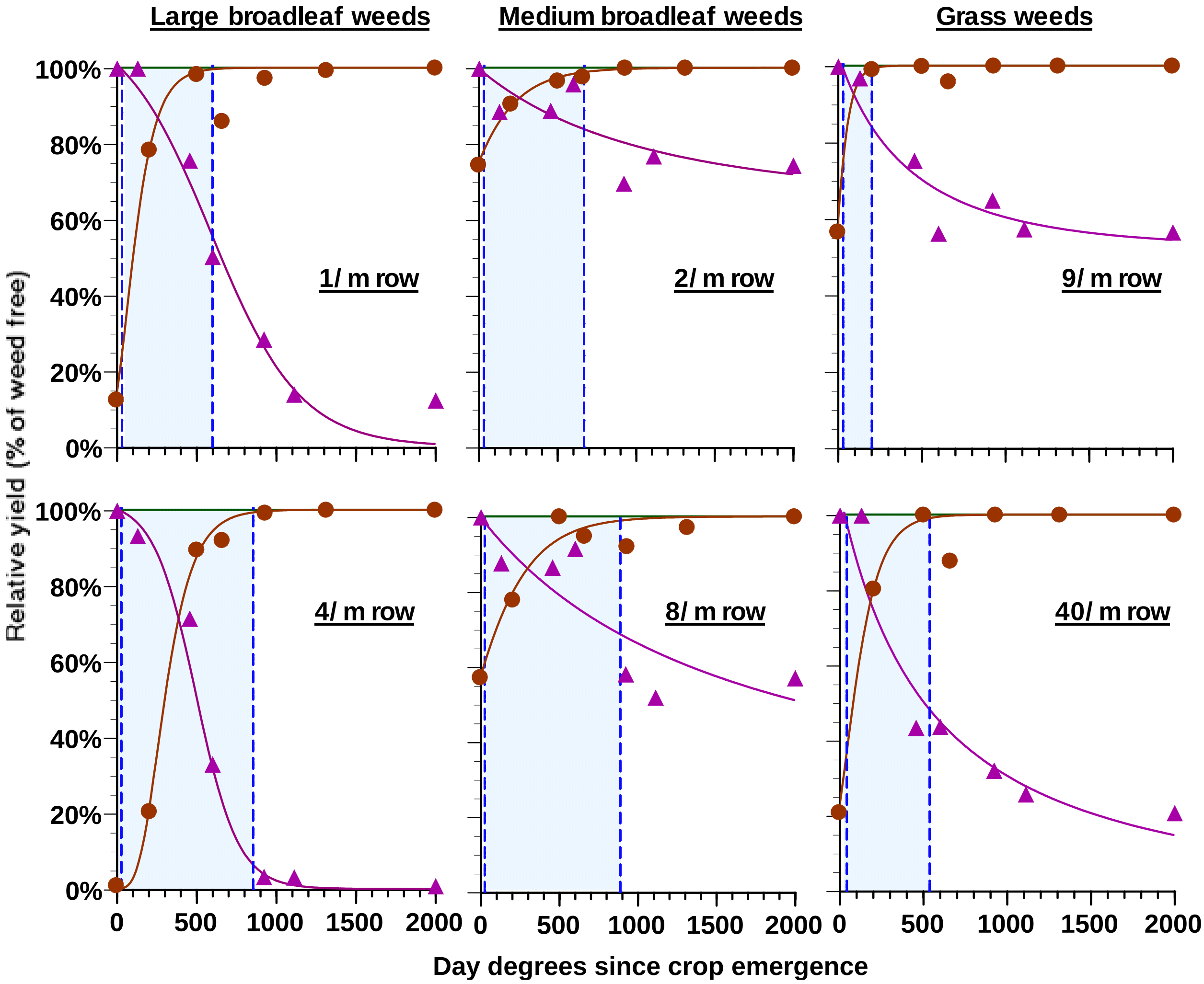

Figure 1. *Yield relationships for weeds competing in irrigated cotton. Data for large and medium broadleaf and grass weeds are shown. Weed densities are indicated on each figure. The critical period for weed control at a 1% yield threshold is the shaded blue area in each figure. This area is determined by where the curves in each figure cut the chosen economic threshold, which in this example is at 1% yield loss (99% yield).*

The critical periods for weed control defined by these weed competition relationships are dependant on the economic threshold chosen. As an example, results for a 1% yield threshold are indicated in Figure 1 by the shaded blue areas in each figure. These areas are defined by where the maroon and brown lines cut the economic threshold, and determine the start and end of the critical period in day degrees on the bottom axis.

Figure 1 shows that the critical period for weed control at a 1% economic threshold for one large broad-leaf weed/m row starts 30 day degrees after crop emergence and continues till 598 day degrees. In other words, at one large weed/m row, if weed control starts later than 30 day degrees after crop emergence, a yield loss of greater than 1% will occur. Conversely, large broadleaf weeds that emerge at up to 1/m row later than 598 day degrees after crop emergence cause less than a 1% reduction in crop yields. Consequently, controlling these weeds that emerge later than 598 day degrees after the crop can't be justified on the basis of the yield reduction they will cause. They may still need to be controlled, however, as they may interfere with harvesting and may produce a seed load that leads to increased weed problems in later seasons. A layby application of a residual herbicide may be the best option at this point in the season.

The length of the critical period for weed control increases with increasing weed density, climbing from 598 day degrees after crop emergence for 1 large broad-leaf weed/m row to 854 day degrees for 4 weeds/m. The start of the critical period declines slowly as weed density increases, decreasing from 30 day degrees at 1 large broad-leaf weed/m to 26 day degrees for 4/m.

Predicting the critical period for weed control

These data were put together to produce relationships to predict the start and end of the critical period of weed control for any density of these weeds. The relationships predict that for any density of weeds, the maximum critical period is 996 day degrees post crop emergence (Table 1). Weeds that emerged later than 996 day degrees after crop emergence didn't cause more than 1% yield loss, regardless of their type or density.

The start of the critical period for weed control was fairly insensitive to weed density, declining from 43 day degrees at the lightest density of grass weeds.

The length of the critical period was much shorter for the grasses compared to the broad-leaf weeds at the same densities. Season long competition from fewer than 3 grass weeds/m causing less than 1% yield loss. Consequently, control of fewer than 3 grass weeds/m row can't be justified on the basis of yield loss alone. However, failure to control grasses at this density early in the season will lead to problems later in the season with harvesting difficulties and lint contamination. Not controlling grass weeds will result in seeds being added to the seed bank. This seed may germinate following the next rainfall or irrigation event, resulting in greatly increased weed problems later in the season or in subsequent seasons.

Table 1. *The predicted start and the end of the critical period for weed control for a range of weed species and densities.*

Weed density (weeds/m row)	Critical period (day degrees)	
	Start	End
Large broad-leaf weeds		
0.1	31	130
0.2	31	230
0.5	30	427
1	30	598
2	29	747
4	26	854
Medium broad-leaf weeds		
0.1	31	92
0.2	31	169
0.5	30	336
1	30	503
2	29	668
4	26	800
Grass weeds		
2	-	-
3	42	61
4	42	80
8	42	148
16	40	258
32	37	410

Other weeds, such as the vines, may have little impact on yield at low densities but can cause major difficulties for harvesting. Low densities of some weed species may also be problematic as they may harbour pests or diseases, or have the ability to rapidly spread if not controlled. Controlling a low density of small weeds may make a lot more sense than trying to control a heavy density of large weeds later in the season.

Using the ‘critical period for weed control’ data set

The critical period for weed control data will be a valuable tool for managing weeds in cotton into the future. However, the current data is very preliminary and should be viewed with caution. Other research has shown that the results of this type of research can be site and season specific, meaning that different results might be obtained in other seasons and in other cotton areas.

Future research in this project will cover a number of additional points, including developing data sets for mixed populations of real weeds, testing the findings in other regions and developing more robust weed competition assessment tools. Weed densities are never uniform in the real world, and staggered weed germinations can make for difficult decisions. Developing a weed management guide based on measurements such as weed and crop leaf area may give much more robust guidelines than the current findings simply based on weed density.

Nevertheless, these preliminary findings can be used to guide weed management decisions, especially in Roundup Ready Flex® and Liberty Link® cotton crops where over-the-top broad-spectrum herbicides are available. The results firstly indicate that weed control should be commencing early in the season, soon after weed emergence, when light rates of herbicide give good control on small, susceptible weeds. Weeds should not be allowed to grow unchecked in the hope of being able to control multiple weed germinations with a single, high rate herbicide application later in the season.

Secondly, the duration of the weed control period is influenced by weed species and density, but may extend until well into the season in dirtier fields. Weed control may have to be maintained until mid- to late-January, depending on the region and the season. Conversely, weed control with an over-the-top herbicide in relatively clean fields may be largely cosmetic and not justified on the grounds of competition alone. Controlling these weeds with inter-row cultivation or a lay-by herbicide later in the season would be a better option. This is especially the case in fields that are not going back to cotton.

Avoiding herbicide resistance and species shift

One of the biggest concerns with adopting a system which relies largely on a single weed control tool is the development of species shift and herbicide resistance. This is a potential issue for systems such as a Roundup Ready Flex cotton system where few other inputs might be used.

An obvious strategy might seem to be to limit the number of Roundup Ready applications, using maximum rates to control big weeds. This is not advisable for two reasons. Firstly, the critical period for weed control work shows that this strategy will lead to large yield losses. Secondly, using a lesser number of applications of a heavy herbicide rate will not necessarily reduce selection pressure compared to multiple applications of lighter rates on small weeds. The issue is not how many applications are made per season, but whether successive generations are exposed to the same selection pressure.

There are three keys to successfully adopting a low input weed control system. These are:

- Ensuring the herbicide will control all weeds at the rate used,
- Ensuring successive generations of weeds are not exposed to the same herbicide, and
- Ensuring all weed escapes are controlled using a different management tool before they set seed.

High yielding cotton crops can be grown for many years into the future if these strategies are adopted.

USING THE CRITICAL PERIOD FOR WEED CONTROL IN ROUNDUP READY FLEX® COTTON

Graham Charles, Ian Taylor and Tracey Farrell

(NSW Dept of Primary Industries)

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A cotton crop with a heavy infestation of grass weeds in the plant line. This was part of the experiments used to establish the CPWC in cotton.

Introduction

The Critical Period for Weed Control (CPWC) is a concept that relates the yield reduction caused by weed competition to an economic threshold. It establishes a period at the start of the season when weeds do not need to be controlled as they cause no economic loss, and a period towards the end of the season when weeds again cause no economic loss. These periods define the middle, CPWC, in which weeds must be controlled to reduce yield losses.

Work by NSW DPI staff at the Australian Cotton Research Institute (ACRI) at Narrabri has for the first time defined the CPWC in irrigated Australian cotton. Articles describing the work were published in the August-September 2007 edition of the Australian CottonGrower.

Still, the question remains, how can a cotton grower best use this information in a cotton crop?

The main aim of this article is to explore how applying the critical period concept might have worked out in grower's fields over the last three seasons.

The critical period for weed control

In practice, the critical period is defined by the type of weed present, the density of weeds, the potential crop yield, the cost of weed control and the economic threshold the cotton grower chooses.

The CPWC is defined in Table 1 using 1% and 3% weed control thresholds for fully irrigated cotton (1% threshold) and lower yielding or rain-fed crops (3% threshold). These control thresholds were determined from the point where the yield loss caused by the weeds exceeds the cost of control with Roundup Ready Herbicide. As well as reducing lint yield, uncontrolled weeds set seed leading to increasing weed problems over time, impede water flow and pesticide penetration, harbor pests and diseases, and cause harvesting difficulties and lint contamination.

To show how these thresholds might be used in the field, we applied them to Narrabri data for each of the last three seasons.

The simulations and discussion focus on management of a Roundup Ready Flex cotton crop because the critical period approach is most readily adapted to this system. However, the concept can be equally applied to conventional and Liberty Link® cotton crops.

Table 1. *The predicted start and the end of the CPWC for a range of weed species and densities using 1% and 3% thresholds. The critical period is measured in day degrees from planting.*

Weed density (weeds/m row)	Critical period			
	Start		End	
	1%	3% threshold	1%	3% threshold
Large broad-leaf weeds				
0.1	111	-	210	-
0.2	111	178	310	222
0.5	110	177	507	365
1	110	175	678	508
2	109	170	827	653
5	105	158	959	798
Medium broad-leaf weeds				
0.1	111	-	172	-
0.2	111	-	249	-
0.5	110	-	416	-
1	110	175	583	227
2	109	170	748	331
5	105	158	913	517
10	101	142	987	661
Grass weeds				
2	-	-	-	-
3	123	-	141	-
5	122	137	178	148
10	121	136	259	206
20	120	132	383	299
50	115	124	600	477

Model inputs

We tested the CPWC on a relatively dirty field with a mixed weed population of 1 large broadleaf weed/m^2 (eg. thornapple or noogoora burr), 5 medium sized broadleaf weeds/m^2 (eg. bladder ketmia) and 10 grass weeds/m^2 (eg. barnyard grass). Simulations were made for both fully irrigated and rain-fed crops in each season.

Weed germinations were related to rainfall and irrigation events. The simulations assumed most of the weeds emerged between 50 and 100 day degrees after rain (or irrigation), and all weeds were susceptible to Roundup Ready Herbicide.

The irrigated crop was pre-watered and planted on 5th Oct. each season. No residual herbicides were applied prior to or at planting. Roundup was applied before crop emergence to ensure a clean start to the season. Applying a 1% yield loss threshold, the CPWC extended from cotyledon to mid-flowering growth stages (105 to 913 day degrees) for the simulated weed population, as shown by the red lines in the figures.

The "rain-fed" simulations used similar assumptions, with no pre- or at-planting residual herbicides. Planting occurred on the first opportunity following rain after the 5th Oct., and Roundup was again applied before crop emergence to ensure a clean start to the season. Applying a 3% yield loss threshold, the CPWC extended from the 2 node stage to early squaring (136 to 517 day degrees).

A cotton crop showing the effect on crop height and biomass of a heavy weed infestation following a Roundup Ready application (foreground). Weeds have been uncontrolled since planting in the plot behind this. These plots are part of an experiment to test the CPWC in Roundup Ready Flex cotton.

The CPWC in 2004-5

Reasonable rainfall fell in the first half of the 2004-5 season at Narrabri, with a daily maximum of 138 mm recorded in Dec. Multiple weed germination events were triggered by early season rainfall and irrigation later in the season (Figure 1).

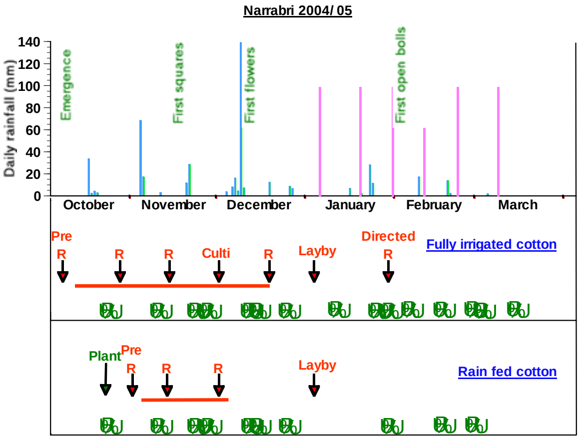

***Figure 1**. A simulation of how the CPWC might have been applied in the 2004-5 season at Narrabri (ACRI). Simulations are for both fully irrigated and rain fed crops. Symbols are: blue bars, daily rainfall (mm); pink bars, irrigations; red lines, the CPWC; red arrows, weed control inputs (R = Roundup Ready® Herbicide, Pre R = a pre-crop emergence Roundup, Culti = inter-row cultivation, Layby = a residual layby herbicide); and green arrow, planting. Periods of peak weed emergence are indicated by .*

With no pre-planting or at-planting residual herbicides used, post-emergence weed control was required following weed emergence on four occasions during the critical period, at 6 nodes, first squares, first flowers and mid-flowering (310, 511, 719 and 946 day degrees). Ideally, weeds need to be controlled within 105 day degrees of their germination, which will be only a few days after seedling emergence. Roundup Ready Herbicide could be used on three of these occasions, with inter-row cultivation and chipping used on one occasion. This combination of inputs conforms with the Roundup Ready Flex Crop Management Plan which requires that: (1) no more than three Roundup Ready Herbicide applications are made during this crop growth period; and (2) that weeds that survive a Roundup Ready Herbicide application are controlled by an alternate method before they set seed (the combination of inter-row cultivation and chipping conforms with this requirement). Only a very light chipping should have been required as few weeds would have survived two Roundup applications and a cultivation pass.

Weeds that emerged later in the season would still need to be controlled to prevent problems such as harvesting difficulties, lint contamination and the build up of the weed seedbank (leading to increasing weed problems over time). These weeds could be controlled with a lay-by application of residual herbicide before canopy closure and a directed application of Roundup Ready Herbicide during the 16 to 22 node stage if required. A pre-harvest application of Roundup Ready Herbicide could also be used to prevent late-season weeds setting seed if sufficient late-season weeds were present to justify this input.

This herbicide program would potentially have used the maximum number of early-season Roundup Ready Herbicide inputs allowed by the label, but probably not all these inputs would have been required in practice, with at least one inter-row cultivation pass replacing a Roundup application. It is also likely that lower than maximum label rates would have been used for the first two Roundup applications as these were applied to young weeds which are easily controlled with lower rates. Rates of 0.5 to 1 kg/ha would give excellent control of most susceptible weed seedlings. An early lay-by application of residual herbicide could have been applied in late-Dec. if an additional weed control input had been required during the critical period.

Rainfall in mid-Oct. allowed a rain-fed crop to be planted on 24th Oct. Post-emergence weed control was required on two occasions, at 5-6 nodes and first squares (282 and 490 day degrees). Weeds which emerged later in the season could have been controlled with a lay-by application of residual herbicide in early Jan. It is unlikely that further weed control inputs would have been required in this season.

The CPWC in 2005-6

Reasonable rainfall again fell in the 2005-6 season at Narrabri, and multiple weed germination events were triggered by rainfall and irrigation (Figure 2).

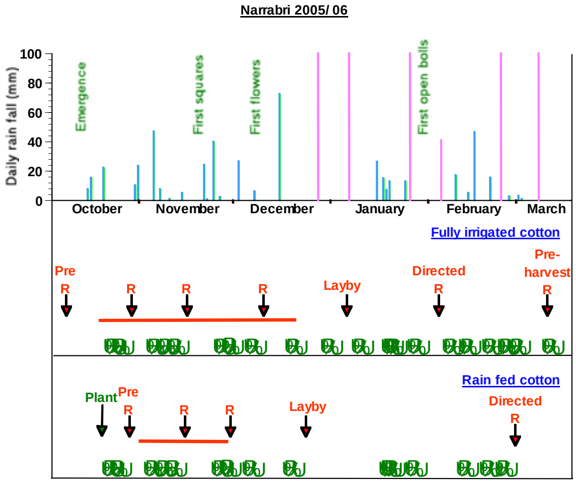

***Figure 2**. Using the CPWC in the 2005-6 season. Simulations for fully irrigated and rain-fed crops are shown. Weed control operations during the CPWC protect cotton yield. Weed control operations after the CPWC prevent weeds from adding seed to the soil seed bank, leading to problems in later seasons.*

Using a 1% yield loss threshold, post-emergence weed control was required at 5 nodes, first squares and first flowers (259, 460, and 803 day degrees). Roundup Ready Herbicide could have been used on all occasions, although an inter-row cultivation and light chipping may have been used on one occasion to remove any weeds that survived the Roundup application, as required by the Crop Management Plan. Weeds which emerged later in the season could have been controlled with a lay-by application of residual herbicide in early Jan. and a directed application of Roundup Ready Herbicide during the 16 to 22 node stage if required. A pre-harvest application of Roundup Ready Herbicide could also be used to prevent late-season weeds setting seed.

This herbicide program may have again used the maximum number of Roundup Ready Herbicide inputs allowed by the label. Lower than maximum label rates would have been required for the first two applications to young weeds, enabling the total in-crop use to remain within label requirements even if both the directed application and the pre-harvest application were required.

Rainfall in mid-Oct allowed a rain-fed crop to be planted on 20th Oct. With a 3% yield loss threshold, post-emergence weed control was required at 7-8 nodes and mid-squaring (245 and 586 day degrees). Later emerging weeds could have been controlled with a lay-by application of residual herbicide in early Jan. A pre-harvest application of Roundup Ready Herbicide may also have been required to prevent late-season weeds setting seed following good rain in Feb.

The CPWC in 2006-7

Very little rain fell in the 2006-7 season at Narrabri, with most weed germination events triggered by irrigation (Figure 3).

Using a 1% yield loss threshold, post-emergence weed control was only required at first squares (460 day degrees). Weeds which emerged later in the season could have been controlled with inter-row cultivation or a lay-by application of residual herbicide. No other weed control may have been necessary.

Rainfall in early Nov. may have allowed a rain-fed crop to be planted on 8th Nov. With a 3% yield loss threshold, no rainfall occurred during the CPWC and it is likely that few if any weeds emerged during this period. Weeds which emerged later in the season could have been controlled with a lay-by application of residual herbicide.

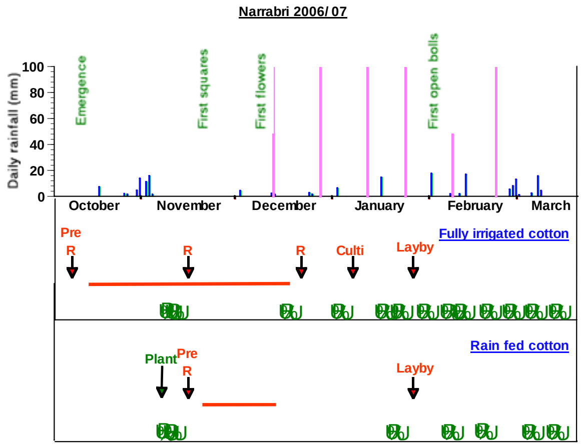

***Figure 3**. Applying the CPWC in the 2006-7 season. Simulations are for fully irrigated and rain-fed crops.*

Observations from these simulations

The CPWC approach can be successfully applied in both irrigated and rain-fed cotton. Applying Roundup Ready Herbicide inputs to small weeds soon after emergence will maximize herbicide efficacy and yields but will not necessarily result in the maximum number of applications being used too early in the season, especially where inter-row cultivation or other herbicides are used on some occasions instead of Roundup.

In seasons where the early season weed pressure is too high (requiring too many early Roundup applications), an early layby application of residual herbicide can be used to replace a Roundup application and reduce weed pressure. Prometyrn (Gesagard) or fluometuron (Cotoran), for example, can be applied as an early layby to cotton as small as 15 cm high and will control a wide range of emerged weeds provided they are applied to small weeds, as well as giving residual control, reducing weed pressure. An alternative residual, such as diuron, could then be applied later in the season as a standard layby application.

Resistance to Roundup

Some cotton growers are concerned that relying too heavily on Roundup is likely to lead to future problems with weeds that are resistant to Roundup (glyphosate). The potential for resistance is very real, as shown by the increasing resistance problems with Roundup Ready crops in the US.

However, resistance can be avoided by following two simple rules.

1. Always follow the Roundup Ready Flex Crop Management Plan. Central to this plan is the requirement that crops are checked after a Roundup application and any surviving weeds controlled using an alternative weed management tool before the weeds set seed.
2. Ensure at least one effective alternative weed management tool is used each season. An inter-row cultivation combined with a light chipping is a sound strategy for avoiding resistance. Alternatively, using a directed layby residual herbicide, incorporated with inter-row cultivation can be equally effective, although a light chipping may still be required to control larger weeds in the plant line.

Conclusions

- Using Roundup Ready Flex cotton without pre- or at-planting residual herbicides can be a sound weed management strategy in low weed pressure fields in most seasons.
- Applying the CPWC and controlling weeds within a few days of germination will minimize yield losses from weeds, while not leading to excessive herbicide use.
- Weeds that emerge after the CPWC still have to be controlled, but timing is not critical provided they are controlled before they set seed.
- Fields that have significant populations of troublesome weeds should always be treated with residual herbicides before or at planting.
- Alternative weed management tools such as inter-row cultivation and chipping can reduce the pressure on Roundup applications.
- Include a directed layby residual herbicide, incorporated with inter-row cultivation in the system.
- Consider an early layby herbicide application if seasonal conditions lead to excessive early season weed pressure.
- These strategies can be applied equally with an alternative technology, such as Liberty Link cotton, although an at-planting residual grass herbicide will be required on most fields with Liberty Link cotton.

Acknowledgements

We gratefully acknowledge the input of the “weeds team” who did the hard and often tedious field work involved in the experiments contributing to this article. This work was funded by NSW Dept Primary Industries, the Cotton Catchment Communities CRC and the Cotton R&D Corporation.

Summary

Application of the Critical Period for Weed Control (CPWC) concept was tested for irrigated and rain-fed Roundup Ready Flex® cotton crops using data from the last three seasons.

The CPWC was applied to a relatively dirty field situation, where large numbers of weeds emerged after each rainfall and irrigation event.

The CPWC required that weeds were controlled while still small, potentially using up the in-crop Roundup Ready® applications early in the season.

The seasons varied from relatively wet (first half of 2004-5) to extremely dry (2006-7).

All weed flushes were able to be controlled in each season using the CPWC approach, with an early application of a residual layby herbicide available as a backup additional weed management tool.

The results show that ensuring weeds are controlled soon after emergence is a practical approach to weed control which will minimise yield losses from weeds.

USING THE CRITICAL PERIOD FOR WEED CONTROL IN THE 2007/8 SEASON

Graham Charles and Ian Taylor
(NSW Dept of Primary Industries)

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Roundup Ready Herbicide® was a powerful tool for controlling weeds in Roundup Ready Flex® cotton in the very wet early-season conditions experienced in the Burdekin this year. The question of the optimum time to apply herbicides still remains.

The critical period for weed control

The critical period for weed control is a concept that relates the yield reduction caused by weed competition to an economic threshold. It establishes an initial period when the weeds are small and do not need to be controlled as they cause no economic loss, and a period at the end of the season when late emerging weeds again cause no economic loss as the cotton plants are relatively large and competitive. These periods define the middle, critical period for weed control, in which weeds must be controlled while still small to avoid significant yield losses. Weeds can be tolerated in the last stage, after the critical period, as they will not reduce crop yields, but may still need to be controlled to avoid harvesting difficulties and lint contamination and should not be allowed to set seed, as this will lead to increased weed problems in later seasons. These weeds can also harbour pests and diseases.

In practice, the critical period is defined by the type of weed present, the density of weeds, the potential crop yield, the cost of weed control and the economic threshold the cotton grower chooses.

The critical period for weed control is defined in Table 1 for large and medium sized broadleaf and grass weeds using 1% and 3% thresholds. These thresholds approximate likely control thresholds for applying glyphosate to fully irrigated cotton (1% threshold) and lower yielding or rain-fed crops (3% threshold). The thresholds approximate the point where the yield loss caused by the weeds equals the cost of control with glyphosate. The point of the threshold is determined by the cost of the control input and the value of the crop.

To show how these thresholds would be used in the field, we applied them to 3 weed densities in irrigated and dryland cotton crops, using climatic data from Narrabri for the 2007/8 season. We used dirty, average and clean fields, with mixed populations of large and medium broadleaf and grass weeds. Weed germinations were related to rainfall and irrigation events. The models assumed most weeds emerged 50 to 100 day degrees after rain (or irrigation), and all weeds were controlled with glyphosate.

It is essential that glyphosate is not the only herbicide used in fields with very heavy weed densities, or where glyphosate tolerant weeds are present. Residual herbicides, such as prometryn, fluometuron and diuron, or alternative contact herbicides, such as Staple® or Envoke®, should be used in fields were significant numbers of glyphosate tolerant weeds, such as burr medic, rhyncho and emu foot are present. The choice of herbicide(s) is determined by the weed species present.

Table 1. *The predicted start and end of the critical period for weed control for a range of weed types and densities, using 1% and 3% control thresholds. Examples of weeds in each category are: thornapples and noogoora burrs (large broad-leaf weeds); bladder ketmia and Chinese lantern (medium broad-leaf weeds); and barnyard grass (grass weed). The minimum weed densities needed to trigger the critical period are also shown.*

	Critical Period for Weed Control (day degrees since planting)											
	Large broad-leaf weeds				Medium broad-leaf weeds				Grass weeds			
Weed	1%		3%		1%		3%		1%		3%	
density	Yield loss threshold				Yield loss threshold				Yield loss threshold			
(no./m²)	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
0.1	111	210	-	-	111	172	-	-	-	-	-	-
0.2	111	310	178	222	111	249	-	-	-	-	-	-
0.5	110	507	177	365	110	416	-	-	-	-	-	-
1	110	678	175	508	110	583	175	227	-	-	-	-
2	109	827	170	653	109	748	170	331	-	-	-	-
3	108	895	166	725	108	831	166	409	123	141	-	-
5	105	959	158	798	105	913	158	517	122	178	137	148
10	101	1014	142	864	101	987	142	661	121	259	136	206
20	94	1044	119	901	94	1029	119	774	120	383	132	299
50	84	1063	89	926	84	1057	89	866	115	600	124	477
Min.density	0.03		0.14		0.04		0.62		2.1		4.2	

Very dirty fields are normally best managed by applying residual herbicides before or at planting, reducing the pressure on glyphosate later in the season. This is generally more satisfactory than applying these herbicides later in the season after problems have already occurred, when it is difficult to achieve good incorporation of the herbicides, especially in the plant line.

The discussion in this article focuses on the management of Roundup Ready Flex cotton crops because the critical period approach is readily adapted to the Roundup system and this is currently the most common cropping option used. The concept can be equally applied to conventional and Liberty Link cotton crops, but the thresholds will need to be modified to take into account the costs of alternative inputs with these crops.

The critical period in irrigated cotton

The crops were watered-up on 8th Oct. No residual herbicides were applied before or at planting.

The start of the critical period was relatively insensitive to weed density, provided there were enough weeds to trigger the critical period. This minimum number of weeds was very low for large broadleaf weeds, at 3/100 m row (1% threshold), but much higher for grass weeds at 2.1/m row.

Given that the threshold weed density was reached, the first Roundup application was required soon after crop emergence (105 - 110 day degrees after planting), as shown in Figure 1. The end of the critical period for weed control was strongly influenced by weed type and density, rising from 583 day degrees post-planting in the clean field, to 1029 day degrees in the dirty field.

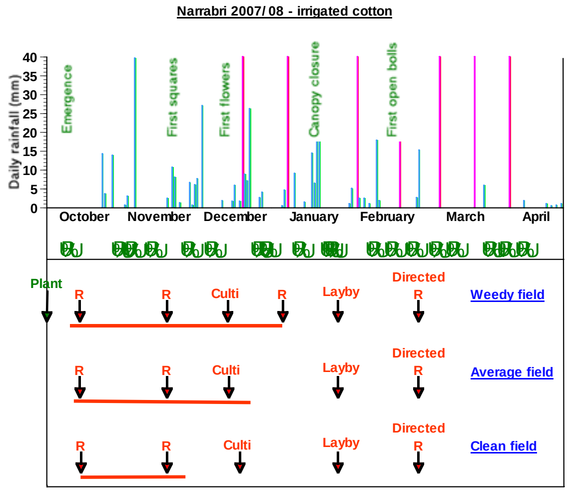

Figure 1*. How the critical period for weed control could have been used in the 2007-8 season at Narrabri for weedy, average and clean fields. Symbols are: (top section) rainfall (**vertical blue bars**) and irrigations (**vertical pink bars**); (middle section) periods of peak weed emergence, ; and (bottom section) the critical period for weed control, **horizontal lines**; and planting and weed control inputs, **arrows**. Symbols used on arrows are: planting, **Plant**; Roundup Ready Herbicide sprays, **R**; inter-row cultivation passes, **Culti**; and application and incorporation of a residual herbicide, **Layby**.*

Reasonable rain fell over late spring and summer, in a relatively long, cool season. This resulted in multiple weed germinations, with later germinations triggered by irrigations. A 2nd Roundup application was required on all fields in early-November to control a flush of weeds after rain in late-October. A fall of 40 mm on 6th November delayed this application till mid-November.

Lower than maximum label rates would have been suitable for Roundup applications to young weeds, as weeds are more easily controlled while they are small, provided they have sufficient leaf area to catch the spray. Rates of 0.8 to 1 kg/ha should be sufficient to control susceptible weed seedlings, reducing cost and maintaining late-season options (the product label precludes the use of maximum label rates for all applications if the maximum number of in-crop Roundup applications is used).

An alternative input, such as a cultivation and light chip, may have been required to remove surviving weeds after this application, as required by the Roundup Ready Flex Crop Management Plan. The need for this input is determined by the in-crop survey of weed survivors. Controlling surviving weeds with an alternative management input is essential to avoid species shift and herbicide resistance.

No further weed control in the critical period was required on the clean field, but all fields were inter-row cultivated in early- to mid-December prior to the first irrigation. This cultivation was undertaken to facilitate water movement and would also have controlled most weeds present. A residual herbicide could have been applied and incorporated at this time if required. No further treatment was required in the critical period on the average field, but an additional Roundup was required at the start of January on the weedy field.

A large number of weeds emerged following good rain in December and January, necessitating treatment by Roundup or the use of an incorporated residual herbicide in late January. Roundup could not have been used on the weedy field as only 3 post-emergence applications are permitted up to the 16 node stage of crop growth (this is a requirement of the product label). An additional directed Roundup application could have been made in late February, and a pre-harvest application could also have been used to prevent late-season weeds setting seed if sufficient weeds were present to justify these inputs.

Applying an incorporated, residual herbicide at canopy closure is a sound strategy for most fields. A residual "layby" herbicide should control any weeds that have survived the Roundup applications (reducing the risk of glyphosate resistance developing), and reduce the risk of weeds emerging later in the season when they will be difficult and expensive to control.

The critical period in dryland cotton

The crops were planted on 28th Oct, following rain on the 25th. No residual herbicides were applied before or at planting.

The start of the critical period was again relatively insensitive to weed density, provided there were enough weeds to trigger the critical period. This minimum number of weeds was low for large broadleaf weeds, at 1 in 10 m row (3% threshold), but much higher for grass weeds at 4.2/m row.

Given that the threshold weed density was reached, the first Roundup application was required soon after crop emergence (158 – 177 day degrees after planting) (Figure 2). The end of the critical period for weed control was strongly influenced by weed type and density, rising from 365 day degrees post-planting in the clean field, to 798 day degrees in the dirty field.

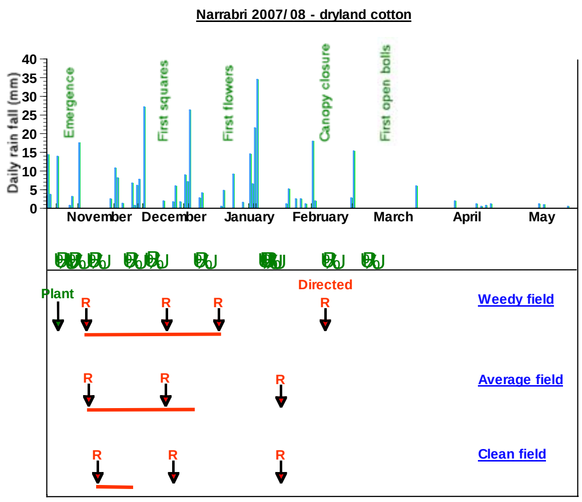

__Figure 2.__ Using the critical period for weed control in dryland cotton in the 2007-8 season at Narrabri for weedy, average and clean fields.

A 2nd Roundup application was required on the average and weedy fields in early-December to control a flush of weeds after rain in late-November. An application may have also been used on the clean field to manage weeds before they set seed.

Lower than maximum label rates would have been suitable for those Roundup applications applied to young weeds, as these weeds are more easily controlled. Rates of 0.8 to 1 kg/ha would give excellent control of susceptible weed seedlings, reducing cost and maintaining late-season options.

No further weed control in the critical period was required on the clean and average fields, but a Roundup may have been used in late-January, again to control weeds before they set seed. A Roundup was required at the start of January on the weedy field.

An alternative treatment, such as a cultivation and light chipping, may have been used to remove surviving weeds after the Roundup applications in mid-December, as required by the Roundup Ready Flex Crop Management Plan. The need for this input is determined by the in-crop survey of weed survivors.

Observations from the 2007/8 season

Using the critical period for weed control approach in this season didn't encounter any difficulties for either irrigated or dryland cotton production and would have closely mirrored the inputs made by good managers. Weeds could have been controlled using Roundup Ready Herbicide within the restrictions of the label.

The main difference for crop management with this approach is that weed control is focussed on the critical period, soon after crop emergence, with all inputs during this period occurring on very small weeds. This contrasts with a more common philosophy, that glyphosate applications to Roundup Ready Flex crops can be delayed to maximise the efficiency of each spray, minimising the number of sprays and ensuring that the maximum number of weeds are controlled with each input. Many cotton growers have concluded that since they are no longer constrained to the 4-node over-the-top glyphosate application window, glyphosate applications can be delayed to about 6 nodes, with a 2nd application at 10 to 12 nodes giving good weed control. While this approach appears to be valid, the science of the critical period has shown that the first glyphosate application may need to occur soon after crop emergence, with further applications following closely after successive weed germination events. This strategy of controlling very small weeds may require more Roundup applications, but can utilize lower herbicide rates and maintains the potential for higher crop yields.

The critical period for weed control approach was successfully applied in both irrigated and dryland cotton in the 2007/9 season. Applying Roundup Ready Herbicide to small weeds soon after emergence maximized herbicide efficacy and crop yields but didn't result in the maximum number of Roundup applications being used too early in the season.

In seasons where the early season weed pressure is excessive (possibly requiring more Roundup applications than are permitted by the product label), an alternative herbicide or early layby application of residual herbicide could be used to replace a Roundup application and reduce weed pressure. Prometyrn (Gesagard) or fluometuron (Cotoran), for example, can be applied as an early layby to cotton as small as 15 cm high and control a wide range of emerged weeds provided they are applied to small weeds, as well as giving residual control, reducing weed pressure. An alternative residual, such as diuron, could be applied later in the season as a standard layby application if necessary.

Resistance to Roundup

Some cotton growers are concerned that relying too heavily on Roundup is likely to lead to future problems with weeds that are resistant to Roundup (glyphosate). The potential for resistance is very real, as shown by the increasing resistance problems with Roundup Ready crops in the US.

However, resistance can be avoided by following two simple rules.

1. Always follow the Roundup Ready Flex Crop Management Plan. The core principle of this plan is to ensure crops are checked after a Roundup application and any surviving weeds are controlled using an alternative weed management tool before they set seed.
2. Ensure at least one effective alternative weed management tool is used each season. An inter-row cultivation combined with a light chipping is a sound strategy for avoiding resistance. Alternatively, using a directed layby residual herbicide, incorporated with inter-row cultivation can be equally effective, although a light chipping may still be required to control larger weeds in the plant line.

The Critical Period for Weed Control was tested using a range of weeds planted and removed at different stages of crop growth. The effects of weeds on crop growth, development and yield was measured.

Conclusions

- Using Roundup Ready Flex cotton without pre- or at-planting residual herbicides can be a sound weed management strategy in low weed pressure fields.
- Including alternative weed management tools in the system, such as inter-row cultivation, can reduce the pressure on Roundup applications.
- Including a directed layby residual herbicide, incorporated with inter-row cultivation, in the system can assist with the management of later emerging weeds and reduce the risk of species shift and herbicide resistance.
- If seasonal conditions lead to excessive early season weed pressure, an early layby herbicide application may be a valuable investment for reducing the pressure on glyphosate.
- Fields with significant populations of glyphosate tolerant or hard-to-control weeds should always be treated with residual herbicides before or at planting.
- These strategies can be applied equally with an alternative technology, such as Liberty Link cotton, although an at-planting residual grass herbicide will be required on most fields with Liberty Link cotton.

Summary

Data from last season was used to test the critical period for weed control approach for irrigated and dryland Roundup Ready Flex® cotton crops.

The critical period for weed control was applied to dirty, average and clean fields, where weeds emerged after each rainfall and irrigation event.

Applying the critical period approach required that the start of weed control began soon after crop emergence, while weeds were still small. A lighter herbicide rate might be appropriate for small weeds. The duration of the critical period depended on the density of weeds that emerged after the first treatment.

All weed flushes in the 2007/8 season were controlled using Roundup during the critical period, with an inter-row cultivation or an early application of a residual layby herbicide available as an additional weed management tool if required.

The results show that ensuring weeds are controlled soon after emergence is a practical approach to weed control which will help optimize crop yields. The approach can be equally applied to irrigated and dryland crops using Roundup Ready Flex, Liberty Link® or conventional cotton varieties.

MANAGING WEEDS USING THE CRITICAL PERIOD FOR WEED CONTROL

Graham Charles and Ian Taylor
(NSW Dept of Primary Industries)

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Weeds can compete strongly with cotton, reducing yields. Weeds can also harbour pests and diseases, interfere with water flow and picking and contaminate lint. This heavy infestation of Australian bindweed is far more serious than it may appear.

The critical period for weed control

The critical period for weed control is a concept that relates the yield losses caused by weed competition to an economic threshold. It establishes an initial period when weeds are small and do not need to be controlled as they cause no economic loss, and a period later in the season when the cotton plants are relatively large and small weeds again cause no economic loss. These periods define the middle, critical period for weed control, in which weeds must be controlled while still small to avoid significant yield losses. Weeds which emerge after the critical period may still need to be controlled to avoid harvesting difficulties and lint contamination and should not be allowed to set seed, as this will lead to increased weed problems in later seasons. These weeds can also harbour pests and diseases. However, the timing of this control is flexible, provided seed set is prevented, and can be delayed to minimise the number of spray applications required over the season.

In practice, the critical period is defined by the type and density of weeds, potential crop yield, the cost of weed control and the economic threshold the cotton grower chooses. The critical period is defined in Table 1 for large and medium sized broadleaf and grass weeds in high yielding, fully irrigated cotton, and lower yielding or rain-fed crops. Earlier articles defined a critical period based on lower thresholds. The increased thresholds reflect the jump in the glyphosate prices late last year.

To show how the critical period would have worked last season, we applied it to irrigated and dryland cotton crops, using climatic data from Narrabri. We used weedy, average and clean fields, with mixed populations of large and medium broadleaf and grass weeds.

The discussion focuses on the management of Roundup Ready Flex cotton crops because the critical period is readily adapted to the Roundup system and this is the most common cropping option used. The concept can be equally applied to conventional and Liberty Link crops.

__Table 1__. The predicted start and end of the critical period for weed control for a range of weed types and densities. Examples of weeds in each category are: thornapples and noogoora burrs (large broad-leaf weeds); bladder ketmia and Chinese lantern (medium broad-leaf weeds); and barnyard grass (grass weed). The minimum weed densities needed to trigger the critical period are also shown.

Weed density (no./m^2)	Start and end of the critical period for weed control (day degrees since planting)											
	Irrigated (high yielding) cotton						Dryland (low yielding) cotton					
	Broad-leaf weeds						Broad-leaf weeds					
	Large		Medium		Grasses		Large		Medium		Grasses	
	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
0.1	145	189	145	172	-	-	-	-	-	-	-	-
0.2	144	275	144	244	-	-	254	229	-	-	-	-
0.5	143	447	143	387	-	-	251	368	-	-	-	-
1	141	600	141	514	-	-	246	498	246	319	-	-
2	139	738	139	627	-	-	238	620	238	421	-	-
5	131	862	131	729	129	174	215	735	215	537	-	-
10	121	915	121	771	127	248	184	785	184	595	152	206
20	106	944	106	795	125	357	142	812	142	631	147	290
50	87	962	87	810	119	531	93	830	93	654	134	431
Min. density	0.06		0.07		2.5		0.24		0.59		5.4	

The critical period in irrigated cotton

The crops were watered-up on 8th Oct. No residual herbicides were applied before or at planting.

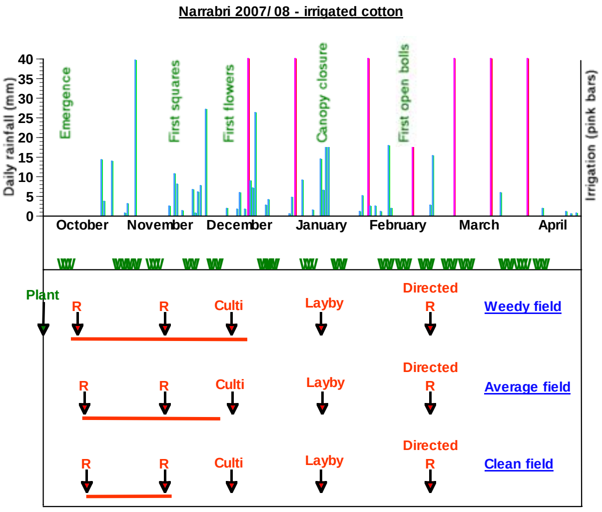


__Figure 1__. How the critical period for weed control could have been used in the 2007-8 season at Narrabri for weedy, average and clean fields. Symbols are: (top section) rainfall (__vertical blue bars__) and irrigations (__vertical pink bars__); (middle section) periods of peak weed emergence, __W__; and (bottom section) the critical period for weed control, __horizontal lines__; and planting and weed control inputs, __arrows__. Symbols used on arrows are: planting, __Plant__; Roundup Ready Herbicide sprays, __R__; inter-row cultivation passes, __Culti__; and application and incorporation of a residual herbicide, __Layby__.

The start of the critical period was relatively insensitive to weed density, provided there were enough weeds to trigger the critical period. Given that the threshold weed density was reached, the first Roundup application was required soon after crop emergence (106 – 141 day degrees after planting, Figure 1). The end of the critical period was strongly influenced by weed type and density, rising from 514 day degrees post-planting in the clean field, to 862 day degrees in the weedy field.

Lower than maximum label rates would have been suitable for Roundup applications to young weeds, as weeds are more easily controlled while they are small, provided they have sufficient leaf area to catch the spray. Rates of 0.8 to 1 kg/ha should be sufficient to control susceptible weed seedlings, reducing cost and maintaining late-season options (the product label precludes the use of maximum label rates for all applications if the maximum number of in-crop Roundup applications is used).

An alternative input, such as a cultivation and light chip, may have been required to remove surviving weeds after this application, as required by the Roundup Ready Flex Crop Management Plan. The need for this input is determined by the in-crop survey of weed survivors. Controlling surviving weeds is essential to avoid species shift and herbicide resistance.

Reasonable rain fell over late spring and summer, in a relatively long, cool season. This resulted in multiple weed germinations, with later germinations triggered by irrigations. A 2nd Roundup application was required on all fields in early-November to control a flush of weeds after rain in late-October. A fall of 40 mm delayed this application till mid-November.

No further weed control in the critical period was required on the clean or average fields, but all fields were inter-row cultivated in early- to mid-December prior to the first irrigation. This cultivation was undertaken to facilitate water movement and would also have controlled most weeds present. A supplementary Roundup application and/or chipping may have been required in the weedy field.

A large number of weeds emerged following further rain in December and January, necessitating treatment by Roundup or the use of an incorporated residual herbicide in mid-January. An additional directed Roundup application could have been made in late-February, and a pre-harvest application could also have been used to prevent late-season weeds setting seed if sufficient weeds were present to justify these inputs.

The critical period in dryland cotton

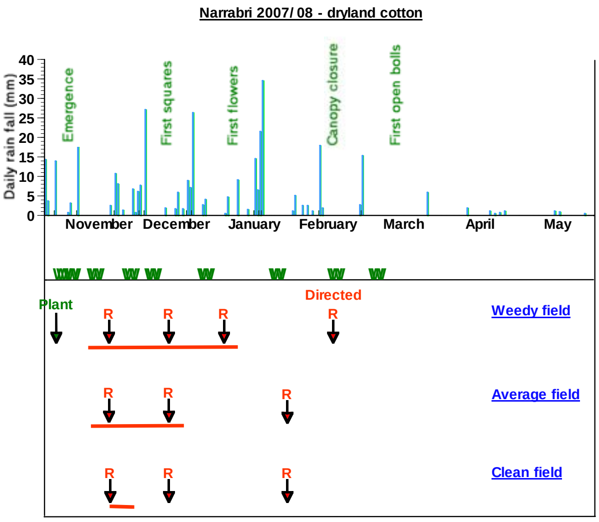


Figure 2. *Using the critical period for weed control in dryland cotton in the 2007-8 season at Narrabri. Symbols are explained in the caption to Figure 1.*

The crops were planted on 28th Oct, following rain on the 25th. No residual herbicides were applied before or at planting.

The start of the critical period was again relatively insensitive to weed density, provided there were enough weeds to trigger the critical period. Given that the threshold weed density was reached, the first Roundup application was required soon after crop emergence (241 day degrees after planting, Figure 2). The end of the critical period was strongly influenced by weed type and density, rising from 368 day degrees post-planting in the clean field, to 735 day degrees in the weedy field.

A 2nd Roundup application was required on the average and weedy fields in early-December to control a flush of weeds after rain in late-November. An application may have also been used on the clean field to control weeds before they set seed.

No further weed control in the critical period was required on the clean and average fields, but a Roundup may have been used in late-January, again to control weeds before they set seed. A Roundup was required at the start of January on the weedy field.

An alternative treatment, such as a cultivation and light chipping, may have been used to remove surviving weeds after the Roundup applications in mid-December, as required by the Roundup Ready Flex Crop Management Plan. The need for this input is determined by the in-crop survey of weed survivors.

An experiment using a naturally occurring weed population to test the application of the critical period for weed control in cotton at ACRI last season.

Observations from the 2007/8 season

Using the critical period for weed control approach in this season didn't encounter any difficulties for either irrigated or dryland cotton production.

The main difference for crop management with this approach is that weed control is focussed on the critical period, soon after crop emergence, with all inputs during this period necessarily occurring on small weeds. This contrasts with a more common philosophy, that glyphosate applications to Roundup Ready Flex crops can be delayed to maximise the efficiency of each spray, minimising the number of sprays and ensuring that the maximum number of weeds are controlled with each input. Many cotton growers have concluded that since they are no longer constrained to the 4-node over-the-top glyphosate application window, glyphosate applications can be delayed to about 6 nodes, with a 2nd application at 10 to 12 nodes giving good weed control. While this approach is valid, the science of the critical period has shown that to avoid yield losses, the first glyphosate application may need to occur soon after crop emergence, with further applications following closely after successive weed germination events. This strategy of controlling very small weeds may require more Roundup applications, but can utilize lower herbicide rates and maintains the potential for higher crop yields.

In seasons where the early season weed pressure is excessive (possibly requiring more Roundup applications than are permitted by the product label), an alternative herbicide or early layby application of residual herbicide could be used to replace a Roundup application and reduce weed pressure. Prometyrn (Gesagard) or fluometuron (Cotoran), for example, can be applied as an early layby to cotton as small as 15 cm high and control a wide range of small emerged weeds, as well as giving residual control, reducing weed pressure. An alternative residual, such as diuron, could be applied later in the season as a standard layby application if necessary.

Summary

Data from last season was used to test the practicality of applying the critical period for weed control for irrigated (higher yielding) and dryland (lower yielding) cotton crops. The critical period was applied to weedy, average and clean Roundup Ready Flex® fields.

Applying the spraying threshold required that weed control began soon after crop emergence, while weeds were still small. A lighter herbicide rate would be appropriate for these weeds. The threshold was reached later in the dryland crop. The duration of the critical period depended on the density of weeds present.

All weed flushes were controlled using Roundup during the critical period within the constraints of the Roundup Ready Herbicide label, with an inter-row cultivation or early layby available as an additional management tool.

The results show that ensuring weeds are controlled soon after emergence is a practical approach to weed control which will help maximize crop yields. The approach can be equally applied to irrigated and dryland crops using Roundup Ready Flex, Liberty Link® or conventional cotton varieties.

SAMPLING METHODS FOR THE CRITICAL PERIOD FOR WEED CONTROL

Graham Charles
(NSW Dept of Primary Industries)

Contents

What is the critical period for weed control

The critical period for weed control is a concept that relates the yield losses caused by weed competition to an economic threshold. It establishes an initial period when weeds are small and do not need to be controlled as they cause no economic loss, and a period later in the season when the cotton plants are relatively large and small weeds again cause no economic loss. These periods define the middle, critical period for weed control, in which weeds must be controlled while still small to avoid significant yield losses. Weeds which emerge after the critical period may still need to be controlled to avoid harvesting difficulties and lint contamination and should not be allowed to set seed, as this will lead to increased weed problems in later seasons. These weeds can also harbour pests and diseases. However, the timing of this control is flexible, provided seed set is prevented, and can be delayed to minimise the number of spray applications required over the season.

In practice, the critical period is defined by the type and density of weeds, potential crop yield, the cost of weed control and the economic threshold the cotton grower chooses. The critical period is defined in Table 1 for large and medium sized broadleaf and grass weeds in high yielding irrigated cotton, and lower yielding or rain-fed crops. Earlier articles defined a critical period based on lower thresholds. The increased thresholds reflect the jump in glyphosate prices late last year.

The discussion focuses on the management of Roundup Ready Flex cotton crops because the critical period is readily adapted to the Roundup system and this is the most common cropping option used. The concept can be equally applied to conventional and Liberty Link crops.

Applying the critical period

Determining the critical period for weed control in a field requires a knowledge of the degree days since crop planting and the type and density of weeds present in the field. Degree days are calculated from the daily maximum and minimum temperatures since planting.

The type and density of weeds is determined from an in-field assessment. This assessment may take 30 - 40 minutes for each field, but is only required in the early part of the season and only after rainfall or irrigation events trigger new flushes of weeds.

The ability to identify weeds to species level is not necessary for the weed assessment, as weeds are grouped into 3 categories. Commonly occurring weeds in each category are:

- Large broadleaf weeds:
  - the noogoora burr group (Noogoora burr, Californian burr and Italian cocklebur),
  - thornapples (fierce thornapple, downy thornapple and common thornapple),
  - sesbania and budda pea

Seedling photos of these weeds can be found in WEEDpak on the COTTONpaks cd or at http://www.cottoncrc.org.au

Table 1*. The start and end of the critical period for weed control for a range of weed types and densities. The minimum weed densities needed to trigger the critical period are also shown.*

The Critical Period for Weed Control in cotton (day degrees since planting)												
	High yielding cotton crops						Low yielding cotton crops					
Weed	Broad-leaf weeds				Grasses		Broad-leaf weeds				Grasses	
density	Large		Medium				Large		Medium			
(no./m^2)	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
0.1	145	189	145	172	-	-	-	-	-	-	-	-
0.2	144	275	144	244	-	-	254	229	-	-	-	-
0.5	143	447	143	387	-	-	251	368	-	-	-	-
1	141	600	141	514	-	-	246	498	246	319	-	-
2	139	738	139	627	-	-	238	620	238	421	-	-
5	131	862	131	729	129	174	215	735	215	537	-	-
10	121	915	121	771	127	248	184	785	184	595	152	206
20	106	944	106	795	125	357	142	812	142	631	147	290
50	87	962	87	810	119	531	93	830	93	654	134	431
Min. density	0.06		0.07		2.5		0.24		0.59		5.4	

- Medium broadleaf weeds:

  - All other weeds can be included in this group. If in doubt, put them here.

- Grasses:

  - includes the grasses and other grass-like species, such as the nutgrasses

The field sampling technique

The sampling technique to estimate the density of each weed type is similar to the technique used in the weed survey required by the Roundup Ready and Liberty Link Crop Management Plans.

Firstly, weed patchiness is assessed by a "drive-by" survey around the perimeter of the field, noting the location of the more weedy areas in the field. The density of each weed type is then assessed in 3 to 5 different areas of the field, with more sampling required on larger fields. The location of these assessments is determined from the drive-by survey, ensuring that the more weedy areas of the field are included in the assessments. Ensure that both head ditch and tail ditch ends of the field are checked, and that the observations are not concentrated on the edge of the field. On deep fields with runs of 1000 m or more, it may be necessary to go further into the field than the 250 m suggested below.

Once the areas for assessment are located, the assessment is undertaken by walking approximately 250 m into the field in each area and estimating weed density and type. The 500m walk (250 m each way) is broken into 50m strips, moving across 10 rows after each 50 m strip and estimating the density of each weed type in each 50 m strip (each strip is 1 m wide, from cotton row to cotton row). Ensure that the survey covers both beds and furrows in 2 m beds or other configurations).

The weed assessment method is simple. In each strip, the density of large and medium broadleaf weeds and grasses is assessed. This is done by estimating the density of each weed type as <5/50 m row, 5-50/50 m row, 50-500/50 m, or > 500/50 m. At first it may be necessary to count a few weeds to get an idea of what these densities look like, but the densities can be easily estimated by eye with experience. Density can be easily calculated in cotton on a 1 m planting configuration by visualizing a 1 m square area and counting the number of weeds in this area. One weed per square m equates to 50 weeds per 50 m^2. The exact length of each transect (50 m) is not critical, but is a guide to the amount of area which should be covered. It is essential that the survey goes towards the middle of the field, as the edge area may not be representative of the whole field.

A table for the weed assessments is given at the end of this document. To use this table:

1. For each 50 m strip, write a score of 1, 2, 3 or 4 corresponding to the estimated density of each weed type.
2. Add the scores in each column and add the columns to give a total for the assessment, as in the example below.

Large broadleaf weeds	Number per 50 m of row <5	5 - 50	50 - 500	>500	
	1	2	3	4	
0-50 m		2			
50-100 m		2			
100-150 m		2			
150-200 m	1				
200-250 m		2			
250-200 m	1				
200-150 m	1				
150-100 m	1				
100-50 m	1				
50 - 0 m			3		Total
Sum	_5_	_8_	_3_	___	16

3. The scores from this assessment, along with the scores from the other assessments done in the paddock are transferred to the Score Summary, as in the example below.

Score Summary	1	2	3	4	5
Large broadleaf	16	12	23	19	30
Medium broadleaf					
Grasses					

4. These numbers are converted to weed density using the table of Scores and Weed densities on the right hand side of the page, recorded in the Assessment Summary, and the average entered, as shown below.

Assessment summary	1	2	3	4	5	Average
Large broadleaf	0.2	0.079	1	0.4	5	_1.3_
Medium broadleaf						___
Grasses						___

5. This average is the field density of broadleaf weeds used to determine the critical period for weed control for this field. In this case, a density of 1.3 translates to a critical period from 139 to 738 day degrees duration, using the closest higher number from the Critical Period table (Table 1).

   If the density of large broadleaf weeds (1.3/m^2) occurred within the Critical period, then a spray should be applied as soon as practical.

   Outside the Critical Period, this weed density could be tolerated, provided the weeds are controlled before they set seed. However, if another flush of weeds emerges soon after, the field may need to be reassessed, as the increased weed density may fall within the new Critical Period that is derived by the new, larger, weed population.

Summary

- Use a drive-by survey to identify patches of heavier weeds in the field
- Assess weeds in 3 - 5 of the more weedy areas (depending on field size)
- Estimate the weed type and density on a 250 m strip into the field at each assessment point
- Use these assessments to determine the Critical Period for Weed Control for this crop.
- Organise to control weeds as soon as practical if the weed flush is within the Critical Period
- If not, monitor the weeds and control them before they set seed.

Applying the critical period requires that weed control begins soon after emergence in high yielding crops, while weeds are still small. A lighter herbicide rate would be appropriate for these weeds. The threshold will be reached later in lower yielding crops. The duration of the critical period depends on the density of weeds present.

All weed flushes can be controlled with Roundup during the critical period within the constraints of the Roundup Ready Herbicide label, with an inter-row cultivation or early layby available as an additional management tool if required.

Ensuring weeds are controlled soon after emergence is a practical approach to weed control which will help maximize crop yields. The approach can be equally applied to irrigated and dryland crops using Roundup Ready Flex, Liberty Link® or conventional cotton varieties.

The Critical Period Weed Sampling Sheet

Date: Recorder:

Property: Field: Assessment:

Number per 50 m of row

Large broadleaf weeds	<5 1	5 - 50 2	50 - 500 3	>500 4	
0-50 m					
50-100 m					
100-150 m					
150-200 m					
200-250 m					
250-200 m					
200-150 m					
150-100 m					
100-50 m					
50 - 0 m					Total
Sum	___	___	___	___	

Large broadleaf – Noogoora burrs, thornapples, sesbania & budda pea

Medium broadleaf – all other broadleaf weeds

Grasses – grasses and all grass like weeds

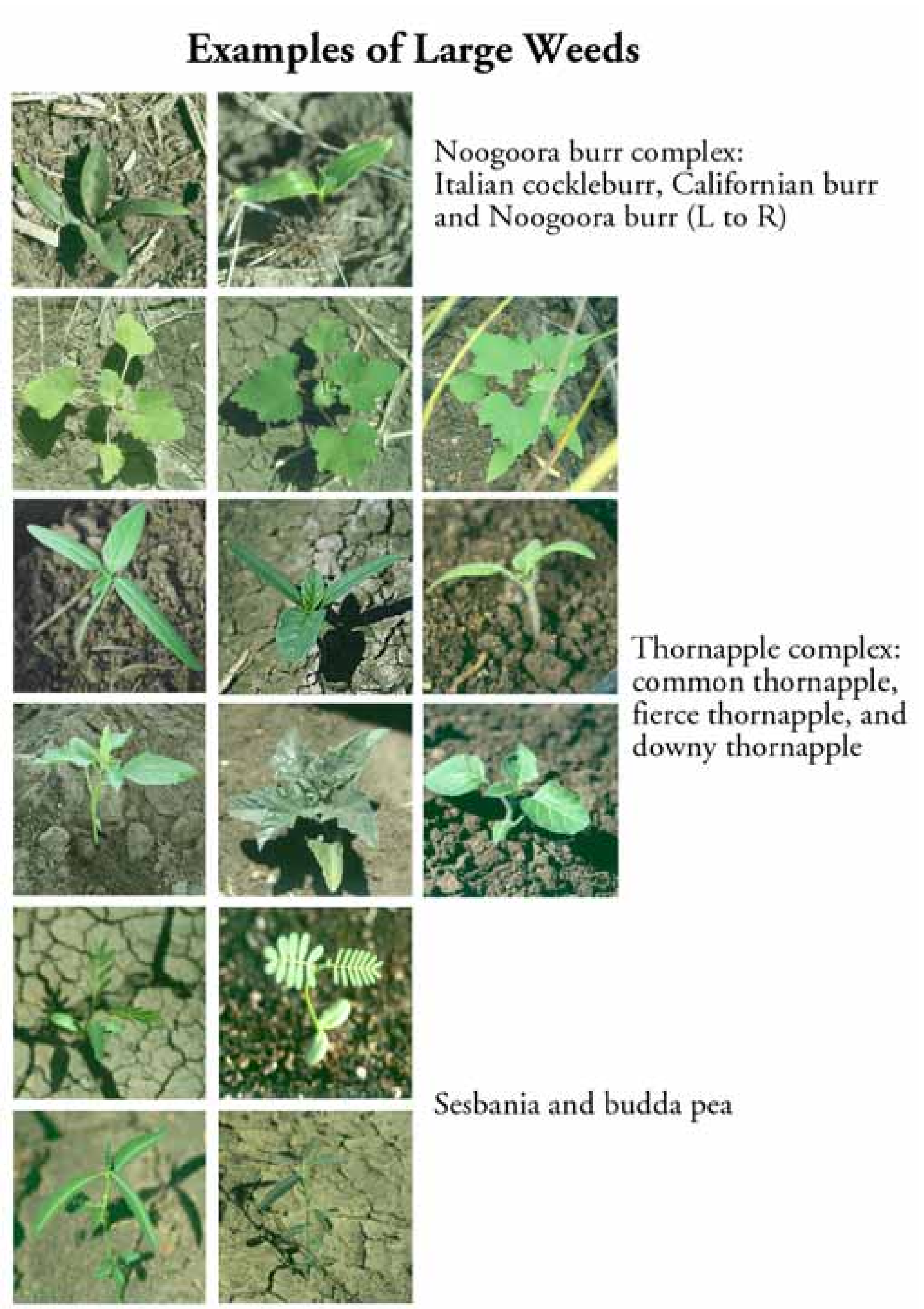
Medium broadleaf weeds	<5 1	5 - 50 2	50 - 500 3	>500 4	
0-50 m					
50-100 m					
100-150 m					
150-200 m					
200-250 m					
250-200 m					
200-150 m					
150-100 m					
100-50 m					
50 - 0 m					Total
Sum	___	___	___	___	

Grasses	<5 1	5 - 50 2	50 - 500 3	>500 4	
0-50 m					
50-100 m					
100-150 m					
150-200 m					
200-250 m					
250-200 m					
200-150 m					
150-100 m					
100-50 m					
50 - 0 m					Total
Sum	___	___	___	___	

Assessment score	1	2	3	4	5
Large broadleaf					
Medium broadleaf					
Grasses					

Assessment summary	1	2	3	4	5	Average
Large broadleaf						___
Medium broadleaf						___
Grasses						___

Assessment score	Weed density
1	0.006
2	0.008
3	0.010
4	0.013
5	0.016
6	0.020
7	0.025
8	0.032
9	0.040
10	0.05
11	0.063
12	0.079
13	0.10
14	0.13
15	0.16
16	0.20
17	0.25
18	0.32
19	0.40
20	0.5
21	0.63
22	0.79
23	1.00
24	1.26
25	1.58
26	1.99
27	2.51
28	3.15
29	3.97
30	5
31	6.29
32	7.92
33	10
34	12.6
35	15.8
36	19.9
37	25.1
38	31.5
39	39.7
40	50



The Critical Period for Weed Control in cotton (day degrees since planting)

Weed density (no./m²)	High yielding cotton crops						Low yielding cotton crops					
	Broad-leaf weeds				Grasses		Broad-leaf weeds				Grasses	
	Large		Medium				Large		Medium			
	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
0.1	145	189	145	172	-	-	-	-	-	-	-	-
0.2	144	275	144	244	-	-	254	229	-	-	-	-
0.5	143	447	143	387	-	-	251	368	-	-	-	-
1	141	600	141	514	-	-	246	498	246	319	-	-
2	139	738	139	627	-	-	238	620	238	421	-	-
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50	87	962	87	810	119	531	93	830	93	654	134	431
Min. density	0.06		0.07		2.5		0.24		0.59		5.4	

HERBICIDE RESISTANCE

Introduction

Pesticides have been used widely in agriculture for many decades to manage weeds, insects and diseases. Over this time there has been an ever-increasing range of products available to deal with pests. Products range from those with very specific target sites and minimal environmental impact, to products that are broad-spectrum, and may remain active in the environment for weeks or months.

While there has been an ever increasing range and number of products available to manage weeds, there is also now an increasing number of weeds that are resistant to some of these products. These weeds were initially controlled by the herbicides, but as a result of repeated exposure, resistant individuals have been selected from the population and have come to dominate the population.

Herbicide resistant and particularly glyphosate resistant weeds are mow a major issue for the Australian cotton industry. These resistant weeds will rapidly come to dominate fields unless there is a change in the weed management strategies.

Cotton growers need to return to using an integrated approach to weed management, ensuring that herbicides, and especially herbicides with the same mode of action, are never used as the only method of weed control. Steps to developing a sustainable system are covered in the following articles.

C2. Managing Herbicide Resistance in Cotton

When applied correctly, a herbicide effectively controls its target weed. Repeated use of a herbicide has two effects. Firstly, the herbicide selects for the more tolerant weed species, resulting in a species shift in favour of those tolerant species. Secondly, the herbicide selects out the more herbicide resistant individuals from within a species and the frequency of these individuals increases within the population, leading to the development of herbicide resistance.

The development of species shift and herbicide resistance can be managed using an integrated weed management strategy that combines the use of all the weed management tools, including herbicides from different herbicide groups, cultivation, chipping and good crop agronomy.

Basic information is given on herbicide resistance, herbicide groups, herbicide modes of action, weed monitoring and the necessary response to a suspected case of herbicide resistance.

C3. Herbicide Resistance and the Crop Management Plan

The conservation farming system is failing due to overreliance on glyphosate in the system, resulting in the wide spread emergence of glyphosate resistant weeds in summer fallows. The potential for this resistance to spiral into disaster is very real, as shown by the increasing resistance problems with herbicide resistance in the US.

This paper discusses these issues and explains the value of the approach used in the Crop Management Plans of Roundup Ready, Roundup Ready Flex and Liberty Link cotton for managing the development of resistance.

MANAGING HERBICIDE RESISTANCE IN COTTON

Graham Charles
(NSW Dept of Primary Industries)

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Herbicide resistance

Herbicide resistance occurs when a plant is able to tolerate a rate of a herbicide that kills other plants of the same species under the same conditions (both spray conditions and plant growing conditions).

Herbicide resistant individuals can occur at very low frequency in any natural plant population. Although these individuals may be present before a herbicide is first used in a field, their frequency is likely to remain low until a selection pressure is applied. This happens when a herbicide is applied. Individuals that are more tolerant of the herbicide survive the herbicide application and grow to set seed. This seed produces more individuals that tolerate the herbicide and set more seed, and so on. Eventually, the herbicide tolerant individuals represent a noticeable proportion of the weed population, and herbicide resistance is observed.

Genetic variability

Genetic variability is a characteristic of all populations. Even in a population where all individuals appear to be identical, there will be some genetic variability. Many of these genetic differences are of no obvious importance. Leaf shape and leaf colour in sow thistle, for example, are quite variable, especially in seedlings, but the differences do not appear to confer any difference in fitness or competitive ability.

Genetic differences that confer differences in the plant's tolerance to herbicides can exist in any plant population. Sometimes these differences are large enough that some individual plants may be able to tolerate quite high levels of herbicide without any apparent effect. These individuals are said to be herbicide resistant.

The level of herbicide resistance depends on the nature of the resistance and the genetic differences between resistance and susceptible individuals. Herbicide resistance could be as simple as the production of a waxy leaf surface that prevents the herbicide entering the leaf. Alternatively, resistance could be inferred by an individual over-producing a plant enzyme that was blocked by the herbicide, or producing a completely new enzyme that substitutes for the enzyme blocked by the herbicide, or by any number of other pathways.

The expression of herbicide resistance also depends on the genetics involved. Where herbicide resistance is caused by a single plant gene, this gene could be recessive and only expressed when the individual is homozygote (carries two copies of the gene). Alternatively, the gene could be dominant, expressing even when the plant only carries a single copy of the gene (heterozygote). In many cases, the heterozygote individual will express a lower level of herbicide resistance than homozygote individuals. A range of levels of herbicide resistance could occur when resistance is conferred by multiple genes.

Nevertheless, the selection for herbicide resistant individuals is the inevitable outcome of

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repeated use of a single herbicide or herbicide group. This selection pressure is greatly reduced when other weed management tools are used in combination with the herbicide.

Worldwide, 220 different weed species have been documented to have resistance to herbicides and some weeds have developed resistance to a range of different herbicides. Annual ryegrass in Australia, for example, is resistant to a wide range of herbicides from nine different herbicide groups.

Selection pressure

When applied correctly, a herbicide effectively controls its target weed. Repeated use of a herbicide has two effects. Firstly, the herbicide selects for the more tolerant weed species, resulting in a species shift in favour of those tolerant species. That is, the frequency of the species most susceptible to the herbicide declines most rapidly, while there is a relative increase in the frequency of species that are more tolerant of the herbicide. Species shift is the normal consequence of any selection pressure. Secondly, the herbicide selects out the more herbicide resistant individuals from within a species (if these are present) and the frequency of these individuals increases within the population, leading to the development of herbicide resistance.

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

- the selection pressure imposed, which is determined by herbicide efficacy, the frequency of herbicide application and the generation interval of the weed,
- the level of tolerance to the herbicide, the frequency of herbicide resistant individuals within the population, and the nature of the weed's reproductive mechanism,
- the relative fitness of resistant individuals,
- dilution of the population from the seed bank and external sources, and
- use of other weed management tools that reduce the population of tolerant and resistant individuals.

Herbicide groups

Every herbicide comes with detailed product information attached to the chemical container. Additional information may be included in an attached product booklet. This information includes details on the use of the product, the range of weeds controlled, the required application conditions, safety, and herbicide resistance (for the more recently registered products).

Included on the product label is information on the herbicide group to which the product belongs. This information is displayed prominently on the front of the product label.

The herbicide group information is essential for developing a weed management strategy which reduces the risk of selecting out herbicide resistant weeds. The herbicide groups are indicated by a lettering system, as shown in Table 1.

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.

- herbicides with high risk (groups **A** and **B**).
- herbicides with moderate risk (groups **C** to **Z**).

The herbicide groups are based on the modes of action of the various herbicides, that is, the specific ways the herbicides work within a plant. There are many different modes of herbicidal action and a single herbicide may act on more than one plant process.

The herbicide risk categories have been developed from an understanding of the modes of action of these herbicide groups, and have been proven in practice.

The high risk herbicides (Groups **A** and **B**) target specific processes in the plant cell. Plants that are resistant to these herbicides occur relatively commonly in some weed populations. Herbicide resistant populations of weeds, such as ryegrass and black oats, for example, have been selected out after as few as two or three herbicide applications in extreme cases. This means that the herbicide completely fails to control the weeds by the third or fourth application because by this time the weed population is dominated by individuals that are resistant to the herbicide.

The post-emergence grass herbicides, Envoke® and Staple® are all in the high risk category. Resistance to these products is likely to occur within 3 to 5 years if they are used repeatedly without other weed management tools.

The herbicides in the moderate risk category (Groups C to Z) are less specific in their modes of action, targeting more general plant processes. Individual plants with resistance to these herbicides may still occur, but they are less likely. Some of these herbicides, such as 2,4-D and trifluralin, were used repeatedly over many years without any apparent resistance problems occurring. Nevertheless, resistance can occur and has now occurred to nearly all the herbicide groups. Resistance to 2,4-D and trifluralin have now been found and further resistance to 2,4-D is suspected.

Once herbicide resistance develops, an alternate management approach is needed, as the herbicide is no longer of any use for controlling the target weed. Loss of a broad-spectrum herbicide, such as glyphosate, has a major negative impact on the cotton farming system.

Further information on weeds that have developed resistance to herbicides in Australia is covered in the document Integrated Weed Management Systems for Australian Cotton Production in WEEDpak.

Table 1. *The herbicide groups of the herbicides more commonly used in the cotton farming system. Examples of products containing these active ingredients are shown.*

	Herbicide group	Active ingredient	Example
High risk	A	butroxydim	Factor®
		clethodim	Select®
		fluazifop-P	Fusilade®
		haloxyfop	Verdict®
		propaquizafop	Correct®
		sethoxydim	Sertin®
	B	chlorsulfuron	Glean®
		halosulfuron-methyl	Sempra®
		imazapyr	Arsenal®
		metsulfuron-methyl	Ally®
		pyrithiobac sodium	Staple®
		trioxysulfuron	Envoke®
Moderate risk	C	atrazine	
		diuron	
		fluometuron	Cotoran®
		prometryn	Gesagard®
	D	pendimethalin	Stomp®
		trifluralin	
	F	norflurazon	Zoliar®
	G	flumioxazin	Valor®
		oxyfluorfen	Goal®
	H	isoxzflutole	Balance®
	I	2,4-D	
		dicamba	
		fluroxypyr	Starane®
		MCPA	
	K	metolachlor	Dual®
	L	diquat	Reglone®
		paraquat	Gramoxone®
	M	glyphosate	
		glyphosate-trimesium	Touchdown®
	N	glufosinate	Liberty®
	Q	amitrole	Amitrole T®
	Z	MSMA	Daconate®

Over-use of glyphosate and a lack of residual grass herbicides in this system 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.

Herbicide modes of action

Herbicides have their effects by disrupting specific plant processes. Group A herbicides, for example, inhibit the acetyl-CoA carboxylase enzyme, which inhibits fatty acid synthesis in the plant. Even though there are a large number of Group A herbicides that are all chemically different, they all target the same mechanism in the plant, all inhibiting fatty acid synthesis. Group H herbicides, as another example, inhibit the protoporphyrinogen oxidase enzyme, which inhibits the production of chlorophyll and heme, inhibiting photosynthesis and electron transfer and leading to the build up of protoporphyrin and toxic levels of oxygen. Consequently, the herbicides have been grouped according to their target site mechanisms or modes of action.

Similar herbicides often have similar modes of action. For example, all the post-emergence grass herbicides are Group As, with the same mode of action. Consequently, although six chemically distinct herbicides are listed in Group A in Table 1, they all act on the same plant pathway and have the same mode of action. In practice, a weed that develops resistance to any one of these herbicides will have some level of resistance to all six herbicides, even though it may never have been exposed to the other five herbicides. This is called cross-resistance. Conversely, any herbicide with grass activity from a different mode of action herbicide group will control Group A resistant and susceptible plants equally well, as resistance to Group A shouldn't confer any resistance to another mode of action group.

Apparently similar herbicides do not always have similar modes of action. Of the pre-emergent grass herbicides, trifluralin and pendimethalin are both group D herbicides, which inhibit tubulin formation, effectively inhibiting plant growth, while metolachlor is a group K herbicide, with multiple modes of action, inhibiting growth and root elongation. If a weed repeatedly exposed to trifluralin developed resistance to this herbicide, it may have cross-resistance to pendimethalin, but shouldn't have resistance to metolachlor.

Resistance mechanisms

Weeds develop resistance mechanisms that either block the target sites of the herbicides (target site mechanisms) or are more general, blocking the herbicide at some either point (non-target site mechanisms). Non-target site mechanisms include blocking the transport mechanism, over-expressing the target enzyme, demetabolising the herbicide, or sequesting the herbicide into less sensitive plant parts. The resistance mechanisms may be as simple as a waxy surface on the leaf, reducing the penetration of the herbicide into the plant.

Generally, the target site mechanisms confer much higher levels of resistance than the non-target site mechanisms and are conferred by simple substitutions in the plant's genetic code which can be detected by gene mapping.

Non-target site mechanisms are generally weaker, are not due to single gene substitutions and often appear to be polygenic. They are also the more common form of resistance and it is likely that resistant plants commonly have more than one non-target site resistance mechanism, with mechanisms stacking up over generations are selection pressure is continued. It also seems likely that most weeds that develop target site resistance also have non-target site resistance mechanisms.

The consequence of this is that even amongst a single resistant field population there are likely to be varying levels of resistance and that separate populations that develop resistance won't necessarily have exactly the same resistance mechanisms. Recent testing of eight populations of glyphosate resistant awnless barnyard grass collected from northern NSW, for example, found different levels of resistance in all eight populations. This result suggests that there are multiple resistance mechanisms involved, with different combinations of these mechanisms in the different populations.

Weeds around channels, roads and water storages can contribute large quantities of seeds to cotton fields. Using glyphosate as the main control tool on these weeds leads to high selection pressure for resistance.

Rotating herbicide groups

Where herbicides with similar weed spectrums have different modes of action, opportunity exists to rotate herbicides, reducing the risk of selecting weeds resistant to any one herbicidal mode of action. This strategy is difficult to implement in cotton, as many of the herbicides that could be readily substituted are from the same herbicide groups.

For example, as discussed earlier, although the post-emergence grass herbicides Correct®, Factor®, Fusilade®, Select®, Sertin® and Verdict® are chemically different, they are all group **A** herbicides with similar modes of action. A weed that develops resistance to one of these herbicides may be 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 similar modes of action.

However, the pre-emergent grass herbicides belong to groups **D** (trifluralin and pendimethalin), **K** (metolachlor) and **F** (Zoliar®). Use of these herbicides in rotation allows an opportunity to expose weeds to totally different herbicide groups, greatly reducing the risk of developing herbicide resistance to any one of these herbicides.

Overall, the most effective approach to reduce the risk of the development of herbicide resistance and species shift to herbicide tolerant individuals, is to ensure that herbicides are used correctly, and to use an integrated approach to weed management, using as wide a range of herbicide groups as practical, and a variety of non-herbicidal weed management tools. Detailed information on the integrated weed management tools and developing an integrated weed management system in cotton is covered in the document Integrated Weed Management Systems for Australian Cotton Production in WEEDpak.

Special care needs to be taken when making repeated use of the high risk group **A** and **B** herbicides.

Multiple & cross-resistance

Herbicide resistance has become a very serious problem in many parts of the world over the last decade. Not only has resistance developed in a large number of plants, but many populations have developing resistance to multiple herbicides with different modes of action, and resistance has not always followed the same rules.

There have been examples where multiple resistance has crossed the modes of action groups. Resistance has developed in ryegrass, for example, to both glyphosate and glufosinate (Liberty), Group M and Group N herbicides, even thought the plants were never previously exposed to a Group N herbicide. This has happened because the resistance mechanism is a metabolism mechanism and it breaks down glyphosate and glufosinate equally well, with no regard to their modes of action. Similarly, it is likely that some of the other non-target site resistance mechanisms could confer resistance to herbicides with different modes of action.

Similarly, cross-resistance is likely to occur within a mode of action group, with resistant plants having some resistance to other herbicides within the same mode of action. However, there are examples reported where this has not been the situation. In the US, for example, hydrilla (a water weed) has developed resistance to fluridone, a Group F herbicide. The resistant plants are cross-resistant to norflurazon, another Group F herbicide, but have increased sensitivity to three other Group F herbicides.

Many of the early examples of herbicide resistance involved a fitness penalty, such that the resistant plants were less fit than the susceptible plants of the same species. This can occur because there is a cost to the resistance mechanism. Where resistance occurs due to a change in the enzyme that is targeted by the herbicide, for example, the modified enzyme may not be as effective as the original, inferring a fitness penalty. The significance of this can be that the resistant plants are smaller, less competitive and produce fewer seeds. Where this occurs, swapping to an alternative mode of action herbicide is a very effective strategy, as the proportion of resistant plants in the population will decline over time once the original herbicide is no longer used.

However, there is little or no fitness penalty with many of the more recent examples of resistance, such as glyphosate resistance and in some situations, such as the US, resistant weeds are spreading into areas where the susceptible weed wasn't previously found.

Weed monitoring

The underlying principle of integrated weed management is to continually monitor the presence of weeds and the success or otherwise of the weed management tools used. Where a weed is not successfully controlled by one tool (herbicide, cultivation, chipping etc.), an alternate tool should then be used to manage the weed before it can set seed. This approach of scouting and rotating weed management tools as necessary, will not only result in an effective weed management system, but will also reduce the risk of developing herbicide resistance.

Cotton growers should always check fields after every herbicide application to ensure that the target weeds have been satisfactorily controlled. Where control has not been satisfactory, an alternate management tool should be used. A weed control failure may not be due to herbicide resistance, but could be caused by a variety of other factors such as:

- poor application. Nozzles may have been poorly positioned, such as too high from the target, or too little herbicide hit the target due to inadequate water rates, high temperature, small droplets, strong winds etc.,
- an inappropriate (too low) herbicide rate. Larger weeds generally require higher herbicide rates. Mature weeds may be impossible to control with a given herbicide,
- unsuitable conditions. Weeds may be moisture, heat or cold stressed, or conditions may have been too hot for spraying, humidity too low etc., or
- incorrect weed identification. Similar, closely related weeds may have very different susceptibility to some herbicides.

Where weeds that should have been controlled by a herbicide have survived the application, growers should immediately act to ensure that the surviving weeds do not set seed. Assistance from an agronomist or chemical company representative should then be sought to determine whether the survival of the weeds is due to herbicide resistance. Action to manage the weed must be taken as soon as resistance is confirmed. In most cases a small area of resistant weeds can be readily managed, but a problem that is allowed to become a large area could cause issues for many years.

If resistance is suspected and the plants are likely to set seed before resistance can be confirmed, the area should be treated as if it is resistant and all plants controlled. Where resistance occurs in an out-crossing species or a species with small seed that can be spread by wind, the pollen or seed has the potential to spread for kilometres and it is vital that resistant plants are controlled before they are able to spread.

Suspected herbicide resistance

Many suspected cases of herbicide resistance are due to other factors. Incorrect identification of the weed is a common problem. Similar looking weeds often occur in mixed populations without being individually identified. A good example of this occurs with yellow vine and caltrop. Broad-spectrum herbicides such as trifluralin and glyphosate are equally effective in controlling both weeds, but specific herbicides such as Staple® may only be effective in controlling one species (Staple® only controls yellow vine). An apparent spray failure with Staple® on yellow vine can be caused by Staple® effectively controlling the yellow vine, but leaving a large population of caltrop. An alternative control method is needed for the caltrop.

Another general guide to herbicide resistance is that the problem is most likely to show up in a small area of a field, corresponding to the location of the individual plant that initially had resistance. A resistance problem would be unlikely to first appear on a field-wide basis, unless the problem had been spread by land-levelling in the previous season. A field-wide problem would be a very good indication of an application problem or herbicide rate problem.

If the weed has been correctly identified, and no other problems are apparent, then the simplest method of checking for resistance is to re-apply the herbicide at a range of rates on test-strips, ensuring that no suspect weeds are allowed to set seed. Contact a chemical company representative and a weeds agronomist from NSW Dept. Primary Industries or Queensland Department of Primary Industries immediately if the weeds are still not controlled by the recommended rate.

Managing herbicide resistance

Weeds are relatively immobile and will only move large distances if wind blown or transported by water, animals, people, or machinery. Experience from other cropping systems has shown that resistance can often be confined to a single paddock, or even to an area within a paddock.

Where resistance is identified before it has become widely spread, and appropriate measures are taken, resistance can be relatively easily managed and may eventually be eliminated from an area. The keys to managing resistance are:

- early identification, before the problem becomes widespread,
- treatment, preventing the weeds seeding, and
- isolation, to prevent the weed spreading to new areas.

Glyphosate & the resistance spiral

Simple weed management systems centred around glyphosate have been widely adopted by farmers over the last decade and more, particularly with the use of Roundup Ready cotton, maize and soybean crops.

The 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 timelininess 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.

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 in Australia. 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 to diuron within only a few years.

Similarly, using a double-knock in fallows with glyphosate followed by Spray.Seed is a useful strategy for controlling some of the more difficult weeds. However, it is only effective as long as both glyphosate and Spray.Seed are effective. Relying solely on Spray.Seed to control glyphosate resistant weeds is a recipe for developing Group I resistance. Relying on a Group A or B herbicide to control feathertop Rhodes grass is guaranteed to fail.

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.

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.

Summary

Herbicide resistant plants can naturally occur in any plant population. Over-reliance on a single herbicide or herbicide group will cause a species shift to weeds that are tolerant of the herbicide and will eventually result in the emergence of weeds resistant to the herbicide.

The development of herbicide resistance is now a reality for the cotton production system, with glyphosate resistant weeds becoming increasingly common. This has not primarily occurred due to a failure in the cotton system, but due to a widespread failure in the whole farming system, due largely to the long-term use of glyphosate to replace all the other components of an integrated weed management strategy.

Now that resistance has occurred, it is essential that growers change to manage their weeds in a more sustainable fashion, re-implementing an integrated approach to weed management. Growers need to return to using a wider range of herbicides and other weed management tools, ensuring that any survivors of every herbicide application are controlled with an alternative weed management tool before they set seed.

Herbicide resistance can't be solved by just adding a second herbicide to manage the escapes from the first herbicide. This strategy places very strong selection pressure on the second herbicide, which is often an older herbicide that has a history of previous use. The result of the strong selection pressure inevitably is resistance developing to this herbicide, and then the next herbicide and so on.

Herbicide resistance is not unmanageable at the present and it is essential that cotton growers act now to ensure the value of their herbicides into the future. The alternative is returning to cultivation and hand hoeing as the primary methods of weed control, with all the associated issues of this approach.

HERBICIDE RESISTANCE AND THE CROP MANAGEMENT PLAN

Graham Charles
(NSW Dept of Primary Industries)

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Background

For many years herbicide resistance has been the big issue in the winter cropping zones of South Australia and Western Australia but a relatively minor issue in the cotton area of NSW and Queensland. However, those days are gone, and glyphosate resistance is now a major issue for the whole of the northern farming system, threatening the viability of the more marginal areas.

This paper discusses the issue of glyphosate resistance and explains the value of the approach used in the Crop Management Plans of Roundup Ready and Liberty Link cotton for managing the development of resistance.

Introduction

One of the first questions I was asked 25 years ago when I started in the cotton industry was: "Do we have herbicide resistant weeds in the cotton industry yet?"

The answer at the time was a resounding "no", and we shouldn't get resistant weeds as long as we keep using a multi-input approach to weed management in cotton (an integrated weed management approach).

Unfortunately, 25 years later, this is no-longer the case, with glyphosate resistance rapidly becoming one of the biggest issues for the northern cropping system. Cotton is now being grown in a glyphosate centric system, where glyphosate has replaced nearly all the other weed management tools. There are glyphosate resistant weeds in the cereal component of the cotton farming system on most properties, and glyphosate resistant weeds are becoming increasingly common in the cotton component. While these resistance problems may not have been caused by the way weeds were managed in cotton, in the end it doesn't matter. The problem doesn't go away just because it was caused somewhere else in the system.

There are now 220 different weed species resistant to a herbicide somewhere in the world. Thirty six weed species have resistance in Australia, and while many of these are resistant to the high risk Group A and B[1] herbicides, there is resistance to nearly every herbicide group, including the groups that include our residual cotton herbicides and glyphosate. In WA and the US, resistance has even developed to 2,4-D (Group I), a herbicide very widely used since the 50's, which had never had a resistance problem anywhere in the world up until a couple of years ago. It just shows that if you push the system hard enough, resistance will eventually occur.

[1] Herbicides are grouped according to their mode of action. Group A & B herbicides are at high risk of developing resistance, Groups C to Z are at moderate risk. Resistance to any group is possible, regardless of the ranking.

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In the cotton growing areas there are numerous instances of ryegrass and wild oats populations with resistance to Group A and B herbicides. We now also have glyphosate (Group M) resistant populations of:

- Annual ryegrass,
- Awnless barnyard grass,
- Liverseed grass,
- Windmill grass, and
- Flaxleaf fleabane.

We have also seen species shift to a number of glyphosate tolerant weeds that are becoming increasingly problematic in the cotton system. These weeds are not glyphosate resistant, but were never effectively controlled by glyphosate, making them equally problematic as resistant weeds. Top of the list of these weeds is:

- Feathertop Rhodes grass

So what causes the problems?

In a single word (or two): selection pressure. The more effective a product is, the more strongly it selects for resistant individuals. If a highly effective product is used often enough on enough individuals, eventually a resistant individual is likely to be encountered and selected (assuming that resistant individuals exist). This is the start of resistance.

A big unknown is the proportion of resistant individuals in the natural population. It is possible that no individuals resistant to a given herbicide exist in a weed population, but there is no way of knowing this. Unfortunately, experience is showing that individual weeds carrying a resistance gene occur in many weed populations, with resistance to a wide range of herbicides now common.

Selection pressure occurs every time a population is exposed to a herbicide. However, it is not simply a matter of how many times a herbicide is applied in a season, but of how many generations of a weed are selected and whether these generations are also being controlled by another input or inputs. The selection pressure is greatly reduced where a range of other inputs is also used on the same weed population (as commonly occurred in the traditional cotton system), as a resistant individual has to simultaneously develop resistance to more than one weed management tool in order to survive.

So, the selection pressure on glyphosate was not overly strong in the traditional weed management system where survivors from a glyphosate spray are normally controlled by cultivation, hand hoeing or a residual herbicide. However, the selection pressure in the glyphosate centric system that has evolved in the north is very strong, selecting for glyphosate resistant and glyphosate tolerant weeds.

Herbicide resistance in the cotton system

The traditional cotton system was a robust system for managing most weeds because it employed a range of weed management tools, including multiple applications of residual herbicides with different modes of action, cultivation, hand hoeing, cropping rotations etc. Few, if any, of the weed management inputs (herbicides, cultivation etc.) were 100% effective (most were less than 95% effective, giving low selection pressure), but the combined system was effective for most weeds. Any weeds which survived the multiple residual herbicide applications (and there were always a few survivors), were controlled by the cultivator, or if they escape this, by the hand hoeing crew, or the next cultivator and the next hand hoeing crew, or the next herbicide etc. Herbicide resistant weeds were unlikely to emerge in this system, as the system responded to any survivors by throwing yet another (different) management tool at them.

Unfortunately, this system had its drawbacks, including expense (in dollars, time, manpower, and soil moisture), undesirable off-target impacts of herbicides and unavoidable damage to the cotton crop. Twenty five years ago, many hand hoeing bills were in excess of $100/ha, with bills of up to $300/ha not uncommon (1990 dollars – so multiply the numbers by 2 or 3 to get today's dollars). These bills are not affordable in the current economic climate, even if the large chipping crews were still available, which they generally are not. These issues forced the weed management system to evolve over the years to one which is glyphosate centric, substituting glyphosate for residual and other contact herbicides, cultivation and hand hoeing.

The down-side with the widespread adoption of Roundup Ready Flex technology in the cotton system is that the system which has evolved relies very heavily on glyphosate in both the cotton and fallow phases, and in some instances, especially with dryland cotton, may be relying exclusively on glyphosate for the control of some weeds. This places very strong selection pressure on glyphosate and is a recipe for glyphosate resistance. Species shift is also an inevitable outcome of this glyphosate intensive system, which has selected for glyphosate-tolerant species. Many of the glyphosate tolerant species, such as rhyncho and emu foot, which were minor pests of the traditional cotton system, have increased in number in the glyphosate intensive system, slowly becoming significant weed problems. Ultimately, the density of these weeds will increase to the point that other weed management tools will have to be reintroduced to manage them.

So, how to maintain a glyphosate based system?

Selection in a glyphosate based system

A number of factors influence the genetic response to selection pressure, including the frequency of resistant genes, the plants reproductive characteristics, seed-bank longevity and the fitness of resistant individuals.

Resistance is not simply a factor of how many times a herbicide is applied in a season, but of how many generations of a weed are selected, the characteristics of the plant and whether other effective weed management tools are being used on the same generation/s.

There was relatively weak selection pressure on glyphosate in a traditional weed management system, where survivors from a glyphosate spray were controlled by cultivation, hand hoeing or another herbicide. However, the selection pressure on individual weed species may be stronger than it appeared to be at first glance. For example, nutgrass is a weed which is not well managed by the traditional weed management system, but can be effectively managed when glyphosate is added to the system. However, when it is only being controlled by the glyphosate component of the system, nutgrass is under intensive selection pressure from glyphosate in the traditional cotton system. Nutgrass would be under the same level of selection pressure in a Roundup Ready Flex crop, where it is again only being controlled by glyphosate. The additional residual herbicides, inter-row cultivation and hand hoeing in the traditional system are not controlling nutgrass, so they do not reduce the selection pressure on this weed. Fortunately, nutgrass is a very low risk weed which is unlikely to develop resistance to glyphosate. This is primarily because nutgrass predominantly reproduces vegetatively, producing ‘clones’ of itself, so that most, if not all, plants in a field are effectively from the same generation and genetically identical. Even plants in different years are likely to be from a single generation and genetically identical. Continual selection pressure with glyphosate is still only selecting from a single generation and so should not lead to resistance.

Some weeds are exposed to much stronger selection pressure in a Roundup Ready Flex system. A weed such as awnless barnyard grass, for example, was controlled to some extent by each of the residual herbicide inputs used in the traditional system. However, awnless barnyard grass could have 2 or 3 generations within a single season and each generation might be exposed to selection from glyphosate in a Roundup Ready Flex system. Consequently, this weed is at a high risk of developing resistance to glyphosate in this system and numerous examples of resistance have now been found.

Other weeds are at lower risk of developing resistance. The selection pressure on a weed such as Italian cockleburr (one of the Noogoora burr complex), is low in both traditional and Roundup Ready Flex systems. The selection pressure on Italian cocklebur in Roundup Ready Flex cotton, where three or four Roundup Ready Herbicide applications are made during the season, is no higher than the selection pressure where only one application is made. This is because all applications are made to the same generation of the weed (the burrs don’t flower until late summer and autumn). Effectively, one late-season application to all burrs would impose the same selection pressure as four applications during the season, although the single application is not a practical option, as the weeds would be very large by this time, would have reduced crop yield and would be difficult to control. Traditional and Roundup Ready Flex systems, where surviving burrs are controlled by hand hoeing or spot-spraying, impose no effective selection pressure on this weed.

Starting the season with low weed numbers is an important component of the CMP with herbicide tolerant cotton varieties. High weed numbers necessitate multiple herbicides inputs and high selection pressure.

The importance of the crop management plan

Of the factors in the development of herbicide resistance, the one a farmer has the most control over is selection pressure. In order to reduce the selection pressure on a weed, it is essential that weeds which survive a herbicide are subsequently controlled by another (different) management tool before they set seed. If this is done, then there is effectively no selection pressure from the first herbicide.

This is the core principle of the crop management plans developed for Roundup Ready and Liberty Link cottons. These plans require that at least once a season, each field is assessed for weeds that have survived a herbicide application (the weed audit), and any survivors are controlled by a different tool (herbicide, cultivation or hand hoeing) before they set seed. Ideally, this would be done after each herbicide application and no surviving weeds would be allowed to set seed. While the requirements of the weed audit may seem onerous, it is a simple way to ensure that each crop is checked for surviving weeds at least once a season, and provides a valuable set of data to TIMS and the APVMA. Collective information over valleys and years provides a broad overview of the performance of these products and gives these bodies a basis for confidence in the application of these transgenic systems, as well as guidance on any issues which may arise.

In reality, good operators check the performance of each weed management input (and other inputs) throughout the season and rectify issues as they arise. The crop management plan provides a simple, auditable framework to facilitate this process.

A second factor the farmer has control over is the number of weeds in a field. This is important because as weed numbers increase in a field, the chance of a resistant individual being present also increases and the chance of the resistant individual surviving a herbicide application increases. This is why the crop management plans recommend entering a cropping phase with low weed numbers. It is statistically unlikely that any resistant individuals will be present in fields with low numbers of weeds.

Low weed numbers can be achieved in one of two ways. Firstly, low weed numbers can be the result of good weed management practices over a number of years. Weed surveys over the last 25 years have found that generally cotton fields have become cleaner, with fewer weeds over time. Fields with low weed numbers are ideally suited to the transgenic systems where residual herbicides are replaced by contact herbicides.

A second way of achieving low weed numbers is by retaining some residual herbicides in the system. Residual herbicides might be applied pre-planting or at-planting, or can be applied from around 6 – 8 nodes (15 cm of crop height) post-emergence. The type of residual herbicide and time of application can be tailored to meet the expected weed population. Inclusion of a residual grass herbicide, for example, is strongly recommended in fields which have a history of high grass numbers. Use of these residual herbicides is a simple and effective way of greatly reducing the numbers of weeds that have to be controlled by the post-emergence contact herbicides, reducing the selection pressure on these herbicides. In practice, if residual herbicides are not included at planting in fields with high weed numbers, post-emergence inputs, which will probably include residual herbicides, will be required to control survivors from the contact herbicides. Where high weed numbers are expected, it is simpler and more effective to apply the residual herbicides at planting.

Maintaining the whole glyphosate system

The biggest threat to the sustainability of the Roundup Ready system is the use of glyphosate in the rest of the farming system and failure to control survivors of glyphosate applications in fallows.

Where cotton is grown in a wheat rotation in an irrigated system, it is common for a field to be in fallow for nearly 12 months in every 24 month period. In this system, weeds in the fallow are commonly controlled with glyphosate, and the field may receive 5 or 6 applications (or even more) over the fallow period, especially where wheat stubble is retained. This places strong selection pressure on glyphosate, but can be addressed using the same approach of controlling any survivors of a glyphosate application using an alternative option before they set seed. This control input could be an alternative herbicide, such as Spray.Seed®, Alliance® or Amitrole T, cultivation or hand hoeing.

An approach increasingly commonly used is to follow a glyphosate application with a Spray.Seed application as a double-knock, with 5 to 7 days between the herbicide applications. This combination is effective for controlling small, annual weeds and the strategy is very effective for preventing resistance developing, provided that resistance to either of these herbicides has not already occurred. The double-knock strategy can be equally applied using a range of alternative management tools, such as cultivation, or other herbicides following closely after the glyphosate application.

One practice commonly used in the cotton system is to tank-mix an alternative herbicide such as 2,4-D with glyphosate applications made to fallows during winter. This may appear to be an effective way of reducing selection pressure on glyphosate, but has major limitations. Firstly, most weeds are seasonal and are more prolific in either the winter or summer. This is more so in the southern areas. Consequently, the spectrum of weeds exposed to the glyphosate/2,4-D combination will not necessarily be the same as the spectrum controlled by just glyphosate in the summer. Some weeds, which predominantly grow in summer, will not be exposed to 2,4-D and so are still under very strong selection pressure. Secondly, the reduction in selection pressure is only applied to broad-leaf weeds. Grass weeds are not controlled by 2,4-D, and so the addition of 2,4-D does not reduce the selection pressure on grasses. Thirdly, the mixture is normally used to achieve some synergism between the two products, increasing the spectrum of weeds controlled but with a reduction in the rate of glyphosate used. To be effective to reduce selection pressure, it is necessary that both products are used at rates that will kill the target weeds, so that if there is resistance to one product, the weed is still killed by the other product. Adding 2,4-D to a reduced rate of glyphosate will improve the spectrum of weeds controlled, but will not reduce the selection pressure on glyphosate.

Selection pressure can be even stronger in the dryland system, where cotton might only be grown every third year, with long fallow periods and little if any thorough cultivation. Glyphosate resistance is most likely to occur in these systems unless an alternative weed control input is used to control weeds which survive the glyphosate applications. The cases of awnless barnyard grass which have developed resistance to glyphosate in the cotton growing area have occurred in zero-tillage dryland farming systems where fallow weeds are being controlled by glyphosate year after year. Unless farmers are proactive in controlling weed survivors, it seems certain that glyphosate resistance will become a major problem in the dryland cotton farming system.

Glyphosate & the resistance spiral

With the increasing number and spread of glyphosate resistant weeds, the conservation farming 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 many of 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 to manage these resistant weeds. The approach of reintroducing components of the traditional weed management system to reduce the selection pressure on glyphosate is sound, but the approach is flawed if resistance to glyphosate has already occurred.

A pre-planting application of diuron, for example, is becoming widely used to manage glyphosate-resistant flaxleaf fleabane in Australia. 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 to diuron within only a few years. The solution to resistant fleabane, is not to manage it with diuron, but to manage it with a range of manage tools, so that diuron is only one component of the system. Using a tank mix of diuron and Spray.Seed, for example, backed up with strategic cultivation and spot spraying with Amitrole as necessary is a much more sound approach that is likely to be sustainable in the longer-term.

Similarly, using a double-knock in fallows with glyphosate followed by Spray.Seed is a useful strategy for controlling some of the more difficult weeds. However, it is only effective as long as both glyphosate and Spray.Seed are effective. Relying solely on Spray.Seed to control glyphosate resistant weeds is a recipe for developing Group L resistance. Relying on a Group A or B herbicide to control feathertop Rhodes grass is guaranteed to fail within 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 is now proving, with many of the more problematic weeds in the US having multiple resistance often to 4 or 5 modes of herbicidal action.

Glyphosate resistant flaxleaf fleabane is now very common and in many cases, such as this, elimination is no longer an option. There has to be a change in the whole farm system to ensure it is managed.

Using Liberty Link® cotton

With the increasing number and spread of glyphosate resistant weeds, the idea of rotating to cotton varieties using the Liberty Link technology is looking increasingly attractive. Liberty Link technology, which allows the use of glufosinate over the top of the crop, allows cotton growers to rotate to a new mode of action herbicide, glufosinate, which is a Group N herbicide. Given that most fields have little or no history of Group N use, rotating to this group is a sound concept.

Glufosinate is effective on a wide range of broadleaf weeds, including some that are not well controlled by glyphosate. Foremost of these are the vines, cowvine and bellvine. Glufosinate is very effective on these two weeds, controlling quite large plants at label rates. Using glufosinate to manage the problem of species shift to glyphosate tolerant weeds is a sound strategy and should be the option of choice in many situations.

However, glufosinate is weak on most of the grasses, including the glyphosate resistant grasses. To manage glyphosate resistant grasses in a Liberty Link crop, it is essential that a residual grass herbicide be applied prior to or at planting, Liberty herbicide be applied only to small, actively growing grasses and a layby application may also be needed. Consequently, there is little advantage to using Liberty Link technology to manage glyphosate resistant grasses. Growers having problems with glyphosate resistant grasses may be better off by adding the grass herbicides and other inputs to the Roundup Ready Flex system and concentrate on managing the weeds in their existing system.

Living with glyphosate resistance

Eliminating small patches of glyphosate resistant weeds before they spread is always the best strategy for managing resistance. How this is done depends on the size of the patch and its location. Quarantining a small part of a field and effectively sterilizing the area for a couple of years may well be the best approach to managing an outbreak of resistance.

One of the advantages in the current scenario is that all the known glyphosate resistance weeds have short seed bank longevity and don't emerge from depth. Consequently, it is possible to eliminate any of these weeds from a field by preventing all seed set over a couple of seasons, provided there has been no seed burial through cultivation.

Cultivation is a useful tool for managing these weeds, as any seed buried in the soil is effectively removed from the gene pool, but buried seed can last for far longer than will seed that remains on the soil surface. If cultivation is used to bury the bulk of the seed, it is essential that there is no further cultivation that would bring the seeds back to the surface.

If it is impractical to eliminate the resistant plants, such as with resistant fleabane that can blow in from a neighbouring field, then there has to be a change in the whole farm weed management approach to ensure these resistant weeds are effectively managed in the system.

At risk weeds

While herbicide resistance can develop in any species, some weed species are more at risk than others. The plant characteristics which contribute to the risk of developing resistance are: method of reproduction, plant frequency (how common the weed is), seed production rate and seed dormancy (seed-bank longevity). Plants at the highest risk are those which reproduce sexually, commonly occur at high densities, produce large numbers of seeds and have little or no seed dormancy (the seed dormancy can act like a refuge, diluting the population with older, non-resistant plants). Unfortunately, weeds such as awnless barnyard grass, common sowthistle and fleabane are already problematic in a glyphosate dominant system and are at high risk of developing resistance. These plants are often present at 10s or even 100s per m^2 early in the season, can produce thousands of seeds per plant and have little or no seed dormancy, with two or three generations possible each season.

Many of the weeds which are more problematic in the traditional cotton system and tend to get more attention by managers, such as thornapples and the burrs, are at much less risk of developing resistance. They are normally present at much lower densities (1 Italian cocklebur per m^2 would be a major infestation), produce fewer seeds (a few hundred per plant), have only one generation per year, and have strong seed dormancy, prolonging the effective generation period.

Consequently, managing a glyphosate dominant system requires a mind-shift, where the most important weeds become not just those that can individually cause the greatest yield reductions (such as thornapples), but those that have the greatest risk of developing resistance (such as awnless barnyard grass). Resistance in awnless barnyard grass, for example, would be a major nuisance in cotton, requiring a cotton grower to revert to a system which included a residual grass herbicide and regular inclusion of an alternative herbicide such as Spray.Seed in fallows. This would significantly increase the cost of weed control in the system. Resistant sowthistle would be even more expensive to manage, being very difficult to control in crop and in summer fallows without reverting to hormone sprays or other products which are themselves highly problematic.

The easiest way to manage herbicide resistance is to avoid it, but if resistance is suspected, it is vital that it is identified as soon as possible. Even the best farmer can end up with herbicide resistance due to the accidental introduction of a resistant seed or plant from an external source. Dirty headers, hay and grain are all likely potential sources of herbicide resistant weed seeds. Herbicide resistance has the potential to rapidly expand from a small problem in one field to a farm-wide problem within a season or two, and has no respect for farm boundaries.

Any cotton-grower suspecting herbicide resistance in a transgenic cotton crop is required to notify the respective technology provider immediately. This is a legal requirement under the crop management plan. The TIMS committee will also be notified to ensure that appropriate action is taken as soon as possible.

Herbicide resistance is a whole-season and whole-farm problem. High weed numbers in a rotation crop, such as this sorghum, are just as much a problem as if they were in cotton.

Plant characteristics that contribute to the risk of developing herbicide resistance.

Risk	Reproduction method	Frequency	Seed production	Seed dormancy	Examples
High risk	Sexual	Common	Large	Short	Awnless barnyard grass
Moderate risk	Sexual	Common	Small	Long	Thornapple
	Sexual	Uncommon	Large	Short	Tall sedge
Low risk	Sexual	Uncommon	Small	Long	Desert cowvine
	Vegetative				Nutgrass


Always ensure survivors of a glyphosate application are controlled using an alternative tool before they set seed. Starting the season with survivors from the fallow that are setting seed is a recipe for disaster.

Summary

The best way to manage herbicide resistance is to avoid it. Herbicide resistance can be avoided by following four simple rules.

- Always follow the Crop Management Plan. The core principle of this plan is to ensure crops are checked after herbicide applications and any surviving weeds are controlled using an alternative weed management tool before they set seed.
- Ensure at least one effective alternative weed management tool is used each season on all major weeds, especially those in the high-risk category. An inter-row cultivation, combined with a light hand hoeing, is a sound strategy for avoiding selecting for resistance in-crop. Alternatively, using a directed layby residual herbicide, incorporated with inter-row cultivation, may be equally effective, although a light hand hoeing may still be required to control larger weeds in the plant line.
- Adopt a double-knock or follow-up approach at least once a season for managing weeds in fallows.
- Always control weed escapes before they set seed

HERBICIDES

Introduction

Herbicides are an important component of an integrated weed management plan for Australian cotton farms. However, they need to be used in conjunction with other techniques to prevent the development of herbicide resistance.

There are a number of different herbicides sold by various companies under different brand names. Although these herbicides may have the same active ingredient, differences can exist in the concentration or formulation of the active ingredient.

Herbicides are classified into groups based on their mode of action, with each herbicide within the group having the same mode of action or target site within the weed. There may be a number of different herbicides within a herbicide group, each with a different active ingredient. It is important to remember that the chance of a weed developing resistance to a particular group when sprayed with any herbicide from the same group is very high. Rotating herbicide chemistry from different groups, and using integrated weed management, will help prevent resistance from occurring.

The selection of an appropriate herbicide to treat a correctly identified weed is the first step in the herbicide application process. The second is the effective application of the herbicide. To help ensure that this occurs, this section contains a brief summary of some of the aspects covered by the SPRAYpak manual. The SPRAYpak manual contains a depth of information that should be referred to when herbicides, and other pesticides are applied.

D3. SPRAYpak / Spray applications

An introductory article highlighting some of the important considerations involved with herbicide applications.

More information on spray application and registered chemicals can be found in the annual Cotton Pest Management Guide.

SPRAYpak / SPRAY APPLICATION

Introduction

Herbicides are the principal component of most weed management plans; hence it is important that they are used in the most effective manner possible. Herbicide efficacy is highly dependant on the use of correct application techniques and procedures. SPRAYpak outlines a number of important factors that need to be considered by growers, applicators and other personnel in the cotton industry. The following section gives a brief overview of the contents of SPRAYpak, highlighting some of the important information to consider before applying a herbicide. The reader should refer to SPRAYpak for additional information.

Managing spray applications

Weather conditions play a critical role in all herbicide applications. Therefore, proper monitoring of conditions before, during, and after the application is critical. During herbicide applications the following key meteorological conditions should be monitored and recorded:

- Wind speed – Spraying should only be undertaken when windspeed is between 3 km/hr and 15 km/hr (0.8 – 4.2 m/sec) and relatively steady,
- Wind direction – Take additional precautions if the wind direction is towards environmentally sensitive non-target areas. In addition, consider chemical odours that may persist after the spraying has been completed,
- Atmospheric stability, turbulence, local wind effects, surface temperature inversion layers, changes in wind effects and any changes that occur whilst spraying is being undertaken,
- Temperature – Generally, optimum temperatures for spraying water-based herbicide mixtures are less than 28^{o}C. Risks of reduced efficacy and off-target movement increase at temperatures greater than 28^{o}C. Spraying should proceed with caution at temperatures greater than 28^{o}C and applicators should exercise extreme care if the ambient air temperature at the time of application exceeds 30^{o}C,
- Relative humidity – It is preferable to spray in conditions where the relative humidity is greater than 45%,
- Rainfall – Do not spray if rainfall is imminent. Rainfall during or within 48 hours of an application may reduce efficacy and/or move the herbicide off-target.

Be prepared to stop spraying if conditions change and become unsuitable.

Proper planning is one of the most fundamental prerequisites of effective herbicide applications. The cornerstone of effective planning is the development of a comprehensive pesticide application management plan (PAMP). Relevant training of all farm personnel is another important part of effective, safe herbicide application and must be part of the planning and management processes.

Efficient record keeping is an essential part of herbicide management. Records of chemicals stored on-farm, together with the relevant labels and MSDS should be maintained so that they are readily accessible by all personnel at all times.

Correct identification of the target weed is often crucial. It is important that personnel involved in the spraying have an understanding of how the target weed influences herbicide type and formulation, and equipment selection. SPRAYpak provides guidelines on other important aspects of pesticides in general, and herbicides in particular. The selection of appropriate spray application machinery, calibration, set-up procedures and the selection of nozzles are all outlined.

The reader should refer to SPRAYpak for more information on each of these areas before applying herbicides.

More information on spray application and registered chemicals can be found in the annual Cotton Pest Management Guide.

FARM HYGIENE

Introduction

Weeds are a major problem on most Australian cotton farms and considerable amounts of money are spent annually on the management of weeds that interfere within the cotton crop. Often, however, weeds growing in fallows, along roads, channels and storages and the waste areas on farms are neglected, and these may have a significant impact on production by infesting cotton crops. These weeds can be spread into fields via machinery, water flow in channels and by a number of other means. It is essential that a complete integrated weed management strategy account for the weeds associated with these areas.

This section contains information on a number of different areas of farm hygiene. The following articles have been included in this section: -

F2. Farm Hygiene in Integrated Weed Management

The first article explains that there are a number of steps in achieving good farm hygiene including the identification and detection of weeds, cleaning down machinery and practicing integrated weed management.

F3. Managing Weeds on Roads, Channels and Storages

Good farm hygiene extends to roads, channels and storages. The management of weeds in these areas is explained in the second article. This article also explains what species may be present and how these species spread.

F4. Controlling Volunteer Cotton

Volunteer cotton is one of the more prevalent weeds in cotton farming systems. The third article reviews the management of volunteer cotton with sections on the control of seedlings, established cotton and ratoon cotton.

F5. Plant Protection Interactions with Weeds.

The last article in this section flags the interactions that the common insects and disease causing organisms have with weeds. The interaction between weeds and insects has been well documented in Integrated Pest Management Guidelines for Cotton Production Systems in Australia an Australian Cotton CRC publication. The interaction between weeds, pathogens and cotton diseases is covered in greater detail and a list of weeds known to be hosts of cotton pathogens is included.

FARM HYGIENE IN INTEGRATED WEED MANAGEMENT

Graham Charles[1], Annie and Stephen Johnson[1]
([1]NSW Dept. of Primary Industries)

Contents Page

Maintaining a productive cotton farm is the aim of an effective farm hygiene program.

Introduction

There are a number of steps in achieving good farm hygiene. These include the identification of threats (potentially damaging new diseases, insects and weeds that could inadvertently be introduced to the property), identifying any unknown species that may already be present, detecting any new pests or pests that have limited distributions (diseases, insects or weeds), cleaning soil and crop debris from machinery combined with farm hygiene and practicing integrated disease, insect and weed management. Each of these steps is important in achieving integrated pest management through farm hygiene on cotton farms.

Threat identification

There are a number of weeds that are not present on most properties, but that cotton growers and all farm staff should be on the look out for. These are weeds that are problematic elsewhere in the industry or elsewhere in the world and are often relatively easy to identify if you know what to look for.

Examples include:

- Parthenium weed,
- Velvetleaf,
- Anoda,
- Sesbania, and
- Feathertop Rhodes grass

All staff should know what these weeds look like and there should be a system in place to ensure that suspect plants are investigated as soon as possible. Identification material for these weeds in all growth stages is available in the Weed Identification and Information Guide, section A in WEEDpak.

Australian Government
Cotton Research and Development Corporation

Weed identification

A large number of weed species are likely to be present in every field and the range of weeds can vary from field to field. Over different 200 species of weeds have been identified through surveys of cotton fields, with 50 or more species commonly found in a single field. The person making decisions in the field should ensure they are familiar with all the weeds present in their fields and ideally should have a record of the common abundance of each species. These records will assist with making spray decisions and could be an early-warning of emerging problems. Keeping a record of the results for each field from the post-herbicide application weed audits required with herbicide tolerant cotton varieties (Roundup Ready Flex® or Liberty Link® varieties) would be a valuable way of doing this.

The positive identification of an unknown plant species is the first step in preventing the establishment of the species and controlling its spread. Positive identification can be achieved by using the Weed Identification and Information Guide, section A in WEEDpak, by referring to other publications, or by seeking expert advice from consulting agronomists, weed scientists, or botanists at the State herbaria.

Weed detection

The early detection of a new weed, or one that has a limited distribution on the property, makes it easier to control and prevent it from spreading further. Knowledge of the weed's biology can be a vital piece of information for developing a targeted weed management plan and can be found along with the weed identification material in WEEDpak.

Ensure staff are on the lookout for new weeds and know how to report a suspected problem.

Particular attention should be given to areas where machinery maintenance may have occurred, especially if contractor's equipment such as pickers or headers break down in the field. Small weed seeds, such as parthenium weed seed, can be lodged in machinery and released when panels are removed to make repairs.

Communication

Everyone on the farm should be aware of the importance of problem weeds so that they can take precautions to prevent the spread of these weeds around the farm, or onto other farms. This includes:

- Workers,
- Consultants and visitors,
- Contractors/module carriers, and
- Neighbors.

In return, growers should be kept informed of any potential weed outbreaks that could affect their operation by agronomists and other farm staff.

There needs to be an established system for reporting suspect weeds and recording weed incursions to ensure that valuable observations aren't overlooked or lost during busy times. Any positively identified incursions need to be located on a centrally positioned farm map, with species information and GPS coordinates if possible.

Weed incursions don't get managed by chance, but need a dedicated approach to ensure their removal and long-term monitoring to ensure no viable seeds remain in the seed bank.

Scouting

Agronomists who regularly inspect cotton fields for insects and diseases, can inspect for weeds at the same time. It is important to monitor risk areas, such as river, storages and channel banks for new weeds so that infestations can be controlled before they become widespread.

However, don't just leave this job to the agronomist. Every person of the farm can have an important role in looking for and managing weeds.

Ensure that all vehicles carry either a hoe or a pressure sprayer. It can be far easier to control an unknown weed when it first appears than to try to track it down later.

Good farm hygiene is important to prevent the spread of weeds on farm machinery. Photo: Greg Salmond.

Farm hygiene

Weeds are easily spread between fields and farms, in soil and crop trash, attached to vehicles and machinery. Thorough cleaning practices for all farm vehicles and machinery during the entire year will help prevent the spread of weeds.

Clean off soil and crop debris from:

- Farm vehicles and tyres,
- Boots,
- Cotton pickers and stripers,
- Grain harvesters,
- Tillage implements,
- Stubble pullers and mulchers,
- Modules builders and loaders, and
- Earth movers and laser levelers.

Remember to inspect areas where machinery has broken down as seeds may have dropped from parts of the machinery that are not regularly cleaned.

It is important to clean machinery when moving between different areas of one farm and between different farms to prevent the spread of weeds.

A guide to cleaning vehicles and machinery is contained in the Appendix of the Farm Hygiene booklet of the Best Management Practice Manual.

Always remember to clean off machinery like this root cutter before moving the machinery to different areas. This will help to prevent the spread of weeds. Photo: Greg Salmond.

Managing weeds

(Also refer to Integrated Weeds Management, section B in WEEDpak for further information.)

Integrated weed management needs to be a year round activity to prevent seed set and vegetative spread, because weeds grow at various times of the year. Remember that many weeds support harmful insects and disease causing organisms of cotton. Insects and diseases will be better controlled when weeds are controlled.

Keeping farms clean

(Refer to Managing weeds on Roads, Channels and Water Storages, section F3 in WEEDpak for further information.

- Consider that the seeds of many species may be spread in irrigation water. Remove weeds from around irrigation channels and storages to help prevent this spread.
- Ensure that tail water and storm water run-off is retained on farm to prevent weeds spreading to clean farms.
- Maintain a strict weed control program in and around each field. This includes roadways, channels and fence lines.
- Minimise new weeds entering clean fields by cleaning machinery between fields and properties.

Identification and planning

- Accurate identification of weeds on a farm is important for effective control (see case study).
- Make a priority list of weeds to control.
- Eradicate new weeds when they are in small patches.
- Maintain accurate records of weed control methods and effectiveness.
- Record the field locations of herbicide tolerant cotton varieties. Volunteer crop plants are often the most numerous weeds in the field and this is a particular problem where herbicide tolerant cotton is grown. Accurate field identification will help achieve effective control of herbicide tolerant volunteers. For example, it is important to use weed control tools other than glyphosate in fields following cotton with the Roundup Ready Flex® trait.
- Part of integrated weed management is the rotation of control methods. This will help prevent herbicide resistance (refer Section C, Managing Herbicide Resistance in Cotton in WEEDpak).

Crop Management

- Select rotation crops that enhance the control of weeds in cotton crops.
- Maximising water use efficiency will reduce the amount of weed seeds brought onto farms in irrigation water.

Selection of appropriate rotation crops will help manage weeds in cotton crops.

Herbicides

- Reduce herbicide rates or the number of herbicide applications on fields that you are confident have low weed pressure. Leave untreated strips in the field if you are uncertain of the size of the seed bank.
- Use shielded and weed detecting sprayers with non-selective herbicides.
- Use post-emergent herbicides and herbicide tolerant cotton varieties as another tool in integrated weed management. This will allow weeds to be sprayed after multiple germination events and only when they are present.
- Ensure that weeds that have escaped post-emergent herbicide applications are treated using a different weed control method, for example, cultivation, hand hoeing or the application of herbicides from a different herbicide group (refer to Managing Herbicide Resistance in cotton, section C in WEEDpak).
- Continue the use of residual herbicides in combination with other weed management practices.

Inspecting fields shortly after herbicide application for weed escapes is crucial.

Cultivation and hand hoeing

- Use hand hoeing to prevent weed escapes setting seed.
- Use inter-row cultivation to control weeds in the furrow.
- Beware of shifting weeds along rows and between cultivation sets. Spreading nutgrass tubers down a row, for example, is a common problem when cultivating through nutgrass patches when the soil is moist.

Regularly clean weed from cultivation machinery to help prevent weeds spreading along rows and between sets.

Summary

Good farm hygiene involves:

- Identifying potential threats,
- Identifying any unknown weeds present,
- Detecting any new pests that have limited distributions,
- Scouting for weed escapes after herbicide applications,
- Preventing weeds from setting seed or spreading vegetatively.
- Cleaning soil and crop debris from machinery,
- Preventing weeds from establishing in new areas, and
- Practicing integrated weed management, effectively managing all weeds in the farming system.

Acknowledgements

This article was modified from the Australian Cotton Industry Best Management Practices Manual, September 2000, Editor Allan Williams.

For more detailed information please consult the manual.

The importance of farm hygiene
A grower's perspective

August 2002

Nick Barton the Northern Regional Agronomist for the Twynam Agricultural Group talks about the need for good farm hygiene to manage Velvetleaf (*Abutilon theophrasti* as pictured) on Telleraga Station where he was the former Head Agronomist.

Velvetleaf is not a common weed in Australian cotton but has the potential to be very problematic.

"It was during our BMP (Best Management Practice) audit that we **detected** a new weed that occurred in several small low spots down in our dryland fields beside the Mehi river. Since we didn't know what the weed was we decided to get it **identified** and it turned out to be velvetleaf. Apparently velvetleaf is not very widespread here in Australia but it one of the worst summer cropping weeds in the USA.

We decided that we would **regularly check** the patches of velvetleaf but the weed didn't seem to be spreading very far so we weren't too worried about it. We certainly made everyone on the farm aware that this was a weed to watch. **Good communication** between all the staff on farm, from the tractor drivers right through to the farm manager, is another one of the keys to containing potential weed outbreaks.

We pumped a lot of floodwater into our on farm storages during the floods of 1998. We also had a lot of overland water flows during that time, particularly onto our dryland country. Knowing that any water, and particularly floodwater can spread weed seed, we decided to check the inside of the storages and the dryland fields to see what weeds may have been spread onto the farm once everything started growing some months after the floods.

To our surprise we noticed a lot of velvetleaf that had come up inside the storage walls and in a number of new, low spots in various dryland fields where the water had sat for a while. Unfortunately the velvetleaf in the storages had already set seed and we had inadvertently spread it to our main return storage that was used to supply the whole farm with water. Apparently the mature seed heads and even the seed float quite well and had spread via the irrigation water throughout the farm.

We moved pretty quickly after that and ended up controlling the weeds inside the storage walls so that more seed would not be spread around the farm in the irrigation channels. We had a good success with what we did, but we ensured that we monitored the inside of the storages pretty closely after that to ensure that new plants didn't come back through. Hopefully having the storage full of water resulted in the seed rotting in the mud inside the storage.

The velvetleaf in the dryland fields was less of a worry, but we certainly got rid of it before it went to seed and spread any further. It is always better to try and get rid of any weed while ever it is in small patches that you can keep an eye on and control. We also made sure that we **cleaned down the machinery** that we used in the fields with this weed before we moved it onto clean areas, just in case the machinery spread seed in attached soil or crop trash.

It is so important to keep an eye out for potential new weeds, to have them correctly identified and to try and control them before they start spreading otherwise things can quickly get away on you. We had enough worry about with the current weeds that we had".

The importance of farm hygiene
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*Mature seed heads of velvetleaf (*Abutilon theophrasti*)*

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MANAGING WEEDS ON ROADS, CHANNELS AND WATER STORAGES

Graham Charles[1], Anne Sullivan, Ingrid Roth and Grant Roberts

([1]NSW Dept. of Primary Industries)

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A very weedy water storage, dominated by sesbania and cumbungi. This storage is a source of weed seed to the cotton crop and a host for pests and diseases.

The problem

Weeds on roads and irrigation structures are a problem because they:

- can be hosts for insects and diseases;
- are a source of weed seeds that contaminate cotton fields and add to the weed seed-bank;
- may restrict the flow of water, which in turn can reduce irrigation effectiveness, increase water logging, lead to blockages in irrigation channels, and can cause erosion and failure of banks;
- make access to channels and structures difficult and provide a habitat for snakes and other pests in areas where siphons are being set;
- can contaminate modules; and
- act as harbours for feral pigs.

Ownership and responsibility for weed management may be difficult to establish in some situations. Weeds may not be able to be managed on adjoining public land.

Australian Government
Cotton Research and Development Corporation

Weed management options

The options for managing weeds on roads and irrigation structures are:

- chemical control with herbicides,
- mechanical control with cultivators, graders, excavators and hand hoeing, and
- burning.

A weed management plan should not rely solely on one weed management strategy, as heavy reliance on a single strategy will inevitably see the emergence of weeds that are able to tolerate that strategy. Over reliance on a single herbicide may result in the selection of weeds that are resistant to that herbicide. For more information, refer to Managing Weeds in Cotton and Managing Herbicide Resistance in Cotton section B2 and C2 in WEEDpak.

Weeds are not generally a big problem on roads, as weeds do not grow well on compacted areas and most weeds can be controlled with herbicides and mechanical removal. Weeds are far more difficult to manage on irrigation structures, where water movement, and the physical size, shape and location of the structures requires management with specialised equipment.

Weed management on adjoining private and public land can be a problem. Weeds growing on roadsides (such as this road between two cotton properties) can be a continual source of infestation. Photo: Sandra Williams.

Table 1. *Herbicides registered for controlling weeds on non-agricultural areas. A range of commercial formulations may be available for each active ingredient. Refer to the product label for specific directions regarding the use of a product.*

Herbicide active ingredient	Concentration and formulation	Application rate	Comments
amitrole + ammonium thyocianate	250 g/L AC 220 g/L	0.28 – 4.5 L/100 L water	Check the label for details. Controls a wide range of plants from seedling grasses, at low rates, to perennial grasses at high rates. Controls young broadleaf plants.
diuron	500 g/L SC 900 g/kg WG	72-144 L/ha (Qld) 20-40 L/ha (NSW) 22 kg/ha (Qld) 40 kg/ha (NSW)	Check the label for details. Weeds controlled: Annual and perennial grasses and broadleaf weeds (except Nutgrass, Bindweed and Russian knapweed). Do not use in water-logged areas. Do not use in irrigation channels or drains unless all irrigation tail water and rainfall can be captured and held on farm. Channels must be flushed after application.
glyphosate	360 g/L AC 500 g/L AC 510 g/L AC	2-9 L/ha 1.44-6.48 L/ha 2.1-6.3 kg/ha	Check label for details Controls most weeds. Lower rates for annual grasses. Higher rates for perennials and broadleaves. Reduction in effectiveness may result if more than ¼ of the above ground portion of the weed is submerged at treatment.
glyphosate	450 g/L AC 540 g/L AC 680 g/kg WG	1.6-7.2 L/ha 1.35-6 L/ha 1-4.5 kg/ha	Check label for details Controls most weeds. Lower rates for annual grasses. Higher rates for perennials and broadleaves. Do not apply to weeds growing in or over water. Do not allow water to return to dry channels and drains within 4 days of application.
pendimethalin	330 g/L EC 440 g/L EC 455 g/L	4.5-9 L/ha 3.4-6.75 L/ha 3.3-6.5 L/ha	Check the label for details. Do not apply where waterlogging is likely to occur. If 25-50 mm rain has not fallen within 14 days the channel should be filled with water and allowed to stand for 1 day. The water in the channel should then be drained off and used to pre-irrigate cotton fields.
2,2-DPA	740 g / kg WP	10-20 kg / ha	Controls annual and perennial grasses. Controls rush and sedge, cumbungi, water couch.

Herbicide options

A range of herbicides is registered for controlling weeds on non-agricultural areas, roads, drains, and irrigation structures, as shown in Table 1. Always refer to the product label for specific use directions.

Weeds can be very difficult to control on irrigation structures with herbicides as:

- The herbicides may not be safe to use on cotton or other crops, and so must be applied in conditions that preclude drift to crops or movement in water,
- Soil incorporated residual herbicides are difficult to incorporate to irrigation structures, and may wash into cotton fields,
- Residual herbicides may need to be applied at very high rates, which makes them very expensive to apply,
- Herbicides may need to be applied in the "off-season" when channels are empty. Channels may have to be flushed before use to dilute high rates of residual herbicides,
- Structures may be large enough to make it difficult to apply herbicide to all parts of the structure. Specially designed spray booms are often used for channels and irrigation structures.
- Plants growing in water can not be treated with residual herbicides,
- The constantly changing water level in some channels makes it difficult to treat all weeds at the same time. Some supply channels may remain wet throughout the cotton season, making them very difficult to manage with herbicides, and
- Residual herbicide (diuron) can only be applied where all irrigation tailwater and rainfall can be captured and held on farm.

In using herbicides to manage weeds in channels, head-ditches and storages during the cotton season, it is essential to prevent the movement of herbicides into the crop, either as drift or in water from irrigation or rainfall. The risk greatly diminishes at the end of the cotton season, when the crop is no longer as susceptible to the herbicides. Rotation crops and pastures, however, may also be susceptible to damage from these herbicides, so care must be taken all year round.

A purpose-built sprayer, designed for spraying irrigation channels. Photo by Sandra Williams.

Drift can be reduced by applying herbicides with low pressure and high water volume, through low-pressure nozzles, with air assisted sprays and as shielded sprays. Minimising release height, avoiding high ground speeds and using larger droplets will decrease the risk of drift. The overwhelming influence on drift, however, is to only apply herbicides under suitable environmental conditions. Windy and dead-calm conditions are equally unsuitable for spraying and must be avoided. Don't be fooled that a gentle breeze in the tractor cabin equates to similar conditions outside!!

Contact (non-residual) herbicides

Contact, or knockdown herbicides, kill plants that are growing at the time of application. They are generally very effective on seedlings and young plants, but may be less effective on mature and perennial plants.

Glyphosate is generally regarded as the safest, easiest to use knockdown herbicide option for roads, channels and storages where both grasses and broadleaf weeds are present. It is effective on most annual and perennial weeds, but has the potential to cause considerable damage to conventional cotton plants, alternative crops pastures and riparian areas if it is applied inappropriately. Relatively light rates are required to kill most grass weeds, while heavier rates are needed for many broad leaf and perennial weeds. Glyphosate is a slow-acting herbicide. Complete death of weeds may occur up to two to three weeks after application.

Some formulations of glyphosate should not be applied to water or to weeds standing in water. Where glyphosate is applied to dry drains, there may be a requirement that water not be returned to these drains for some period after herbicide application.

Some formulations, such as Roundup® Bioactive are registered for use on aquatic areas, for controlling emerged weeds that may be standing in water. Always check the product label for specific directions on product use.

Roundup Ready Flex® cotton volunteer plants may be a problem along roadways and channels, as these plants have been modified to make them tolerant of glyphosate. Cotton varieties with the Roundup Ready Flex trait can not be controlled by glyphosate, and needs to be controlled using an alternative option, such as mechanical control or an alternative herbicide.

Repeated use of glyphosate to manage weeds over many years places high selection pressure on the weeds and will result in both species shift to weeds which are more tolerant of glyphosate and selection for resistance to glyphosate. It is essential to only rely on glyphosate as one of a range of tools for managing weeds in every situation, including roads, channels and water storages.

Selective grass herbicides may be very useful where grass weeds are the predominant weed problem along the edges of cotton fields. These herbicides are most effective against young, actively growing grass weeds. They may be ineffective when applied to mature or stressed grass weeds. Several of these herbicides are available, and are registered for use in cotton, so can be used without risk of damage to the cotton. Great care must be taken however, when using the grass herbicides near sensitive rotation crops such as sorghum, millet, and winter cereals.

The selective grass herbicides are also very prone to developing resistance and can only be used as an occasional management tool when supported by a range of other tools. See Section C, Herbicide Resistance in WEEDpak for more information on developing weed management systems that avoid herbicide resistance.

Residual herbicides

The residual herbicides provide longer-term control of weeds than the contact herbicides, but are difficult to apply to irrigation structures during the cotton season. They must be applied to dry soil. Residual herbicides are normally applied to irrigation structures in autumn after the final irrigation on the cotton. Channels must be flushed prior to the next irrigation to dilute any excessive levels of herbicide that may remain. Non-residual herbicides are generally used to control any weeds that emerge during the irrigation period.

For best results, the residual herbicides require either mechanical or water incorporation (rain or irrigation). Application and mechanical incorporation is easily undertaken on roadways, but may be very difficult to achieve on irrigation structures, and particularly on steep banks. Incorporation with irrigation is more easily achieved, but may wash much of the herbicide away from the target site.

Channels are regularly re-shaped and de-silted with excavators, graders, and delvers.

Mechanical control

Regular grading and upkeep of roadways and channels provides an effective, non-chemical means of weeds control. This may be combined with de-silting operations in channels when required. However, the silt may contain large numbers of weed seeds that will need later control. It is a useful strategy to leave the silt on roadways as much as possible, where emerging weeds can be more readily controlled.

Hand hoeing of channels is sometimes done where large weeds such as sesbania, bladder ketmia, the burrs or Roundup Ready Flex cotton volunteers need controlling in sensitive or inaccessible areas, or areas where spraying is not an option due to wind conditions.

Burning

In severe cases, where large weeds have grown out of control, burning has been used to remove the bulk of dead weed material. Burning may also kill many weed seeds, pests and diseases. Permits may be required for burning, particularly during the summer months.

Common weeds of roads and channels

Any weed can be a problem on roads and irrigation structures, but some species are more difficult to manage than are others. Among the more troublesome weeds are:

Brown beetle grass	*Leptochloa fusca*
Cumbungi	*Typha* spp.
Knotweed	*Perscaria* spp.
Nutgrass	*Cyperus rotundus*
Noogoora burr	*Xanthium occidentale*
Italian cocklebur	*Xanthium italicum*
Sesbania pea	*Sesbania cannabina*
Cowvine	*Ipomoea lonchophylla*
Bellvine	*Ipomoea plebeia*
Awnless barnyard grass	*Echinochloa colona*
Summer grass	*Digitaria ciliaris*
Caltrop	*Tribulus terrestris*
Spineless caltrop	*Tribulus micrococcus*
Couch	*Cynodon dactylon*
Downs nutgrass	*Cyperus bifax*
Volunteer cotton	

These weeds are generally problems because they;

- tolerate the herbicides normally used to control weeds on these areas, or
- grow in water, and so are difficult to treat with either contact or residual herbicides.

An irrigation channel heavily infested with brown beetle grass. The infestation has been sprayed with glyphosate and burned off, but will regrow.

Brown beetle grass is a major weed of irrigation channels and is increasingly becoming a problem in cotton where no residual herbicides are used. Plants produce a large amount of viable seed and can grow to form large tussocks that obstruct channels. Seeds from plants growing on channels are transported into fields in irrigation water and readily grow and establish in cotton fields.

Brown beetle grass is difficult to control on channels with most herbicides. Pendimethalin will control brown beetle grass, but is difficult to incorporate on irrigation structures. Brown beetle grass is easily controlled in-crop with the residual grass herbicides trifluralin, pendimethalin, metolachlor, and Zoliar. Brown beetle grass can be a problem in the furrows in fields where these products are applied in a band behind the planter, with no residual grass herbicide applied to the furrow.

Mechanical control is an option both in-channels and in-crop but this can be time consuming and expensive. Brown beetle grass is very difficult to control in-crop after crop canopy closure.

Brown beetle grass produces masses of seed that germinate and grow in moist places such as channels and irrigation furrows.

Cumbungi and knotweed are not generally problems in irrigation channels where the water level varies, but are more often problems in irrigation storages. Isolated plants are of little importance, but they are large plants, and can form dense mats that are almost impenetrable. They can be hosts to pests including feral pigs. Once established, they are very difficult to control with herbicides. When these weeds become a problem, they may need to be removed with excavators.

Nutgrass is difficult to control with either herbicides or mechanical control, regardless of its location. It not as big a problem in channels as it is in cotton, but can restrict water flow and cause the build-up of silt, and is able to spread with machinery and water movement. Nutgrass spreads primarily by tubers, which can float and be moved around in water. Any nutgrass patch can act as a source in infestation to cotton fields.

Cumbungi is a large plant that grows in water and is tolerant of glyphosate.

Nutgrass thrives in wet conditions. Nutgrass tubers move in water and are a constant source of infestation to cotton fields.

Knotweed can form an almost impenetrable mass.

The burrs, Noogoora burr and Italian cockleburr, are perennial problems where ever they occur. They can produce seed while very small, but can become very large plants, producing masses of seed. Their seed easily catches in clothing and cotton lint and can remain viable in the soil for many years.

The burrs are relatively easily controlled with herbicides, but their ability to germinate after every rainfall or irrigation event makes them a major nuisance. Burrs growing on irrigation structures may be a major source of seed infestation into cotton fields.

Italian cocklebur growing on the side of a channel. These plants are carrying a mass of seed, much of which may end up in the field. Note also the presence of sesbania and barnyard grass on the channel bank.

Sesbania is another potentially large weed that produces masses of seed. These seeds move in irrigation water and can easily move from irrigation channels into fields. Sesbania is relatively tolerant of glyphosate and difficult to control with residual herbicides on channels.

A heavy infestation of sesbania in a head-ditch. Sesbania was not common on this property, but seed has been introduced through the irrigation water. The weed will soon become established in the cotton field if it is not controlled.

Cowvine and **bellvine** are difficult to control in conventional cotton. Plants growing on channels and irrigation structures can be an important source of weed seed going into fields.

This channel bank is covered in cowvine plants. These plants are a source of weed seed for the cotton field.

Spread of seeds through irrigation water

Irrigation water can be an important source of weed infestation into cotton fields, and may include large numbers of weed seeds. When this water is being drawn from an external source, such as a river, the cotton grower has little control over the weed seed load in the water. Generally, however, the numbers of seeds introduced in irrigation water is not large in comparison with the numbers of seeds already present in the soil. A study on one field, heavily infested with cowvine, found that around 5500 cowvine seeds were introduced into the field from irrigation water over a single summer. However, this field already had approximately 2000 seeds/m^2, or 800 million cowvine seeds in the seedbank. The extra 5500 seeds per season are of little importance until the seedbank in the field is greatly reduced.

A study by David Hawkey found large numbers of grass seeds in irrigation water entering fields in the Macquarie Valley. Nevertheless, the introductions still amounted to only a small proportion of the total numbers of weed seeds already present in the fields.

Irrigation water is most important as a potential source of infestation of new weeds to a farm. In the example given above, 5500 seeds per season of a new weed species introduced to a field, would be a major problem and would soon see the weed well established in that field.

The problem of weed seed contamination in irrigation water is generally far worse when pumping floodwater. Some weed seeds are regularly falling into water from plants established on riverbanks etc., but most of these seeds move only a short distance. During a flood, there is the potential for weeds established away from the rivers to contribute large seed loads to the floodwater. Examples of this, were the introduction of velvetleaf to one property in the Gwydir watercourse country during the 1998 flood, and Downs nutgrass to a field on another property during the flood of February 2001, when flood water inundated a cotton field.

There are a number of factors that influence the number and species of seeds that are found in irrigation water. These factors include: soil type; cropping and weed control practices; drainage water return into the channel; distance from the river or main water source; the nature of the watershed; and the environment through which the irrigation channel passes. Weed management in and around channels is likely to influence the numbers and species of seeds that are introduced to fields in irrigation water. Studies have found that the length of time that weed seeds remain viable in fresh water may range from a few months to five or more years, depending on the species concerned.

Channels with poor weed control usually contribute the largest number of seeds to the irrigation water. As water moves through the channel system, the number of seeds in the water is likely to increase from plants growing along the channel banks, seeds blowing into open channels, and by return flows from irrigated fields. The greater the distance that water travels in channels, the longer the exposure to weedy banks. Irrigation is capable of carrying weed seeds over long distances and has the potential to introduce new weed species to a field and a region.

Only one viable seed is needed to start a weed infestation in a field. For this reason, the control of weeds in and around channels and drainage ways should receive as much attention as the weeds that occur in the paddock.

Summary

Weeds are undesirable on roads and irrigation structures, as they are a source of weed infestation for cotton fields and can negatively impact on the irrigation system. Control is equally important on channels and structures that may not be in use. All structures should be given the same importance as cotton fields.

A number of strategies can be used to reduce the movement of weed seeds into cotton fields.

1. Carefully monitor irrigation structures for the presence of weeds that are not commonly found on the farm. These species deserve special attention. Elimination of a single plant may remove the need to manage infested fields in later years.
2. Keep all irrigation water sourced from off-farm in a water storage for as long as possible before use (this is especially important with floodwater), in order to allow the weed seeds to sink during storage, effectively removing them from the irrigation water.
3. Flush dirty channels before use, removing most weed seeds into the water storage system.
4. Treat channels with a residual herbicide after the final irrigation.
5. Use non-residual herbicides as often as necessary to control weeds that emerge during the cotton season.

CONTROLLING VOLUNTEER COTTON

Graham Charles[1], Grant Roberts, Sarah Kerlin and Mark Hickman[2]

([1]NSW Dept. Primary Industries, Qld. Dept. Primary Industries)

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Introduction

The control of unwanted cotton in the farming system is an important component of rotational flexibility and management and an essential component in farm hygiene. Three types of cotton are often required to be controlled:

- seedling volunteer cotton,
- established cotton, and
- regrowth or 'ratoon' cotton.

Controlling volunteer cotton on all areas of cotton farms and roadsides is highly desirable as they are, in effect, a weed. Seedling volunteers are often scattered across furrows and plant lines within fields, and rarely yield as well as newly planted seed due to seedling disease and early emergence in cool conditions. All three types of volunteers can also be found in channels and along and roadsides creating a farm hygiene problem, especially around module pads, although less so with round bales. They create problems for resistance management of Bt cotton, reduce seed purity and can act as early host plants for pests such as spider mites and aphids. In addition, susceptible varieties can interfere with disease management strategies.

The use of cotton varieties including the Roundup Ready Flex® trait also eliminates the use of glyphosate as a herbicide for managing the volunteers with this gene. The control of seedling volunteer cotton also provides an opportunity to rotate herbicide chemistry modes of action or to use cultivation, which are both important components of an integrated weed management program.

Volunteer cotton plants with the Roundup Ready Flex® trait can be highly problematic where glyphosate is used as the primary method of weed control.

Controlling Seedling Cotton

Volunteer cotton plants are plants that have germinated, emerged and established unintentionally. Volunteers normally come from seed cotton (lint + seed) but can also establish directly from fuzzy seed (ginned seed) or planting seed (delinted seed). The source of the seed cotton on cotton fields is mainly from previous cotton crops in which the seed cotton has fallen from the plant to the ground and from around module pads where seed cotton is lost during the picking process. Seed cotton is also distributed over cotton farms and surrounding roadsides at picking when large volumes of harvested cotton are transported to cotton gins and seed cotton is lost during the transport process.

Volunteers established from fuzzy seed are usually the result of seed escapes during the transportation of fuzzy seed from gins to end point use. These destinations include crushing plants and stock feeding points.

It is also common that planting seed can be spilt accidentally in transportation on-route to, or within fields, creating a ready source of volunteers.

Cultivation and herbicides are the two most common methods of controlling volunteer cotton seedlings. Both require the cotton seedlings to have germinated and emerged before control can occur. This is particularly important if the volunteer seedlings being controlled have the Roundup Ready Flex® gene and the following crop is cotton. Glyphosate will not control these seedlings and an alternative herbicide option must be used. Cultivation will remove the in-furrow volunteers but miss the volunteers situated in the plant line. Rainfall or pre-irrigation is required to germinate these volunteer plants prior to planting, after which effective control can be attempted.

Pre-irrigating cotton should be the option of choice on back-to-back fields where volunteers are likely to be a problem. This is especially true following a dry period, when much of the fallen seed is still likely to be viable. Pre-irrigation will germinate the bulk of the volunteer seed, allowing a herbicide to be used to control these volunteers prior to planting the crop.

Established Roundup Ready Flex® cotton volunteers on a farm road. These plants have grown from seed cotton lost during picking

Cultivation

Broadacre cultivation readily controls seedling cotton volunteers in most soil conditions, as the root systems and hypocotyls of seedlings are easily destroyed by the cultivation process. Any damage that occurs below the cotyledons kills the seedlings, as there are no growing points from which the plants can recover. Effective cultivation only occurs if the cultivation implement cultivates both the furrow and hill, avoiding leaving uncultivated strips.

Cultivation will also manage other weeds besides volunteer cotton seedlings. This non-herbicide method of weed control is an essential part of an Integrated Weed Management system (refer to the Integrated Weed Management (IWM) Guidelines in section B3 of WEEDpak). The disadvantage of cultivation is that it only controls established seedlings, is slow, and can cause moisture loss or soil damage if conducted at the wrong time (refer to SOILpak for more information about the potential for soil damage from cultivating wet soil).

In addition, volunteers mainly establish in periods very close to planting, which is an inappropriate time to be conducting large scale tillage operations. Nevertheless, cultivation is a valuable integrated weed management tool and should always be considered as an option for controlling difficult weeds such as volunteer cotton.

Broadacre cultivation is an effective tool for controlling volunteer cotton seedlings and larger plants.

Herbicides for seedling cotton

The broad spectrum herbicide glyphosate has often been used extensively to control volunteer cotton seedlings. Control has either been deliberate or inadvertent when targeting other weeds prior to cotton planting, as a fallow spray, or within crop as a shielded spray. Glyphosate rates of 1.2 L/ha (450 g/L.) will control seedling cotton at the 1st and 2nd true leaf stage.

However, the widespread adoption of cotton varieties including the Roundup Ready Flex® trait, which are genetically modified to tolerate glyphosate, eliminates the use of this herbicide as a control tool for managing these seedlings.

As a result, alternative herbicides that control the volunteers but do not have residual affects to subsequent crops, including cotton, need to be utilised. Table 1. provides a list of herbicides registered for controlling cotton seedlings.

Cotton seedlings with the Roundup Ready Flex® trait readily establish anywhere glyphosate is used as the primary method of weed control.

Table 1. *A guide to the herbicides registered for controlling volunteer cotton plants, including Roundup Ready Flex® volunteers. Some products may be available under other product names.*

Product	Active ingredient	Mode of action group	Applied rate per ha	Plant growth stage	Situation	Plant back to cotton
Alliance®	amitrole 250 g/L + paraquat 125 g/L	L + Q	2-4 L	≤ 6 – 8 leaf	Fallow	Nil
Amitrole T	amitrole 250 g/L + ammonium thiocynate 220 g/L	Q	4.3-5.6 L	Cotyledon - 8 leaf	Fallow	Nil
Broadstrike®	flumetsulam 800 g/kg	B	50 g	Pre-emergence	Pigeon peas	9 months
bromoxynil#	bromoxynil 200 g/L	C	1-1.5 L	Cotyledon - 6 leaf	Fallow & non-crop	Nil
Hammer®	carfentrazone 240 g/L	G	50-75+ ml 75-100* ml	2 – 6 leaf	Fallow	Nil
Liberty®/Basta®	glufosinate-ammonium	N	3.75 L	2 – 6 leaf^	Fallow	14 days
metribuzin#	metribuzin 750 g/kg	C	470 g	Seedling stage	Pigeon peas¤	12 months
paraquat + diquat#	paraquat 135 g/L+ diquat 115 g/L	L	1.6-2.4 L 2.4-3.2 L	1 – 4 leaf 5 – 9 leaf	Fallow	Nil
Sharpen®	saflufenacil 700 g/kg	G	9g 17g 26g	< 2 leaf < 4 leaf < 26 leaf	Fallow	42 days
fluroxypyr#	fluroxypyr 333 g/L	I	450 ml 600 ml	2 – 6 leaf 5 – 7 leaf	Fallow	14 days 28 days
Valor®	flumioxazin 500 g/kg	G	45 g	≤ 4 leaf	Fallow	Nil

 # Sold under various trade names.
+Rate for varieties not including the Roundup Ready Flex trait when added to the recommended rate of glyphosate.
** Rate for varieties including the Roundup Ready Flex trait.*
^ Will not control cotton volunteers with the Liberty Link® trait.
¤ Only on some metribuzin labels, so check the product label for details.

Other herbicides with activity on seedling cotton

While a pre-planting spray may be applied to control emerging cotton seedlings, it is also common to apply a fallow spray to control a wide range of weeds that may include cotton seedlings. Consequently, a range of herbicides were screened for efficacy against seedling volunteers at 4 and 8 nodes of growth (Table 2). These herbicides were selected on their likely efficacy of controlling seedling cotton with minimal residual carryover to either cotton or rotation crops. Glyphosate and mixtures that utilised glyphosate as the main active ingredient were excluded from testing so that results could be inferred for Roundup Ready Flex® volunteers, as well as conventional and Liberty Link® volunteers (with the exception of Basta®, which is ineffective on Liberty Link volunteers).

The results indicate that Spray.Seed®, Hammer® and bromoxynil would be most effective in controlling seedling cotton (including Roundup Ready Flex® volunteers) at both 4 and 8 leaf growth stages.

Surpass™, Basta®, Starane® and MCPA amine are also good options but are likely to be less reliable, giving good to very good control at Narrabri but poorer control at St George. In addition (excluding Basta), there are spray management considerations with these herbicides, including drift and plant-back times to cotton (refer to Managing Weeds in Cotton, section B2 of WEEDpak).

Both Spray.Seed and Hammer are contact herbicides, with no residual carryover and their use patterns have been designed as pre-emergent knockdowns. The active components of Spray.Seed (paraquat and diquat) are from the bipyridyl group of herbicides (Group L), which inhibit photosynthesis at photosystem I. Hammer (carfentrazone) is a member of the aryl triazoline group (Group G), which inhibits protoporphyrinogen oxidase. Both herbicides differ in modes of action to glyphosate, which inhibits EPSP synthase (group M) and these differences are inportant, as it allows these herbicides to control glyphosate tolerant cotton and also control weeds using a different herbicide mode of action.

Rotating herbicide chemistry (modes of action) is an important component of preventing herbicide resistance. Hammer can also be mixed with glyphosate or Spray.Seed, improving the weed spectrum it controls. In theory, a mixture of Hammer (at an adequate rate) and glyphosate would control Roundup Ready Flex seedling volunteers, as well as the usual weeds glyphosate is effective on.

Excellent spray coverage is essential for adequate control with all contact herbicides. This generally means high water volumes are required to get the best out of the herbicides (e.g. 100L/ha).

Table 2. Effect of herbicides on seedling cotton at St George (4 true leaves) and Narrabri (8 true leaves) in 2001-02.

Herbicide	Rate/ha (kg or L)	Percentage Control#	
		St George 4 true leaves	Narrabri 8 true leaves
Unsprayed	-	0	0
Buctril 200 (200 g/L)	4	100	100
Hammer 240 EC (240 g/L)	0.15	100	100
Spray.Seed 250 (135 + 115 g/L)	2	100	100
Basta (200 g/l)	3	92	96
Surpass (300 g/L)	2	0	95
Starane 200 (200 g/L)	1	25	95
MCPA 500 (500 g/L)	2	30	88
Gesagard 500 SC (500 g/L)	3	19	10
Goal CT (240 g/L)	0.25	15	0
Banvel 200 (200 g/L)	1.4	2	0
Lontrel (300 g/L)	0.15	0	0
Diuron DF (800 g/kg)	1.9	0	0
Nu-Tron 900 DF (900 g/kg)	1.9	0	0
Garlon (600 g/L)	0.15	0	0

 # Plants were still considered alive if they had green foliage or stems and if they regrew at any stage.

Using the double-knock strategy to control cotton seedlings

The double-knock strategy, of applying a herbicide at full rate and then a 2nd herbicide again at full rate around 7 to 14 days after the first herbicide has become a well accepted way to control some of the more difficult weeds. The value of this approach for controlling larger cotton seedlings was tested with 9 day and 28 day respray intervals, as shown in Table 3.

The results for all herbicides were disappointing, with the double-knock approach making little difference. Allowing the plants to regrow some green leaf after the first application did not improve the control (the double knock at 28 days).

These poor results emphasise the need to control cotton seedlings while they are small, ideally at 2 - 4 nodes. These small seedlings can be readily controlled with a range of herbicides, but larger seedlings are difficult to control, even with a double-knock strategy.

A double-knock of Spray.Seed, applied 9 days apart, gave good control of most cotton seedlings, but there was some subsequent regrowth.

Table 3. Exploring the value of the double-knock strategy for controlling volunteer cotton seedlings.

Herbicide	Applied at	Percentage Kill#				
		7 DAS	23 DAS	37 DAS	59 DAS	133 DAS
Unsprayed	-	0	0	0	0	0
Basta (200 g/l) 3.75 L/ha	Day 0	61	8	10	0	10
	Days 0 & 9	80	60	50	27	43
	Days 0 & 28	75	8	0	0	0
Bromicide 200 (200 g/L) 1.5 L/ha	Day 0	25	1	11	0	15
	Days 0 & 9	30	3	10	0	0
	Days 0 & 28	30	0	0	0	23
Hammer 240 EC (240 g/L) 60 ml/ha	Day 0	35	0	9	0	25
	Days 0 & 9	40	0	18	0	0
	Days 0 & 28	40	0	24	0	0
Spray.Seed 250 (135 + 115 g/L) 3.2 L/ha	Day 0	68	46	64	61	74
	Days 0 & 9	100	84	86	67	81
	Days 0 & 28	100	76	90	52	72

 # Plants were still considered alive if they had green foliage or stems and if they regrew at any stage. Some plants that initially appeared to be dead later regrew.

Controlling established cotton

Occasionally, cotton plants become well established before there is opportunity to control them due to unforseen circumstances such as:

- Adverse weather,
- Hail,
- Poor plant establishment,
- Major insect problems,
- Unmanageable weeds,
- Disease problems, or
- Changing economics.

When these situations occur, the cotton grower may wish to abandon the field and replant with an alternative summer crop or a winter crop. Conventional mechanical methods of destroying the cotton would involve mulching, root cutting and cultivation. These methods are very effective at controlling established cotton, but, in some circumstances the use of cultivation is undesirable. Examples of this could include dryland crops that need to be controlled without cultivation due to the increased risk of soil erosion and the need to conserve moisture. Herbicide control may be an option provided the *Helicoverpa* pupae have not started diapausing under the crop.

Herbicides for controlling established cotton

Established cotton is very difficult to control with herbicides alone, although the large leaf area does provide an opportunity to attain good coverage of the herbicide. Table 4 provides a list of herbicides that were screened for the control of established cotton. These herbicides were initially applied as a 100% over-the-top band. This initial application did not appear to work due to poor spray coverage and penetration, with only the tops of the plants being affected. A second application was made using side directed spray nozzles on droppers and one nozzle over the top.

The results suggest that Starane® and a glyphosate + 2,4-D amine mixture (Surpass™) can provide some control of established cotton. The glyphosate + 2, 4-D amine mix is also very effective at controlling a large range of broadleaf and grass weeds at the same time.

However, none of these options is registered for this use. It is important to remember with 2,4-D amine that up to 28 days is required before replanting some crops and 15mm of rain is required in dry soils before the commencement of this plant back period. Starane® has a plant back period of 7-28 days depending on the crop. Alos, as with all Group I herbicides, the risk of spray drift onto susceptible crops is a major hazard to be avoided and thorough decontamination of all spray equipment is critical.

Table 4. *Percentage of dead cotton plants after applying two applications of herbicide. Note that the Roundup treatments would have been ineffective on cotton varieties with the Roundup Ready Flex trait.*

Herbicide treatments	% Dead cotton plants
Starane® (4L/ha)	100
Roundup CT Xtra (2L/ha) + Surpass™ (4 L/ha)	94
Roundup CT Xtra (2L/ha) + Surpass ™ (2 L/ha)	80
Roundup CT Xtra (2L/ha) + Glean (25g/ha) + BS1000# (200ml/ha)	22

 # A non-ionic surfactant.

Using the double-knock strategy to control cotton plants

The herbicides used in Table 3 were also used in double-knock treatments to cotton at 16 and 24 nodes (Tables 5 & 6), with some extra treatments added for Spray.Seed at 24 nodes.

Basta, Bromicide 200 and Hammer gave poor control of these much larger cotton plants, as might be expected, as the plants were far larger than the size specified on the product labels.

A single application of Spray.Seed was also ineffective for controlling cotton plants, and the double-knock was equally ineffective when the applications were less than 7 days apart.

However, Spray.Seed gave surprisingly good control with the double-knock at 30 days apart for 16 node cotton, and 7 days apart for 24 node cotton. Part of the reason for the good results was the very large leaf area of the plants at this age, allowing a large quantity of herbicide to affect the plants. Interestingly, applying Spray.Seed twice on the same day gave as good a result as the best double-knock.

Defoliating cotton plants

In some situations, using a double-knock application of a paraquat/diquat mix, such as Spray.Seed, to defoliate volunteer cotton plants may be a useful strategy, killing some plants, but also buying time. Applying Spray.Seed to cotton plants will defoliate the plants, burning off most or all the leaves, setting plant growth back by many weeks. This will greatly reduce the growth rate of the plants, greatly reduce the moisture use of the plants, and greatly reduce their fruit production, reducing the potential for new seeds and problems further down the track. If plants already have green bolls, it is likely that the herbicides will sterilize the seed in the bolls.

These plants can then be removed by cultivation at a later date before they resume normal growth.

A double-knock of Spray.Seed, applied 7 days apart gave excellent control of large, 24 node, cotton plants.

Many plants regrow 34 days after a double-knock of Spray.Seed 21 days apart, but the herbicide effectively set the plants back by at least 6 weeks, allowing time for an alternative option to be used at a later date.

Table 5. Exploring the value of the double-knock strategy for controlling established cotton plants at 16 nodes of growth.

Herbicide	Applied at	Percentage Kill#		
		7 DAS	23 DAS	37 DAS
Unsprayed	-	1	0	9
Basta (200 g/l) 3.75 L/ha	Day 0	0	0	4
	Days 0 & 9	0	3	6
	Days 0 & 30	5	3	18
Bromicide 200 (200 g/L) 1.5 L/ha	Day 0	0	0	9
	Days 0 & 9	0	0	8
	Days 0 & 30	0	0	23
Hammer 240 EC (240 g/L) 60 ml/ha	Day 0	0	0	6
	Days 0 & 9	0	0	5
	Days 0 & 30	0	0	6
Spray.Seed 250 (135 + 115 g/L) 3.2 L/ha	Day 0	45	0	14
	Days 0 & 9	45	57	36
	Days 0 & 30	48	94	92

 # Plants were still considered alive if they had green foliage or stems and if they regrew at any stage.

Table 6. Exploring the value of the double-knock strategy for controlling established cotton plants at 24 nodes of growth.

Herbicide	Applied at	Percentage Kill# 76 DAS
Unsprayed	-	9
Basta (200 g/l) 3.75 L/ha	Day 0	8
	Days 0 & 7	15
	Days 0 & 21	16
Bromicide 200 (200 g/L) 1.5 L/ha	Day 0	11
	Days 0 & 7	3
	Days 0 & 21	8
Hammer 240 EC (240 g/L) 60 ml/ha	Day 0	14
	Days 0 & 7	6
	Days 0 & 21	9
Spray.Seed 250 (135 + 115 g/L) 3.2 L/ha	Day 0	31
	Days 0 & 2	21
	Days 0 & 4	23
	Days 0 & 7	95
	Days 0 & 21	70
	Days 0, 2 & 4	90
	Day 0 & 0	96

 # Plants were still considered alive if they had green foliage or stems and if they regrew at any stage.

Controlling regrowth or 'ratoon' cotton

'Ratoon' cotton is cotton that has regrown from the root stock from a previous season. The control of ratoon cotton is important for the management of insects and diseases, as both can be harboured over winter by the ratoon cotton, allowing an easy method of infection for future crops. The pathogens that cause the diseases black root rot, verticillium wilt, alterneria leaf spot, fusarium wilt and bunchy top are all capable of transferring easily from one season to the next via ratoon cotton. In addition ratoon plants can act as hosts for aphids, spider mites, whitefly and early food for *Helicoverpa*.

In theory, ratoon cotton should not occur due to the requirement of harvested cotton to be controlled with adequate cultivation and soil disturbance as soon as practical after picking. This usually involves some sort of mulching and/or root cutting, followed by cultivation to destroy the cotton root system. In conducting this cultivation, an additional aim is to destroy over-wintering helicoverpa pupae. This pupae control is a frontline strategy in managing insecticide resistance for the cotton industry and is mandatory if growing cotton varieties with the Bollgard® technology (refer to ENTOpak and MACHINEpak for information on pupae busting).

However, in some seasons, fields may become flooded soon after picking or adverse weather may make cultivation undesirable. In these scenarios, the use of a herbicide would seem appropriate to manage cotton immediately after picking. Unfortunately, due to the large root system on ratoon cotton and relatively small leaf areas, no herbicides are likely to give effective control and no herbicides registered for this purpose.

A limited range of herbicides were evaluated for the control of ratoon cotton (Table 7), but none were effective. A double-knock application may have been more successful, but it is clear that ratoon cotton is extremely difficult to control with herbicides alone due to the small leaf area available for herbicide absorption compared to the large root system available for carbon and nutrient supply that enables the plant to continue growing.

Mulching harvested cotton.

Root cutting prior to cultivation to stop cotton ratooning.

Ratoon cotton is a problem wherever it occurs. This ratoon will need to be controlled with cultivation and hand hoeing.

Table 7. *The effect of selected herbicides on ratoon cotton. Herbicides were applied 25 days before the first irrigation. The first assessment occurred 10 days before irrigation and second assessment 20 days after.*

Herbicide	1st assessment % regrowth	2nd assessment % regrowth
Unsprayed	80%	95%
Roundup CT Xtra 4.6 L/ha	47%	93%
Basta 5 L/ha	53%	92%
Starane 2 L/ha	7%	91%
Starane 4 L/ha	5%	92%
Bromoxynil 3 L/ha	37%	93%
Prometryn 6 L/ha + DC trate 2 L/ha	47%	94%

Summary

Volunteer cotton is problematic wherever it occurs, causing a variety of problems including harbouring pests and diseases.

Cultivation is an effective and efficient method of controlling all types of volunteer cotton, seedling, established and ratoon but is not always a practical solution.

A range of herbicides is registered for controlling seedling cotton and these herbicides are generally most effective on small seedlings.

Larger plants are very difficult to control with herbicides and no herbicides are registered for controlling plants larger than 9 nodes in size.

Ratoon cotton needs to be controlled with mechanical methods, as no herbicides are effective for these plants.

PLANT PROTECTION INTERACTIONS WITH WEEDS

Stephen Johnson[1], Leah MacKinnon and Susan Hazlewood

([1]Dept. Primary Industries)

Introduction

Weeds may act as hosts for both insects and pathogenic organisms that have adverse impacts on cotton production. Integrated weed management practices will assist in managing these problems.

The interaction between weeds and insects has been examined in the articles Integrated pest management guidelines for Australian cotton, and in particular, Support document 4. Cotton insect pests and their weed hosts, both in ENTOpak.

The interaction between weeds, pathogens and cotton diseases is outlined below. For more details on weeds and diseases, the reader is referred to the Integrated Disease Management Guidelines. Details of all these publications are given below.

Weeds, pathogens and cotton diseases

Apart from the obvious effects of weeds on cotton production and yield, weeds may also harbour pathogenic organisms responsible for many of the diseases associated with cotton production. Weeds may act as alternative hosts for some cotton pathogens (Table 1) and enable the survival of the pathogen during the period between subsequent cotton crops. Bladder ketmia, for example, can act as an alternative host for the pathogens that cause Verticillium wilt, Fusarium wilt and Alternaria leaf spot of cotton.

The presence of a pathogen on a weed host is not always obvious and it is possible that the symptoms normally associated with the disease may not be apparent (a symptomless weed host). Sesbania pea, bladder ketmia and dwarf amaranth are known to be symptomless hosts of the Fusarium wilt pathogen.

An infected weed can also contribute to the dispersal of a plant pathogen. The burrs of noogoora burr carry the Verticillium wilt pathogen, enabling wide dispersion of the pathogen by animals or through irrigation channels, rivers and streams, and flood waters.

Similarly, volunteer cotton plants and cotton regrowth must also be considered as significant pathogen hosts in and around cotton crops. Control of volunteers and ratoon cotton is essential to prevent the further spread of disease (see Controlling volunteer cotton section F4 in WEEDpak).

Further reading

Evans, G. (1971). Influence of weed hosts on the ecology of *Verticillium dahliae* in newly cultivated areas of the Namoi Valley, New South Wales. *Annals of Applied Biology*, **67**, 169- 175.

Mensah, R., Dillon, M., Kahn, M., Tann, C. and Wilson, L. (1999). *Support document 4. Cotton insect pests and their weed hosts*. ENTOpak, Australian Cotton CRC, Narrabri.

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Integrated Disease Management Guidelines (2002). Australian Cotton CRC, Narrabri.

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***Table 1.** Weeds known to be hosts of cotton pathogens*

WEED SPECIES		PATHOGEN			
Common Name	Scientific Name	*Alternaria macrospora*	*Verticillium dahliae*	*Fusarium oxysporum* f.sp. *vasinfectum*	Black Root Rot
Amaranth dwarf	*Amaranthus macrocarpus*		✓✓	✓✓	
Amaranth redroot	*Amaranthus retroflexus*		✓		
Anoda weed	*Anoda cristata* (m)	maybe	✓		
Bathurst burr	*Xanthium spinosum*		✓✓		
Bellvine	*Ipomoea plebeia*		*		
Bindweed Australian	*Convolvulus erubescens*		✓✓		
Bindweed black	*Fallopia convolvulus*		*		
Blackberry nightshade	*Solanum nigrum*		✓		
Bladder ketmia	*Hibiscus trionum* (m)	✓✓	✓✓	✓✓	
Burr medic	*Medicago polymorpha*		✓✓		maybe
Cobler's pegs	*Bidens pilosa*		*		
Common joyweed	*Alternanthera nodiflora*		*		
Cotton regrowth	*Gossypium hirsutum* (m)	✓	✓✓	✓✓	✓✓
Cowvine/Peachvine	*Ipomoea lonchophylla*		✓		
Dead nettle	*Lamium amlexicaule*		✓		definitely not
Dock curled	*Rumex crispus*		✓✓		
Gooseberry wild/Chinese lantern	*Physalis minima*		*		
Groundcherry perennial	*Physalis virginiana*		*		
Groundcherry/Annual ground cherry	*Physalis ixocarpa*		✓✓		
Mallow small flowered	*Malva parviflora* (m)	maybe	✓		
Malvastrum spiked	*Malvastrum americanum* (m)	maybe			
Medic	*Medicago* spp.		✓✓		maybe
Mintweed	*Salvia reflexa*		✓✓		
Noogoora burr	*Xanthium occidentale*		✓✓		
Nutgrass	*Cyperus rotundus*				definitely not
Pigweed Red	*Portulaca oleracea*		✓✓		
Purpletop	*Verbena bonariensis*		✓✓		
Saffron thistle	*Carthamus lanatus*		✓		
Sesbania pea	*Sesbania cannabina*			✓✓	
Sowthistle common/Milkthistle	*Sonchus oleraceus*				
Sunflowers volunteer	*Helianthis annuus*		✓✓		
Thornapple common	*Datura stramonum*		✓		✓✓
Thornapple fierce	*Datura ferox*		✓✓		
Tobacco wild	*Nicotiana* spp.		✓✓		maybe
Turnip weed	*Rapistrum rugosum*		✓✓		
Turnip wild	*Brassica* spp.		✓		
Variegated thistle	*Silybum marianum*		✓		
Velvetleaf	*Abutilon theophrasti* (m)		✓✓		✓✓
Verbena trailing	*Verbena supina*		*		

Key

✓✓ *HOST – definite*
✓ *HOST – indications*
blank unknown
* *in other species of the same genera*
(m) weeds related to cotton (Malvaceae family)

MANAGING PROBLEM WEEDS

Introduction

While all weeds that occur in cotton are problems that must be dealt with, some weeds are far more difficult to control than others. Nevertheless, most of these difficult weeds can be adequately managed in the cotton farming system with an integrated management system, using herbicides, cultivation and chipping in conjunction with other management tools. These weeds are often problems in newly developed cotton blocks, but become less of a problem over time. However, there is a group of problem weeds that are not controlled with normal farming practices. These weeds can spread and become progressively worse year after year, in spite of the cotton grower's efforts.

Specific management strategies are required to manage these problem weeds.

Contents:

H2. Managing Cowvine in Cotton

Cowvine is an annual weed that is a problem both in crops and in fallows. It is not easy to control in a farming system due to a number of characteristics including: strong seed dormancy; long seed life in the seedbank; ability to germinate rapidly after rain, all year round; rapid seedling growth; and a twining growth habit.

Post-emergence applications of diuron and prometryn consistently give the best control of cowvine of the herbicides normally used in cotton. Glyphosate can be effective in controlling cowvine seedlings in conventional and Roundup Ready cotton. Glyphosate is most effective on actively growing cowvine seedlings. Good control of older, actively growing plants is possible with glyphosate.

An effective cowvine management system will use all the available control options (cultivation, chipping and herbicides) in combination. Management of this weed will be an on-going process over many seasons.

H3. Managing Nutgrass in Cotton

Eight different nutgrass species are commonly found in or around cotton fields. These species are quite different in their ability to spread from seed or rhizomes, and consequently require specific management strategies. Positive identification of the problem species is essential as the first step in management. Identification material for these species is given.

A range of management tools is available to manage these weeds. These tools include residual and contact herbicides, cultivation, and crop competition. There are also some management practices that can exacerbate a nutgrass problem and should be avoided whenever possible. Management of nutgrass needs a long-term approach, as these weeds will not be eliminated by any single management option. A successful management program will include all the management tools, used in combination as opportunity arises.

Glyphosate and Zoliar® herbicides have given the most effective control over time. Glyphosate should ideally be applied in-crop twice each season. Attention to machinery hygiene can be pivotal in a successful management program.

H4. Managing Polymeria (Take-all) in Cotton

Polymeria is a deep rooted, rhizomatous, perennial weed that spreads from seeds and rhizomes. It tolerates and can be spread by normal cultivation practices.

No herbicides are registered for controlling polymeria. A permit must be obtained from the Australian Pesticides & Veterinary Medicines Authority before using a herbicide to control polymeria in any situation.

Polymeria can best be managed in cotton with repeated applications of glyphosate on actively growing polymeria, applied through well constructed shields, used under appropriate conditions. Glyphosate should be spot-applied to the polymeria patches to improve crop safety. The addition of Pulse Penetrant or a non-ionic surfactant may improve spray efficacy. Good crop agronomy is also important, resulting is competitive, strong cotton.

Polymeria growing in fallow can be controlled with glyphosate on actively growing patches and with fluroxypyr (eg. Starane) in autumn. Grazon may be useful for controlling polymeria in fallows that are not going back to cotton. Imazapyr (eg. Arsenal) may be useful for controlling polymeria on non-cropping and waste areas.

H5. Managing Bellvine in Cotton

Bellvine is an annual weed that is difficult to control in cotton. It is an aggressive, highly competitive weed that can grow through and over a cotton crop and can tangle inter-row and harvesting equipment. Very high densities of bellvine seedlings can emerge with the cotton crop, and successive germinations may occur throughout the season.

None of the pre-emergence residual herbicides were effective in controlling bellvine. Best results were achieved with trifluralin, diuron and Zoliar. The 4-leaf stage Roundup Ready Herbicide application was effective in controlling bellvine seedlings in Roundup Ready cotton. Moderate infestations of bellvine can be managed with the combination of pre-planting residuals and in-crop applications of Roundup.

Directed applications of diuron and prometryn were relatively effective in controlling bellvine seedlings later in the season in-crop. Both mid-season and lay-by applications of residuals may be required in combination with the 4-leaf Roundup Ready Herbicide application to control bellvine in a heavy infestation. Directed applications of Roundup were not effective in controlling bellvine seedlings later in the season.

An effective bellvine management system will use all the available control options (cultivation, chipping, herbicides, rotation and fallows) in combination, with both contact and residual herbicides used in-crop.

Note. Roundup Ready Herbicide is not registered for controlling bellvine in cotton.

H6. Managing Caustic Weed in Cotton

Caustic weed is an annual weed of cotton that competes for nutrients and water, and at high densities can reduce yields. It is a persistent weed that may become more problematic in reduced input systems.

Stomp and diuron gave the best control of the residual herbicides, with diuron giving good post-emergence control as well as some pre-emergence control of caustic weed. Glyphosate (Roundup CT) also gave good post-emergence control of caustic weed in an irrigated field.

An integrated weed management system including inter-row cultivation, residual herbicides and glyphosate should effectively control this weed. A mid-season directed application of diuron may be a useful tool in fields where no pre-planting residual herbicides are used.

H7. Managing Mintweed in Cotton

Mintweed is a minor annual weed of cotton that can emerge in large numbers at or soon after crop emergence. Mintweed seedlings grow more rapidly than cotton seedlings in spring conditions and can compete for sunlight, nutrients and water.

A pre-planting combination of Dual and Diuron gave the best residual control of mintweed. Atrazine and simazine also gave good residual control of mintweed, although they can not be safely used in cotton.

Glyphosate gave good post-emergence control of mintweed in cotton, and should be an effective management option for this weed in Roundup Ready Flex cotton crops.

H8. Managing Lippia in the Cotton Farming System

Lippia is a highly undesirable, invasive weed that is negatively impacting the grazing industry and the riparian zone. Once established, lippia competes very strongly with all other species, often resulting in almost pure lippia stands. Lippia should not be allowed to establish in the cotton industry. Particular care must be taken to ensure that lippia doesn't establish on irrigation structures as its presence is likely to lead to the failure of these structures.

Lippia should be controlled with cultivation where appropriate, or repeated applications of Lantana 600 on non-crop areas, or glyphosate on fallows. Glyphosate plus metsulfuron is the preferred option on fallows on non-alkaline soils, where cotton will not be a following crop.

2,4-D amine may be used to control lippia in pastures provided that there is no risk of spray drift to sensitive crops such as cotton.

H9. Managing Flaxleaf Fleabane in Cotton

The success of fleabane in the cotton system can be attributed to its ability to emerge in different seasons, relative tolerance to glyphosate and its prolific fecundity. Flaxleaf fleabane seedlings can establish in fallows and under crops at any time of year, running up to head in the warmer months. This weed is most problematic in zero-tillage situations.

A long term (2 – 3 years), whole farm, integrated approach is needed for its effective control. It can be controlled using a combination of contact and residual herbicides, together with crop competition, cultivation and spot-spraying. Control can be improved by using a double-knock approach. The best control was observed with a tank-mix of glyphosate and Tordon 75-D followed by Spray.Seed (double-knock) in combination with a residual herbicide. However, Tordon 75-D can't be used in or around cotton.

The cotton herbicides, diuron, prometyrn and Convoy all gave effective residual control of fleabane and could be used in cotton in combination with cultivation.

Fleabane should be managed in all crop and fallows as well as non-crop areas, such as roads, irrigation channels and fence lines, to prevent re-infestation into the cropping area.

H10. Managing Feathertop Rhodes Grass in Cotton

Feathertop Rhodes grass is becoming increasingly prevalent in cropping systems in the northern region and is a major problem in central Queensland due to its apparent tolerance to glyphosate, and competitiveness in minimum and no-till, glyphosate based cropping systems.

It is a small-seeded annual species, so the key to its management lies in managing the seed bank and preventing new seed from entering the soil.

This can best be achieved by:

- Utilising tillage and pre-emergent herbicides to reduce numbers of seedlings emerging
- Monitoring emergences and controlling seedlings when they are small
- Using robust herbicides and rates and the double knock tactic to control plants and prevent seed set

Feathertop Rhodes grass seeds have a relatively short life compared to other species, so intensive management for up to two years can have a major impact on driving down the seed bank.

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MANAGING COWVINE IN COTTON

Graham Charles
(NSW Dept of Primary Industries)

Contents

The morning glory family

Cowvine (*Ipomoea lonchophylla*), also known as peachvine, is a member of the Convolvulaceae family. It is a native Australian plant, closely related to sweet potato (*Ipomoea batatas*). Other morning glories that are problems in cotton include bellvine (*Ipomoea plebeia*) and common morning glory (*Ipomoea purpurea*).

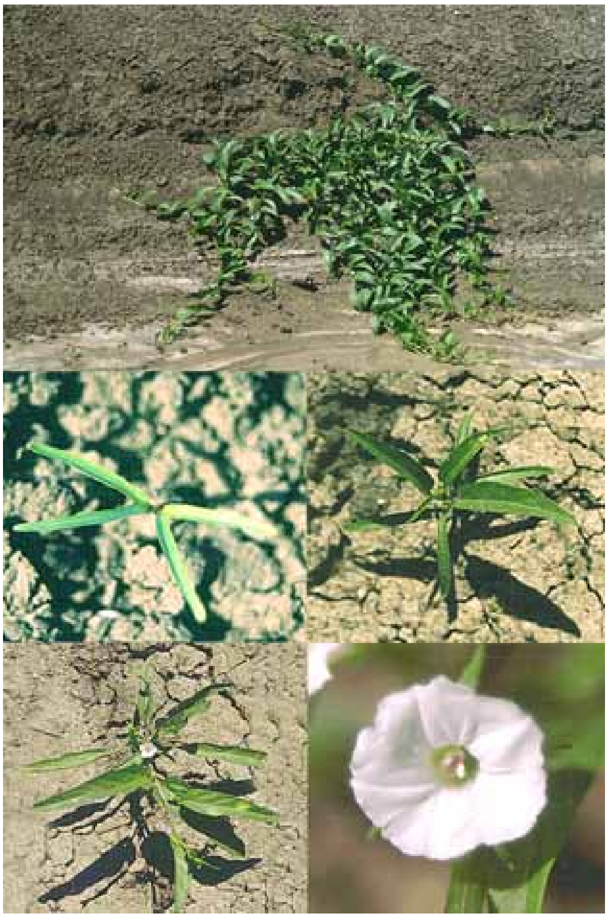
The cowvine plant

Cowvine is a common weed throughout the cotton industry, although it tends to be a far bigger problem in some areas than others.

Cowvine is an annual weed that grows over the warmer months. Seedlings emerge all year round following rain, but are killed by frosts. A flush of cowvine seedlings normally occurs after every rainfall and irrigation event, even in mid-winter.

Cowvine seedlings have unusual, very strongly lobed, "V" shaped cotyledon leaves. The plant is easily identified from the cotyledon shape at this stage. Seedlings grow rapidly after emergence during warm weather, and develop long, twining branches. Large plants may be 3 or 4 m in diameter. Flowering can start early in plant growth, when plants have only 2 or 3 true leaves. Under hot conditions, flowering can commence within a week of seedling emergence. Flowers continue to be produced throughout the plant's life. Three or four seeds are produced in each seed capsule.

Observations on small and larger plants found 206 seeds on a cowvine plant 0.2 m in diameter, and 791 seeds on a plant 2.8 m in diameter. Larger and older plants could produce many more seeds.



Cowvine is a member of the morning glory family. It is a vine weed, which can be a major problem in cotton, tangling amongst cotton plants, causing problems for inter-row cultivation and harvesting machinery.

Australian Government
Cotton Research and Development Corporation

Cowvine seeds have a strong dormancy mechanism and can remain viable in the soil for many years (Table 1).

Table 1. *Emergence of cowvine seeds grown in a glasshouse at 15 – 35 °C.*

Seed age at planting	Emergence %			
	0 - 100 days	100 - 300 days	300 - 600 days	600 - 900 days
Fresh	9	0	0	1
58 days	14	3	1	5
1 year	5	25	13	10
3 years	6	21	16	2

Large numbers of cowvine seeds may be present in the soil seedbank. Soil cores on a heavily infested field found between 1000 and 2500 cowvine seeds/m^2 in the 0 - 30 cm soil zone. Seeds occur predominantly in the 0 - 30 cm soil zone (80%) in a cultivated field, corresponding to the plow-zone, although some seeds were found down to 1 metre (Table 2).

Table 2. *Distribution of cowvine seeds in the soil. Samples were taken from the hill and furrow areas of an irrigated cotton field.*

	Distribution %	
Soil depth zone	Hill	Furrow
0 - 10 cm	40	50
10 – 20 cm	24	18
20 – 30 cm	16	11
30 – 40 cm	0	4
40 – 50 cm	4	4
50 – 100 cm	16	13

Few cowvine seeds are able to emerge from more than 5 cm depth in the soil, although a small proportion may emerge from as deep as 15 cm (Table 3).

Table 3. *Cumulative emergence of cowvine seedlings from seeds placed at varying depths in the soil. Seeds were mechanically scarified to promote germination.*

	Emergence %		
Soil depth	1 month	6 months	1 year
0 cm	25	25	30
1 cm	30	35	60
2 cm	45	50	50
3 cm	35	50	50
4 cm	30	50	55
5 cm	5	5	20
7.5 cm	0	0	0
10 cm	0	0	10
15 cm	0	5	5
20 cm	0	0	0

Cowvine seedlings are slow to emerge from depth and will be vulnerable to cultivation and drying cycles. Seeds may also emerge through soil cracks, or emerge after re-distribution in the soil profile following deep cultivation or re-listing of a field as these seeds may remain viable in the soil for many years. Seed samples taken from the 10-20 cm and 20-30 cm soil zones of a heavily infested field had similar viability to seeds from the 0-10 cm soil zone, showing that these seeds were viable and seedlings could emerge if opportunity arose.

This distribution of seeds in the soil profile means that less than 25% of the cowvine seeds present in an infested field are likely to germinate at any one time. In a field infested with 1500 seeds/m^2 for example, this would equate to less than 375 seedlings/m^2 being able to emerge at any time. However, far fewer than 375 seedlings actually emerge due to the strong seed dormancy characteristic already discussed. Population dynamics and seed density from a typical irrigated cotton field are shown in Figure 1.

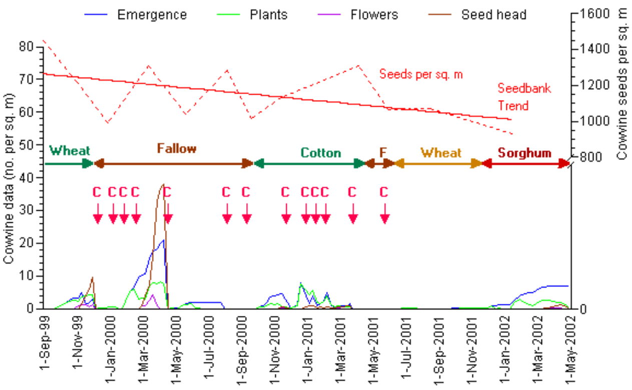


Figure 1. *Population dynamics of cowvine in an irrigated cotton field. The cropping sequence over the 3 seasons is indicated. The sorghum crop was grown to allow the use of atrazine herbicide to manage the cowvine problem. Cultivation events are indicated by a "C" with an arrow.*

In this field (Figure 1), the density of cowvine seeds in the soil (0 - 30 cm zone), decreased by 36% (or 12% per year), from 1447 to 930 seeds/m^2 over the three seasons. A total of only 62 cowvine seedlings emerged during this time. The remaining seeds were lost through predation by insects and microbial breakdown. The highest level of emergence was 22 seedlings/m^2, in the cotton crop in mid-December, 2000. The cowvine plants that established from these seedlings produced a total of 176 new seeds/m^2 over the three seasons, with most seeds produced during a summer fallow in March and April 2000.

Strategies for managing cowvine

Small cowvine plants are readily controlled by shallow cultivation (to 5 cm) and herbicides in fallows, cereal and sorghum crops, but can be difficult to control in broad-leaf crops such as cotton.

The primary difficulty with managing cowvine, both in-crop and in-fallow, is the tendency for small numbers of cowvine seedlings to emerge continuously, all year round, when soil moisture is adequate, coupled with a short generation period and strong seed dormancy. While a single generation of cowvine seedlings can easily be managed in most situations, most growers find it difficult to manage new germinations every few weeks throughout the summer. In the example of Figure 1, the field was cultivated 5 times over 4 months, between December 1999 and April 2000, yet cowvine plants still established and produced 38 new seeds/m^2 during this period. Cowvine was a problem in all cropping phases in this field (cotton, wheat and sorghum), as well as in the fallow.

Consequently, while cowvine can be managed with shallow cultivation or non-residual herbicides alone, an integrated approach, using cultivation, non-residual and residual herbicides in combination is necessary for managing this weed. The use of more disruptive, deep cultivation is problematic, as it will bury many of the cowvine seeds already at the soil surface, but may also bring up large numbers of viable seeds that were previously too deeply buried to be of any importance.

The aim of all management programs must be to reduce the size of the cowvine seedbank by ensuring that cowvine plants are always controlled before they produce viable seed.

Herbicides for controlling cowvine

A wide range of herbicides and herbicide combinations were assessed on cowvine growing in a fallow situation in autumn 2000. Many of these herbicides could not be used in cotton, but might be used in fallow or rotation crops. The herbicides were applied to emerged cowvine plants.

The best post-emergence control was observed with Atrazine, Diuron, Gesagard, Simazine, Basta and Oxytril (Table 4), and herbicide combinations that included these herbicides (Table 5). Of these herbicides, only diuron and prometryn can be safely used in cotton. Atrazine and simazine may be used with some rotation crops.

***Table 4**. Percentage kill of cowvine plants that emerged on the border of a field following rain in March 2000. Control was assessed on May 1, 28 days after spraying.*

Treatment	% Weed kill
Diuron 1 L/ha	100
Oxytril 2.0 L/ha	100
Oxytril 1.0 L/ha	97
Diuron 2 L/ha	97
Atrazine 4 L/ha	97
Atrazine 2 L/ha	97
Basta 2.0 L/ha	93
Grazon 1.0 L/ha	90
Oxytril 0.5 L/ha	90
Gesagard 1 L/ha	87
Gesagard 2 L/ha	87
Simazine 2L/ha	80
Basta 1.0 L/ha	80
Basta 0.5 L/ha	63
Grazon 0.25 L/ha	57
Roundup CT 4 L/ha	53
Simazine 1L/ha	50
Starane 1.0 L/ha	43
Grazon 0.5 L/ha	40
Zoliar 1.5 kg/ha	30
MSMA (800 g/L) 2 L/ha	27
Roundup CT 2 L/ha	20
Starane 0.25 L/ha	20
Starane 0.5 L/ha	20
MSMA (800 g/L) 1 L/ha	7
Untreated	7

***Note.** Cowvine seedlings emerged over the following weeks and a range of ages and sizes were present at spraying, most plants were between 2 leaves and 60 cm in diameter. Most plants were actively growing but some were moisture stressed at the time of spraying on April 3.*

***Table 5**. Percentage kill of cowvine plants in a fallow using herbicide combinations. Details are given in Table 4.*

Treatment	% Weed kill
Basta 1 L + Diuron (800 g/L) 2 L/ha	97
Diuron 2 L + MSMA 1 L/ha	97
Gesagard 1 L + Grazon 100 ml/ha	97
Gesagard 2 L + MSMA 1 L/ha	93
Basta 0.5 L + Gesagard 1 L/ha	90
Roundup CT 2 L + Diuron 2 L/ha	90
Basta 1 L + Grazon 100 ml	87
Roundup CT 2 L + Gesagard 2 L/ha	87
Basta 1 L + Zoliar 1 kg/ha	80
Zoliar 1 kg + Grazon 100 ml/ha	23
Zoliar 1 kg + Starane 0.25 L/ha	17
Roundup CT 1 L + Grazon 100 ml/ha	13
Untreated	7

Atrazine was used in the sorghum crop shown in Figure 1. The grower was very satisfied with the resulting control of cowvine, although some cowvine seedlings still emerged, grew and set seed. Cotton growers should always be aware of the plant-back from these products to cotton. Atrazine, in particular, has a very slow breakdown rate in dry soils, and can persist for long periods in dry conditions.

A fallow field heavily infested with cowvine and bladder ketmia. The cowvine plants were very small (below) but some had already flowered and set seed.

Residual herbicides for cowvine control in cotton

While diuron and prometryn are effective in controlling cowvine post-emergence, none of the residual herbicides that can be used in cotton were effective in controlling cowvine pre-emergence. Gesagard, trifluralin and diuron have some residual pre-emergent activity on cowvine but a high proportion of cowvine seedlings still emerged through maximum label rate applications of these herbicides (Table 6).

Table 6. *Cumulative emergence of cowvine seedlings following applications of pre-emergent herbicides in pots.*

	Emergence %		
Treatment	4 weeks	8 weeks	12 weeks
Gesagard 4.5 L/ha	18%	20%	20%
Trifluralin 2.8 L/ha	22%	27%	28%
Diuron 3.5 L/ha	22%	28%	29%
Dual 2 L/ha	27%	32%	33%
Cotoran 5.6 L/ha	29%	30%	31%
Zoliar 2 kg/ha	31%	34%	36%
Zoliar 4 kg/ha	31%	34%	36%
Cotogard 5 L/ha	31%	34%	38%
Stomp 3 L/ha	41%	43%	45%
Untreated	30%	32%	34%

Not all seedlings that emerge survive, even in the absence of herbicides. Zoliar didn't affect the emergence of cowvine seedlings, but did reduce the survival of the seedlings after emergence, killing around 64% of emerged seedlings soon after emergence (Table 7). However, the efficacy of Zoliar is highly affected by soil moisture level. Consequently, its effectiveness in the field is likely to be quite variable, depending on the soil moisture level following cowvine seedling emergence.

Table 7. *The survival of cowvine seedlings following applications of residual herbicides applied pre-emergence in pots. Establishment percentage should be compared with the emergence percentage in Table 6.*

	Establishment %		
Treatment	4 weeks	8 weeks	12 weeks
Zoliar 4 kg/ha	10%	11%	14%
Gesagard 4.5 L/ha	16%	17%	18%
Diuron 3.5 L/ha	17%	20%	21%
Zoliar 2 kg/ha	20%	24%	25%
Trifluralin 2.8 L/ha	21%	24%	26%
Dual 2 L/ha	23%	28%	29%
Cotoran 5.6 L/ha	26%	28%	29%
Cotogard 5 L/ha	27%	30%	33%
Stomp 3 L/ha	36%	39%	41%
Untreated	25%	27%	28%

Zoliar also gave the best suppression of cowvine in the field in cotton, but the results were variable and less than ideal (Table 8).

Table 8. *Control of cowvine seedlings with pre-planting, soil incorporated, residual herbicides. Emergence of cowvine seedlings was recorded during the cotton season (planting to mid-January, 2002). The results are an average from experiments, at Moree and Dirranbandi.*

Treatments	Seedlings/m²
Untreated	12.2
Dual 2 L/ha	11.8
Gesagard 2.5 L/ha	11.1
Gesagard 5 L/ha	10.3
Diuron 1.5 L/ha	10.3
Cotogard 5 L/ha	9.3
Cotogard 2.5 L/ha	8.8
Cotoran 2.5 L/ha	8.2
Cotoran 5 L/ha	6.6
Diuron 3 L/ha	6.5
Zoliar 1 kg/ha	6.3
Zoliar 4 kg/ha	4.1
Zoliar 2 kg/ha	3.1

Zoliar at 2 kg/ha reduced cowvine seedling density by 74% in experiments in irrigated cotton at Moree and Dirranbandi (Table 8), but this still left 3 seedlings/m^2, more cowvine plants than can be tolerated in cotton. Diuron and Cotoran gave the best results of the other herbicides. Best results were observed early in the season, with poorer control on all treatments later in the season, as the effective herbicide levels in the fields declined.

Cowvine control improved with all herbicides as the herbicide rates increased, but high herbicide rates are not always safe in cotton. No herbicide damage to the cotton was observed at Moree, but significant damage occurred following rain early in the cotton season at Dirranbandi. The worst damage was with the 2 and 4 kg/ha rates of Zoliar and the 3 kg/ha rate of diuron. The cotton plant stand was reduced by these herbicide applications, especially in the tail-ditch end of the field, where water had backed up.

Results from a range of herbicide combinations at the same experimental sites gave the best cowvine control with a combination of diuron and Zoliar, or prometryn and Zoliar (Table 9). These combinations gave similar levels of cowvine control, but with improved crop safety, compared to the results from the high levels of diuron or Zoliar alone.

Table 9. *Control of cowvine seedlings with pre-planting, soil incorporated, residual herbicide combinations. Cowvine emergence was recorded from cotton planting to mid-January 2002, on experiments, situated at Moree and Dirranbandi.*

Treatments	Seedlings/m²
Gesagard 2.5 L/ha + Diuron 1.5 L/ha	8.80
Cotogard 2.5 L/ha + Dual 2 L/ha	7.36
Gesagard 2 L/ha + Diuron 1.5 L/ha + Zoliar 1 kg/ha	6.41
Cotogard 2.5 L/ha + Diuron 1.5 L/ha	6.39
Diuron 1.5 L/ha + Dual 2 L/ha	6.36
Cotoran 2.5 L/ha + Dual 2 L/ha	6.31
Cotoran 2.5 L/ha + Diuron 1.5 L/ha	6.26
Gesagard 2.5 L/ha + Dual 2 L/ha	5.64
Cotogard 2.5 L/ha + Zoliar 1 kg/ha	5.46
Gesagard 2 L/ha + Diuron 1.5 L/ha + Dual 2 L/ha	5.31
Cotogard 2 L/ha + Cotogard 2.5 L/ha	5.19
Cotoran 2.5 L/ha + Zoliar 1 kg/ha	4.87
Diuron 1.5 L/ha + Zoliar 1 kg/ha	3.99
Gesagard 2.5 L/ha + Zoliar 1 kg/ha	3.84

Post-emergence control of cowvine with residual herbicides in cotton

Diuron and prometryn were both effective for controlling emerged cowvine seedlings and small plants in cotton, but gave less than 100% control on some occasions, especially with larger plants (compare Tables 10 and 11, for example). Generally, the addition of a surfactant is necessary to get the best control of emerged cowvine seedlings.

MSMA (Daconate) was commonly tank mixed with residual herbicides for post-emergence control of morning glory seedlings in the US, but is not necessary or desirable for controlling cowvine with diuron or prometryn. MSMA itself has little activity on cowvine (Table 4).

Table 10. *Control of cowvine growing in pots using post-emergence herbicides applied to plants at 4 and 11 leaves.*

Herbicide	% Weed kill	
	4 leaves	11 leaves
Cotoran (500 g/L) 2.8 L/ha	0	25
Diuron (500 g/L) 1.8 L/ha	95	94
Gesagard (500 g/L) 2.2 L/ha	40	100
Staple 120 g/ha	0	0
Untreated	0	0

Diuron and prometryn must be applied as shielded or directed sprays in cotton, applied to avoid contact with the crop foliage. Most product labels only allow diuron application in crop after the cotton is 30 cm high. Prometryn may be able to be applied after the crop reaches 15 cm. Check the product labels for specific use directions. Always follow the label directions.Fluometuron did not adequately control cowvine when applied at 2.8 L/ha, but was more effective at the higher rate (5.6 L/ha, Table 11). The level of control was improved when MSMA was tank mixed at 1 or 2 L/ha, but the level of control was still inferior to that achieved with diuron or prometryn.

Table 11. *Cowvine control with herbicides applied post-emergence to plants with 2, 4, 6 and 12 leaves, growing in pots.*

Herbicide	% Weed kill 6 weeks after spraying			
	2 leaves	4 leaves	6leaves	12 leaves
Cotoran (500 g/L) 2.8 L/ha	25	27	75	50
Cotoran (500 g/L) 5.6 L/ha	75	100	100	62
Diuron (500 g/L) 2 L/ha	75	62	100	50
Diuron (500 g/L) 4 L/ha	75	100	100	75
Gesagard (500 g/L) 2.2 L/ha	100	100	100	100
Gesagard (500 g/L) 4.4 L/ha	100	100	100	100
Staple 30 g/ha	0	0	0	0
Staple 60 g/ha	0	0	0	12
Staple 120 g/ha	0	25	0	0
Roundup CT 1 L/ha	0	50	12	12
Roundup CT 2 L/ha	0	50	12	87
Roundup CT 4 L/ha	100	87	87	100
Untreated	0	4	0	0

Controlling cowvine with non-residual herbicides

With the commercial release of Roundup Ready® cotton, many growers have found that Roundup Ready Herbicide® can be effective for controlling cowvine seedlings in young Roundup Ready cotton even though this weed is not on the product label. Growers have generally found that Roundup at the maximum label rate is effective on cowvine seedlings at the cotyledon stage and up to 2 or 3 true leaves, but is much less effective on older plants.

Glyphosate can be equally effective for controlling cowvine seedlings growing in conventional cotton, but glyphosate is difficult to apply to small cowvine plants in conventional cotton, without risking damage to the cotton plants from herbicide drift or off-target spray. Glyphosate can not be applied as a shielded or directed spray in conventional cotton before the crop reaches 20 cm in height. (Check specific use directions on the product label). Crop safety is much better with shielded applications in conventional and Roundup Ready cotton later in the season, but cowvine plants may be too large to be controlled by glyphosate by this time.

However, the window for glyphosate application to cowvine seedlings may be larger than has often appeared to be the case. The 2 L/ha application of glyphosate (Table 11) gave no control on seedling cowvine, but 87% control of larger plants (12-leaf stage). Glyphosate applications at 2 L/ha also gave good control of cowvine plants at 10 leaves (Table 12) and 22 leaves (Table 13).

Table 12. *Control of cowvine in a pot experiment using non-residual herbicides. Plants were sprayed at 2 and 10 leaves. At the 10-leaf stage, the centre 20 cm of one set of pots was covered to simulate the effect of a shielded spray.*

Herbicide	%Weed kill after 6 weeks		
	2 Leaves	10 Leaves	
	full spray	full spray	centre covered
Roundup CT 1 L/ha	87	25	0
Roundup CT 2 L/ha	100	100	62
Roundup CT 3 L/ha	100	100	75
Basta 2 L/ha	100	100	12
Basta 4 L/ha	100	100	37
Bromoxynil 2 L/ha	100	75	0
Bromoxynil 4 L/ha	100	100	0
Untreated	0	0	0

Table 13. *Control of cowvine in a pot experiment using non-residual herbicides. Plants were sprayed at 2, 9 and 22 leaves. The centre 20 cm of one set of pots was covered to simulate the effect of a shielded spray at the 22-leaf stage.*

Herbicide	%Weed kill after 8 weeks			
	2 Leaves	9 leaves	22 Leaves	
	full spray	full spray	full spray	centre covered
Roundup CT 1 L/ha	62	12	25	0
Roundup CT 2 L/ha	50	87	87	12
Basta 1 L/ha	100	100	100	12
Basta 2 L/ha	100	100	100	25
Bromoxynil 1 L/ha	12	12	12	25
Bromoxynil 2 L/ha	0	37	75	12
Untreated	0	0	12	12

The problem of poor control of cowvine with glyphosate sometimes observed in the field probably relates to two factors; the growing conditions of the plants, and incomplete spray coverage. Glyphosate is most effective on actively growing plants and never as effective on weeds that are stressed. The most likely cause of stress to cowvine plants growing in cotton is moisture stress, as small cowvine seedlings compete for moisture with larger, established cotton plants. Cowvine plants of any size will be difficult to control with glyphosate in cotton in hot, dry conditions, when the plants are not actively growing. Small cowvine plants sprayed soon after an irrigation or rainfall event should be much more easily controlled with glyphosate. Incomplete spray coverage is more difficult to avoid, as some cowvine plants emerge in the cotton row, where they are partially shielded by the cotton plants, and are difficult to spray when using a directed spray or a shielded sprayer. Larger plants may also be difficult to control when some branches are twined in the cotton row, and so avoid the spray.

Although glyphosate does translocate in plants away from the point of spray contact, translocation of glyphosate in cowvine plants appears to be quite limited. The percentage kill of cowvine plants was much lower on plants that were partially sprayed (Table 12 and 13), compared to the kill of plants that were fully sprayed.

Some growers have raised the possibility of using spray additives or different glyphosate formulations to improve the control of cowvine. Data from a glasshouse study showed few differences between glyphosate formulations, although there was an improvement in cowvine control from adding 0.2% of a non-ionic surfactant (Turbo Plus) to Roundup CT (Table 14).

Table 14. *Control of cowvine in a pot experiment using Roundup CT with spray additive or a different glyphosate formulation. Plants were at 4 and 6 leaves at spraying.*

Herbicide	Additive	% Weed kill 6 weeks after spraying	
		4 leaves	14 leaves
Roundup CT 2.2 L/ha		25	25
Roundup CT 2.2 L/ha	0.2% Turbo Plus	37	50
Roundup CT 2.2 L/ha	1% Turbo Plus	50	12
Roundup CT 2.2 L/ha	0.2% Pulse Penetrant	12	12
Roundup CT 2.2 L/ha	1% Pulse Penetrant	12	12
Roundup CT 2.2 L/ha	2% Boost	25	0
Roundup CT 2.2 L/ha	5% Boost	25	12
Roundup CT 2.2 L/ha	2% Urea	25	0
Roundup CT 2.2 L/ha	5% Urea	25	0
Roundup Max 2 L/ha		12	0
Roundup Ready 1.4 kg/ha		25	0
Credit & Bonus 1.9 L/ha		12	0
Untreated		0	0

The overall control rate was quite poor in this experiment. The reason for this is not understood, but is typical of the variability of results sometimes observed in the field with glyphosate and some other herbicides on this weed. Nevertheless, the cowvine plants were strongly affected by the glyphosate applications. Most plants that were not killed by the herbicides had only 2 or 3 live leaves 6 weeks after spraying. Unsprayed plants were much larger.

A similar effect was observed with Staple and Envoke, with a reduction in cowvine growth following an over-the-top applications (Table 15). These herbicides did not reliably kill cowvine seedlings but did suppress regrowth for up to 6 weeks after application.

Table 15. *Control of cowvine in a pot experiment using non-residual, over-the-top herbicides sprayed at 4, 8 and 16 leaves. The number of alive leaves per plant was observed 4 weeks after spraying*

Herbicide	% Weed kill			Leaf number after 4 weeks		
	4 leaves	8 leaves	16 leaves	4 leaves	8 leaves	16 leaves
Roundup Ready 1.5 kg/ha	100	100	75	0	0	2
Staple 120 g/ha	0	37	12	33	21	51
Envoke 15 g/ha	12	0	12	27	10	15
Untreated	0	0	0	60	81	104

Table 16. *Control of cowvine in a pot experiment using Envoke applied over-the-top at 3 and 17 leaves. The number of alive leaves per plant was observed 6 weeks after spraying.*

Herbicide	% Weed kill		Leaf number after 4 weeks	
	3 leaves	17 leaves	3 leaves	17 leaves
Envoke 5 g/ha	0	0	41	70
Envoke 10 g/ha	0	80	29	16
Envoke 15 g/ha	0	75	20	5
Envoke 20 g/ha	12	100	14	0
Untreated	0	0	74	57

Envoke was more effective at higher rates and a broadcast application gave good suppression even on larger cowvine plants (Table 16). However, this result on larger plants was not duplicated in the field where it was not possible to get full spray coverage of larger cowvine plants in a cotton crop.

Similarly variable results were observed with diuron, Cotoran and Gesagard (Tables 10 and 11). Growers should be prepared to use an alternative control strategy, such as cultivation, to manage cowvine seedlings in case of an unsatisfactory spray result.

Basta and bromoxynil are two other non-residual herbicides that might become available for over-the-top use with transgenic, herbicide tolerant cotton varieties, should varieties with these tolerances become commercially available. Basta tolerant cotton varieties are currently being developed, but will not be commercially available for several years. Both these herbicides are effective for controlling cowvine; Basta at 1 L/ha and bromoxynil at 4 L/ha. Oxytril® could be used instead of bromoxynil on the bromoxynil tolerant cotton and is effective on cowvine at lower rates (Table 4).

These two herbicides have the advantages that they are safe to use at any growth stage on tolerant cotton varieties and that they are equally effective on seedling and larger cowvine plants. They have the disadvantage that they are both relatively expensive, and they do not translocate well, needing full plant coverage to be fully effective. The control of cowvine plants partially sprayed with Basta and bromoxynil was much lower than the control of fully sprayed plants (Tables 12 and 13).

Glyphosate can be applied through spray shields to the area between the cotton rows in conventional and Roundup Ready cotton varieties. The spray shields prevent the herbicide contacting the foliage of the crop.

Herbicide combinations for controlling cowvine in cotton

A range of pre- and post-emergence herbicides and herbicide combinations for cowvine control were assessed in 5 field experiments over 3 seasons. No single herbicide or herbicide combination was able to give season long cowvine control, but excellent results were achieved using a range of management tools in combination.

The exact mix of weed management tools needed in any given field depends on a range of factors, including season conditions, weed pressure (density and sequential germinations) and the range of other weeds present in the field.

Of the residual planting herbicides, Zoliar and diuron gave the best early-season control of cowvine (28 Oct, Table 17). However, the control achieved by these herbicides declined rapidly as the season progressed, and large numbers of cowvine seedlings were generally present by mid- to late-November.

Control of these seedlings was most readily achieved using an over-the-top Roundup Ready Herbicide application to Roundup Ready cotton at the 4-leaf stage. The decline in activity of the pre-planting residual herbicides was such that they had little effect on the emergence of cowvine seedlings following the Roundup Ready Herbicide application. Consequently, these residual herbicides were of little value where a 4-leaf Roundup application was made, with similar densities of cowvine seedlings following the Roundup application regardless of the presence or absence of pre-planting residual herbicides (16 Nov, Table 17). The pre-planting residual herbicides would be of much more value in a non-Roundup Ready field.

Table 17. *Early-season control of cowvine in a field experiment. The Roundup Ready crop was planted on 1 0ctober and Roundup Ready Herbicide® was applied over-the-top of the crop on 28 October 2004.*

Pre-planting herbicide 23 Sep 04	4-leaf spray on 28 Oct 04	Seedlings/m² 28 Oct	16 Nov
Diuron 2 kg/ha + Zoliar 1 kg/ha	Roundup 1.5 kg/ha	0.4	0.03
Diuron 2 kg/ha	Roundup 1.5 kg/ha	0.4	0.05
Cotogard 2 kg/ha	Roundup 1.5 kg/ha	0.5	0.06
Zoliar 2 kg/ha	Roundup 1.5 kg/ha	0.6	0.09
Untreated	Roundup 1.5 kg/ha	1.1	0.07

Cowvine can be very difficult to manage in conventional or Roundup Ready UNR (ultra narrow row) cotton which does not allow inter-row cultivation, or shielded or directed spray applications.

It is important that the emergence of cowvine seedlings in the crop is monitored following the 4-leaf Roundup application. Few seedlings are likely to emerge until rainfall or irrigation occurs, and most emerging seedlings can be controlled by inter-row cultivation or a Roundup applications during this window. However, seedlings that do emerge and remain untreated will be difficult to control once they are at the 6 - 8 leaf stage or larger. Large germinations of cowvine can occur following rainfall events and the management of the crop should be driven by the observed cowvine pressure, with treatments scheduled as required.

Applications of glyphosate, prometryn and diuron can all be effective in controlling cowvine seedlings later in crop life, provided the seedlings are actively growing and good spray coverage is achieved. Staple and Envoke can also give useful suppression of cowvine seedlings. In the experiment in Table 17, rainfall occurred following the Roundup Ready application and cowvine numbers steadily increased. A mid-season herbicide application was applied in mid-December with combinations of diuron, Roundup and Envoke. All herbicides and combinations reduced the cowvine density by at least 75%, with the combinations including diuron giving better than 95% control (Table 18).

Table 18. *Mid-season control of cowvine in a field experiment. The field was assessed on 16 December, herbicide was applied as a directed spray on 17 December, and the cowvine density was again assessed on 12 January 2005. The % reduction in the cowvine density is shown*

Mid-season spray 17 Dec	Seedlings/m² 16 Dec	12 Jan	% Reduction
Diuron 2 kg/ha	0.5	0.02	95
Roundup Ready 1.5 kg/ha + Diuron 2 kg/ha + Envoke 5 g/ha	0.8	0.03	96
Roundup Ready 1.5 kg/ha + Diuron 2 kg/ha	0.8	0.03	97
Roundup Ready 1.5 kg/ha	0.7	0.15	80
Roundup Ready 1.5 kg/ha + Envoke 5 g/ha	0.8	0.18	77

The value of these herbicide combinations is not clear. Combinations are often used to improve the spectrum of weeds controlled with a single application, or to improve efficacy on difficult to control weeds. With Roundup Ready cotton, the temptation is to add something to the Roundup to improve its control on those weeds on which it is less effective. Often, however, the addition of another herbicide to glyphosate will reduce the efficacy of the glyphosate and may damage the crop. A reduction in glyphosate efficacy almost always occurs when herbicides such as diuron and prometryn are added to glyphosate, regardless of the formulations used. The addition of ammonium sulphate may improve glyphosate efficacy in these combinations, but is of limited value.

The herbicide combinations in this experiment improved the cowvine control compared to using Roundup Ready Herbicide alone, but didn't improve control over diuron alone. Results from a pot experiment were inconsistent, but suggested that the combination of residual and Roundup Ready Herbicide could give improved control of cowvine in some situations (Table 19). Nevertheless, this combination may give reduced control of other weeds that might be present. Factors that could improve the result with a combination of Roundup Ready Herbicide and a residual are:

- Addition of a suitable spray adjuvant
- High water rates (at least 100 L/ha), and
- Ensuring that the combination is applied to the target as quickly as possible after mixing

Table 19. *Control of cowvine in a pot experiment using post-emergence combinations. Plants were sprayed at 2 and 12 leaves and assessed 6 weeks after spraying.*

Herbicide	% Weed kill after 6 weeks	
	2 leaves	12 leaves
Roundup Ready 1.5 kg/ha	100	69
Diuron 0.5 kg/ha	87	62
Diuron 1 kg/ha	50	37
Diuron 2 kg/ha	100	62
Diuron 0.5 kg/ha + Roundup Ready 1.5 kg/ha	100	87
Diuron 1 kg/ha + Roundup Ready 1.5 kg/ha	87	87
Diuron 2 kg/ha + Roundup Ready 1.5 kg/ha	100	100
Gesagard 0.5 kg/ha	87	75
Gesagard 1 kg/ha	87	87
Gesagard 2 kg/ha	100	75
Gesagard 0.5 kg/ha + Roundup Ready 1.5 kg/ha	75	75
Gesagard 1 kg/ha + Roundup Ready 1.5 kg/ha	100	87
Gesagard 2 kg/ha + Roundup Ready 1.5 kg/ha	100	87
Untreated	0	0

In most situations it will also be necessary to apply a layby residual herbicide prior to canopy closure to control cowvine seedlings that emerge late in the crop. A combination of prometryn and Roundup Ready Herbicide was applied to all treatments in this experiment in late January and resulted in 100% control of all cowvine plants. Plants which emerged after canopy closure had no impact on the crop and were controlled immediately after picking.

These results showed that a cowvine management program that combined good farming practices, Roundup Ready and residual herbicides, and inter-row cultivation could effectively control cowvine in a heavily infested commercial field where management inputs were able to respond to weed pressure.

Inter-row cultivation is a valuable component of an integrated weed management system for controlling cowvine and other weeds.

Alternative residual herbicides for managing cowvine in fallows and rotation crops

Tordon 242 was the only alternative residual herbicide tested which resulted in a long-term reduction in the germination of bellvine seeds (Table 20). Tordon 242 can be applied to cereal and linseed crops, but picloram, one of the constituents of Tordon 242, is toxic to cotton and has a long residual life in the soil (can be up to 300 days half-life). Consequently, there is a minimum 12 month plant-back period to cotton for Tordon 242. None of the other alternative residual herbicides had any effect on cowvine germination

Table 20. Cowvine seedling emergence following applications of residual herbicides.

Herbicide	1 week	2 weeks	4 weeks	1 year
	% Cumulative cowvine germination			
Tordon 242 1 L/ha	3	8	13	17
Spinnaker 400 ml/ha	32	57	62	66
Harmony M 45 g/ha	35	56	59	67
Sencor (750 g/kg) 470 g/ha	47	59	62	67
Lontrel (300 g/L) 500 ml/ha	51	57	60	67
Ally 7 g/ha	47	61	62	69
Simazine (900 g/kg) 2.2 kg/ha	50	63	65	72
Atrazine (900 g/ka) 3.3 kg/ha	44	66	69	77
Untreated	37	61	64	68

Managing cowvine in the farming system

While cowvine can be controlled by cultivation and a range of herbicides, it is not easy to control in a farming system due to:

- strong seed dormancy,
- long seed life in the seedbank,
- ability to germinate rapidly after rain, all year round,
- rapid seedling growth,
- a short generation period (flowering can commence when the plant has only 2 or 3 true leaves), and
- a twining growth habit, making larger plants difficult to control with inter-row cultivation, and difficult to spray in-crop when complete plant coverage is required.

Population dynamics of a typical field were presented in Figure 1. Results from a seedbank experiment are shown in Figures 2 and 3. These treatments were designed to simulate the effect of a standard herbicide management system (Figure 2) and a heavier management system (Figure 3) in back-to-back cotton.

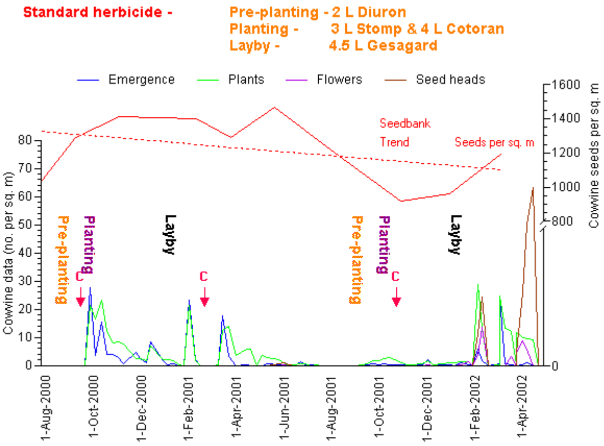


Figure 2. *Population dynamics of cowvine under a standard herbicide regime. Cultivation events are indicated by a "C" with an arrow.*

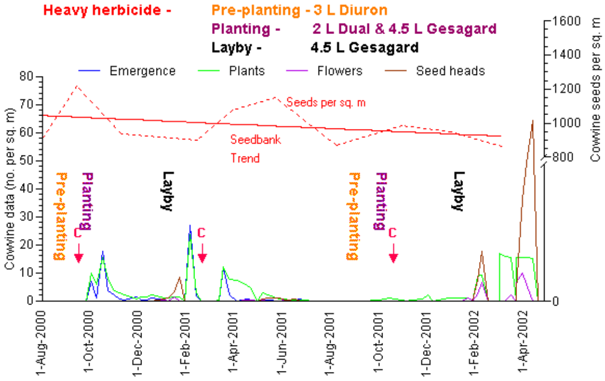


Figure 3. *Population dynamics of cowvine under a heavier herbicide regime. Cultivation events are indicated by a "C" with an arrow.*

As with the earlier data of Figure 1, there has been a downward trend in the seedbank population of cowvine seeds in both treatments in the two seasons of the experiment. Nevertheless, some cowvine seedlings emerged in both systems, grew, and on several occasions set seed. Totals of 310 and 321 cowvine seeds/m^2 were produced on the standard and heavy management systems over the two seasons. These seeds were mostly produced towards the end of the cotton season, when the effective levels of the residual herbicide had declined, with most seeds produced in the dry conditions of autumn 2002.

The management of cowvine in these systems should improve over time, provided the number of cowvine seeds in the seedbank continues to decline. Failure to control the cowvine on just one occasion could result in the seedbank increasing back to previous levels. The seedbank is only declining at around 10% per year. It will be many years before cowvine ceases to be a problem in this field.

Cowvine seeds can float and move in irrigation water. However, the number of seeds that do move in irrigation water is quite low, representing only a small fraction of the number of seeds present in an infested field. Consequently, seed movement in irrigation water is not an issue, except as a source of infestation for previously clean fields.

A heavy infestation of young cowvine plants on an irrigation channel. These plants will produce large numbers of seeds that can move in the irrigation water and spread the weed to previously clean fields.

Summary

Cowvine is an annual weed that is a problem both in crops and in fallows. Cowvine can be controlled by cultivation and a range of herbicides. It is not easy to control in a farming system due to a number of characteristics, including:

- strong seed dormancy
- long seed life in the seedbank
- ability to germinate rapidly after rain, all year round,
- rapid seedling growth,
- a short generation period (flowering can commence when the plant has only 2 or 3 true leaves), and
- a twining growth habit, making larger plants difficult to control with inter-row cultivation, and difficult to spray in-crop when complete plant coverage is required.

Typically, around 1000 to 2000 cowvine seeds per m^2 are present in the seedbank of a heavily infested field. These seeds occur predominantly in the 0 to 30 cm soil zone. Seeds can emerge all year round and plants may flower within a week of germination.

None of the pre-emergence residual herbicides were effective in controlling cowvine. Best results were achieved with combinations of diuron and Zoliar, and prometryn and Zoliar. These combinations reduced the in-field infestation of cowvine by around 75%. Post-emergence, diuron and prometryn consistently give the best control of cowvine of the herbicides normally used in cotton. Glyphosate can be effective in controlling cowvine seedlings in conventional and Roundup Ready cotton. Glyphosate is most effective on actively growing cowvine seedlings. Good control of older, actively growing plants with glyphosate is possible.

An effective cowvine management system will use all the available control options (cultivation, chipping and herbicides) in combination. Management of this weed will be an on-going process over many seasons.

WEEDpak

MANAGING NUTGRASS IN COTTON

Graham Charles

(NSW Dept. of Primary Industries)

Contents	Page

A heavy "nutgrass" infestation in cotton. The field was infested with four different species. The cotton was infested with downs nutgrass and yelka, while dirty Dora and umbrella sedge infested the head ditch.

Contents	Page

Preface

This document was first complied in 2002 from extensive research and observations undertaken in the years prior to the release of cotton varieties with the Roundup Ready® trait.

The regular and widespread use of glyphosate in crop over the last decade and more has gone a long way to managing this weed and much of the information in this document is no longer essential for managing nutgrass.

However, all the information has been left in the document to assist those who don't use varieties with the Roundup Ready Flex technology.

For those using the Roundup Ready Flex® technology, you may choose to skim through a lot of this document, but you will also find a lot of information that will assist you to get the best out of glyphosate for managing nutgrass.

Australian Government
Cotton Research and Development Corporation

The four steps for weed management

A successful weed management program is built in four steps. These are:

- **positive identification** of the weed
- **assessment** of the extent of the problem
- targeted **treatment** of the weed, integrating all available management tools, and
- **evaluation** of the farming system, making modifications as required to ensure success.

The nutgrass (*Cyperus*) family

Positive identification is the first step in managing any problem weed, as different management techniques may be needed to control different weeds, even though the weeds may be closely related.

Nutgrass belongs to the genus *Cyperus*, of which 38 species are reported to occur in the cotton growing areas of Australia. Of these, 19 species are native to Australia and the remaining 19 species have been introduced.[1] Three of these species are commonly found in or around cotton fields (Table 1), while another five species occasionally occur around cotton fields (Table 2).

Table 1. *Nutgrass species commonly found in and around cotton fields.*

Botanical name	Common name
C. bifax C. B. Clarke	downs nutgrass
C. rotundus L.	nutgrass
C. victoriensis C. B. Clarke	yelka

Table 2. *Other nutgrass species occasionally found around cotton fields.*

Latin name	Common name
C. alterniflorus R. Br.	Tall sedge
C. concinnus R. Br.	Trim sedge
C. difformis L.	Dirty Dora
C. eragrostis Lam.	Umbrella sedge
C. iria L.	Rice flatsedge

This article primarily focuses on the control and management of nutgrass (*C. rotundus*) as by far the most difficult to control of these weeds. Management information for the other species is discussed throughout the article.

Nutgrass (*C. rotundus*) (see p. H3.4)

Nutgrass, called purple nutsedge in the USA, is an introduced, strongly competitive perennial weed that grows from underground tubers. It is an international weed and is a major problem in a range of crops, and especially irrigated farming systems.

Nutgrass favours lighter soil and wetter conditions, but grows well on both dryland and irrigated soils throughout the cotton industry.

It may be relatively short, at 10 – 15 cm, but can grow up to 60 cm high in irrigated cotton. Nutgrass has dark green leaves and stems that are triangular throughout their length. It has a dark purple flower head that is up to 10 cm in diameter and lightens in colour with age. Nutgrass grows in very dense patches, with little space between shoots. Densities of up to 14000 tubers and 2200 shoots/m^2 have been recorded in irrigated Australian cotton. It can reduce cotton yields by up to 90% at these densities.

Nutgrass can be positively identified from the purple colouration on the outer leaves at the base of the plant stem, around the basal bulb. This colouration is seen by stripping back one or two leaves from the base of the nutgrass shoot. Purple colouration persists through several layers of outer leaves, while the inner leaves are light green and then white.

Nutgrass produces large numbers of seeds, but the seed has very low viability (only 1 or 2%) and the seedlings are weak and easily controlled by herbicides such as trifluralin and pendimethalin. Nutgrass plants rarely establish from seed; reproduction is almost always by vegetative propagation through new tubers.

A single nutgrass plant can produce up to 2000 new tubers in a single season. The first tubers are initiated about four weeks after the nutgrass shoots first emerge. These new tubers then produce new shoots that produce new tubers etc. Most tubers are in the top 15 cm of the soil, although tubers can emerge from 30 – 40 cm depth.

Nutgrass is frost susceptible and becomes dormant over winter when conditions are sufficiently cool. Plants re-establish in spring from dormant tubers. Nutgrass tubers may remain dormant in the soil for several years, but require moisture to survive. Tubers are easily killed by desiccation in a dry soil.

[1] Lazarides M. Cowley K. and Hohnen P. (1997). CSIRO handbook of Australian weeds, CSIRO Publishing, Collingwood, Vic.

Downs nutgrass (*C. bifax*) (see p. H3.5)

Downs nutgrass is a native Australian species and is abundant in much of the flood susceptible, watercourse country.

It is similar to nutgrass, but is generally taller at 60 - 80 cm, its leaves and stems are a lighter green in colour, and its seed head is larger (up to 20 cm across) and lighter in colour, starting off brown or orange and fading with age. Its stems are triangular over their full length, but unlike nutgrass, the outer leaves at the base of the stem are light green, and the inner leaves white.

Downs nutgrass produces a large quantity of viable seeds. Typically, it also produces 5 to 20 new tubers per plant each season, and establishes from both seed and tubers. Most tubers are found in the top 10 cm of the soil and are easily killed by desiccation. New downs nutgrass infestations can occur from seeds carried in floodwater and fodder.

Downs nutgrass grows at much lower density than nutgrass and is much less competitive, although downs nutgrass may be more obvious in cotton due to its greater height.

Yelka (*C. victoriensis*) (see p. H3.6)

Yelka is native Australian species that occurs in the watercourse country and is common on roadsides.

It has erect, dark green stems 100 - 120 cm tall with few leaves. The stems are circular at the base, but become more triangular towards the top. Yelka may have a small, purple flower head, with a few short leaves below the flower, but often the flower head is absent. It grows at low densities, produces few seeds and tubers, and is not very competitive. Most tubers are found in the top 10 cm of the soil and are easily killed by desiccation in a dry soil.

Tall sedge (*C. alterniflorus*) (see p. H3.7)

Tall sedge is a perennial native Australian species that occurs sporadically in wet areas such as river and creek banks, lagoons and irrigation ditches.

Mature plants are around 1 m tall and can form large, dense tussocks. The stems are almost circular at the base but become triangular throughout most of their length.

Tall sedge produces rhizomes and masses of seed, but does not spread rapidly. It can be a nuisance in irrigation channels and water storages.

Trim sedge (*C. concinnus*) (see p. H3.8)

Trim sedge is a native Australian species that occurs sporadically on wet areas and table drains.

It grows to around 50 – 60 cm high and produces both seed and rhizomes. Its stems are triangular throughout their length.

Dirty Dora (*C. difformis*) (see p. H3.9)

Dirty Dora is another native Australian species that invades wet areas. It is a major problem weed in rice and cane production in Australia.

Dirty Dora grows from seed and is readily spread by seed. Even small plants can produce large quantities of viable seed. It has no underground tubers. It tends to be relatively short, up to 50 cm, and is a paler, yellowy colour. The stems of dirty Dora are strongly triangular throughout their length.

Small numbers of small plants may occur throughout cotton fields without being noticeable. Dirty Dora plants have germinated from soil samples taken from fields where the plant has never been observed to occur.

Umbrella sedge (*C. eragrostis*) (see p. H3.10)

Umbrella sedge is an introduced species that invades wet areas and can be a problem in water storages and irrigation channels.

Umbrella sedge grows from seed and is readily spread by seed. Even small plants can produce large quantities of viable seed. It has no underground tubers. Plants are generally around 30 - 50 cm tall, although they can grow to 1 m. The stems are almost circular at the base but become triangular throughout most of their length.

Once established, umbrella sedge plants can grow to form a large tussock.

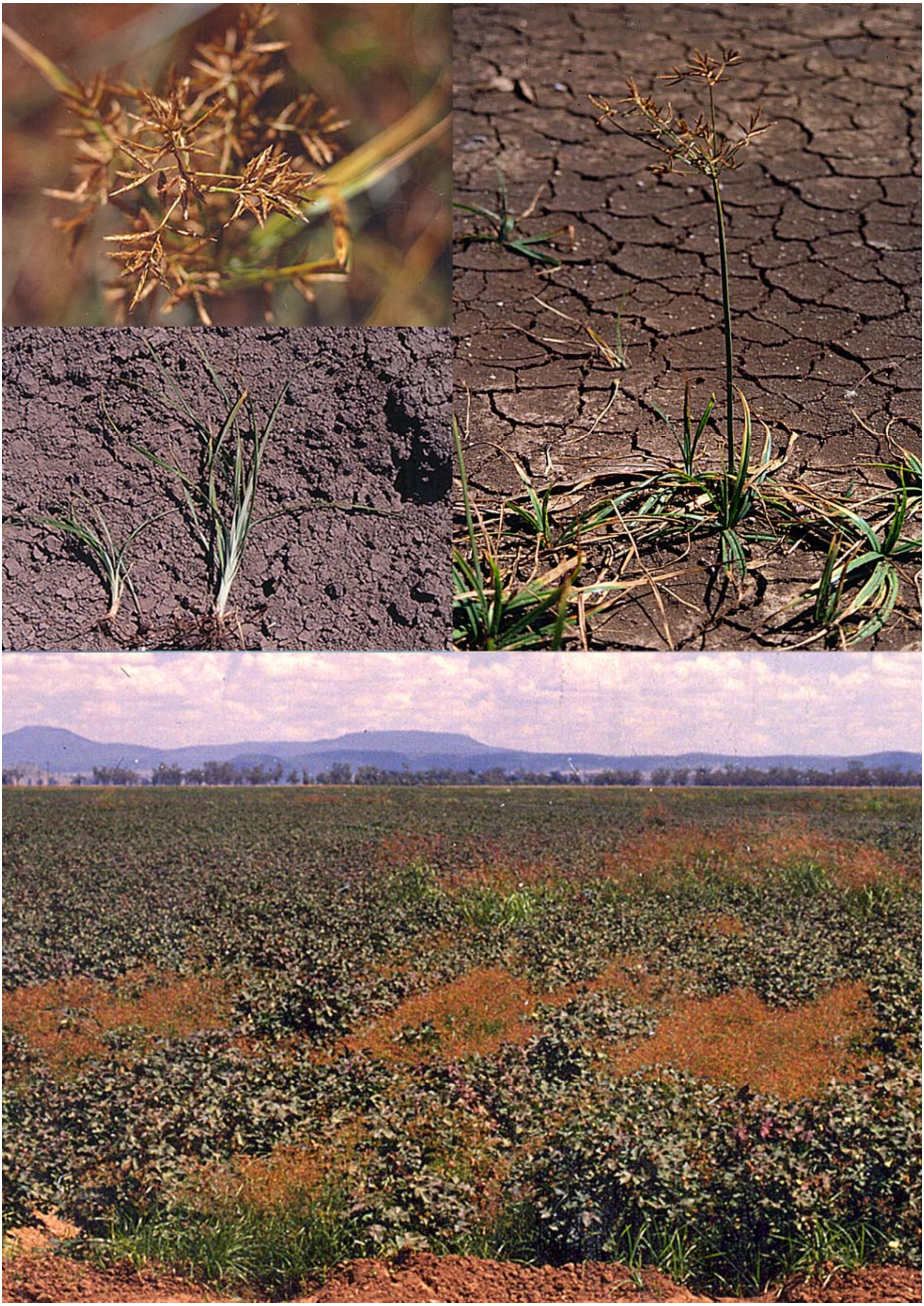
Rice flatsedge (*C. iria*) (see p. H3.11)

Rice flatsedge is a native annual sedge that occurs in wet areas such as table drains and irrigation channels. It grows to 60 to 80 cm in height and produces large quantities of seed. Its stems are strongly triangular throughout their length.

Mullumbimby couch (*C. brevifolius*) (see p. H3.12)

Mullumbimby couch is an introduced weed that thrives in damp and disturbed areas. It is a rhizomatous perennial weed that readily establishes from seed. It is short, up to 15 cm high, but forms dense, competitive mats and masses of seed.

Nutgrass is a strongly competitive perennial weed that grows from tubers.



Downs nutgrass is a native perennial weed commonly found in the watercourse country. It is not very competitive with cotton, but can be very obvious due to its height and colourful flower heads.

Yelka is a native weed commonly found on roadsides and waste areas. It is tall, but has few leaves and grows at relatively low densities.

Tall sedge is a native weed occasionally found on river and creek banks, irrigation channels and water storages. It can form large, dense tussocks.

Trim sedge occurs sporadically on wet areas and table drains.

Dirty Dora is a native species that invades wet areas. It produces masses of seed and can spread very quickly.

Umbrella sedge is an introduced weed that invades wet areas and spreads rapidly from seed.

Rice flatsedge is a native species that invades wet areas.

Mullumbimby couch is an introduced weed that invades wet and disturbed areas and can spread rapidly from seed and rhizomes.

Understanding nutgrass (*C. rotundus*)

Nutgrass produces and survives from vegetative tubers in the soil. These tubers are up to 10 mm in diameter and up to 20 mm in length. Tubers are formed at the end of underground rhizomes that develop from each vegetative plant. A new plant develops from each tuber. Tubers appear to be formed in chains, but each tuber gives rise to a vegetative plant, which gives rise to new tubers, and so on.

These tubers can become dormant in winter or during dry conditions and can survive for years in the soil, extracting moisture through their roots. However, they are vegetative plant structures and cannot survive without water. Tubers are rapidly killed if they are exposed to very dry soil or are exposed at the soil surface after their roots are cut. Tubers without roots into moist soil die within a few hours when exposed at the soil surface in the middle of summer.

Tubers can be found throughout the soil profile, but are most common in the 0-10 cm soil layer. The results from 120 soil cores are shown in Table 3. Cores were from heavily infested fields in the Moree and Wee Waa areas. No tubers were detected below 40 cm, although a small number of tubers have been found at up to 1m depth. These tubers probably fell down cracks in the soil and are of no importance, except when they become exposed by deep cultivation, erosion, earth works, or after levelling.

Table 3*. Distribution of nutgrass tubers down the soil profile (0 to 100 cm). Percentage found in each soil layer.*

	Soil depth (cm)			
	0 - 10	10 - 20	20 - 30	30 - 40
Field 1	66	25	7	1
Field 2	50	38	10	2
Field 3	42	42	14	3
Average	53	35	11	2

Emergence from tubers placed at depth in a sandy soil and a black soil are shown in Table 4. Nutgrass shoots emerged readily from tubers down to 20 cm in depth, with some emergence from 40 cm in the sandy soil. Emergence was slower from the lower depths and was much slower in the black soil. The results from the sandy soil show that shoots could emerge from at least 40 cm in a black soil, where shoots emerge through cracks in the soil. Poor emergence was observed from tubers placed on the soil surface, which were probably killed by desiccation.

Table 4*. Percentage emergence and days to emergence from tubers placed at depth in sandy and black soils in pots.*

Depth	Sandy soil		Black soil	
(cm)	Emergence	Days	Emergence	Days
0	43	13	0	
2.5	100	9	100	7
5	100	9	75	18
7.5	100	12		
10	100	12	100	41
12.5	100	11		
15	100	14	100	54
20	100	18	75	51
25			0	
30	0		0	
40	25	38	0	
50			0	

Post-emergence observations indicated that the depth of the tuber did not affect subsequent plant growth.

Biological control of nutgrass

A range of organisms attack nutgrass, including rust, head smut, scale insects and a caterpillar that bores down through the stem (*Bactra truncculenta*). Feral pigs and other animals will also dig for and eat nutgrass tubers. These organisms normally have little impact on nutgrass infestations, attacking only a small proportion of plants, but can be found in large numbers in heavy nutgrass infestations.

The possibility of biological control of nutgrass has been examined in a number of countries, but has not been effective in significantly reducing weed numbers.

Leaf rust on nutgrass (top left), and downs nutgrass (bottom leaf) and stem rust on yelka plants (right).

Nutgrass affected by smut. This is of little importance, however, as nutgrass spreads primarily by tubers not from seeds.

Nutgrass tubers and shoots parasitised by a scale insect (white spheres).

Treatment options

Nutgrass can most easily be managed using a long-term, integrated weed management (IWM) approach, of which glyphosate is the central component. There are a number of tools that help control nutgrass, and practices that enhance control. These tools need to be used in combination. There are also a number of practices that should be avoided whenever possible.

One of the key components of an effective IWM strategy for nutgrass is to develop a 'whole-farm' approach. It is essential that nutgrass infestations are managed not just in-field, but also on roadways, channels, storages, non-cotton fields and waste areas. Strict field hygiene protocols are needed, especially where large areas of nutgrass are present in non-cotton areas and it is not practical to control the nutgrass on these areas. Nutgrass rarely establishes from seed. Most infestations are caused by tubers being spread from field to field and farm to farm by machinery. It is common to see nutgrass plants initially establish at the end of a field, where they have fallen from cultivators that were previously operating in infested fields. Subsequent cultivation passes spread the infestations throughout the fields.

More information on IWM is covered in the Integrated Weed Management (IWM) Guidelines, Section B3 in WEEDpak.

IWM tools for nutgrass control

Nutgrass can be controlled using:
- cultivation,
- residual herbicides,
- contact herbicides, and
- crop competition.

Cultivation

Mechanical cultivation can be very effective in controlling nutgrass, but it is also the most common means of spreading nutgrass. All too often nutgrass tubers and plants are lifted by a cultivator only to be transplanted further down the field.

Cultivation is effective in controlling nutgrass when it severs all the roots from the tubers, provided that the soil is sufficiently dry to kill the tubers. If the soil is not dry, nutgrass plants will rapidly re-establish after cultivation, and may be spread by the cultivator to new parts of the field or to new fields.

Inter-row cultivation is usually ineffective in controlling nutgrass in cotton, as cultivation generally occurs at relatively high soil moisture content to avoid excessively damaging the cotton, and is not deep enough to fully sever the roots of nutgrass plants and tubers.

Inter-row cultivation can be useful for suppressing very heavy nutgrass infestations, but has the major limitation that it can't control nutgrass in the cotton plant line.

Inter-row cultivation in lightly infested fields will often spread nutgrass and exacerbate the problem. Cultivation of lightly infested fields should be avoided where possible, or the cultivator should be lifted over nutgrass patches or cleaned down after passing through nutgrass patches. A small amount of time spent in cleaning down cultivation machinery can save large costs in time and money required to control the weed in the future.

Multiple inter-row cultivation passes can be used to suppress nutgrass in heavily infested fields, where the spread of tubers is of no importance. Multiple cultivation passes will help the cotton to establish and produce a crop. There will, however, be no lasting reduction in the nutgrass population, which will need to be controlled by another means at a later date.

Heavy cultivation (cultivation to at least 30 cm) is most effective in controlling nutgrass when the soil is completely dry following a cotton or rotation crop. A crop such as lucerne is ideal for completely drying out the soil in the nutgrass root zone. Cultivation should be timed to occur in mid-summer when no rain is forecast and the lucerne crop has dried the soil as much as possible. Heavy cultivation in these conditions can almost completely eliminate a nutgrass infestation from a field. The main limitation to control is the cost of the operation and the practical depth of cultivation.

Cultivation that disturbs the hills prior to planting can also be useful, as it appears to delay nutgrass emergence.

A trailing ripper set up for heavy cultivation of nutgrass after picking. Note the steel cable across the rippers (top photo) designed to cut the nutgrass roots during ripping.

Residual herbicides

Norflurazon (Zoliar®, Group F)[2]

Zoliar is the only residual herbicide currently registered for controlling nutgrass (*Cyperus* sp.) in cotton. It is highly persistent, with a half-life of up to 180 days[3]. Zoliar requires thorough soil incorporation and needs to be used over at least 3 consecutive seasons.

Nutgrass affected by Zoliar, as indicated by the white leaves. Most plants have been severely affected by Zoliar, and some plants in the background have been killed by the herbicide.

Zoliar is registered for application at 2.8 to 4.2 kg/ha, depending on soil type and whether Zoliar was applied in the previous season. Zoliar should be applied at the higher rate in the first season (depending on soil type), but the rate can be reduced in following years. Ideally, it is applied to nutgrass patches in autumn prior to a cotton crop planted in spring. Lower rates should be used if application occurs closer to planting.

Zoliar is readily adsorbed to clay and organic matter in the soil and is relatively immobile. Its efficacy is affected by soil pH and clay content. High rates are required on heavy, alkaline clay soils, but much lighter rates should be used on sandy and acid soils.

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[2] Herbicides are grouped according to mode of action and the risk of weeds developing resistance to the herbicide. Always try to avoid using repeated applications of herbicides belonging to the same herbicide group.
More information on herbicide groups is covered in Managing Herbicide Resistance in Cotton Section C2 in WEEDpak.

[3] Technical information for all products was compiled from label information and from information from the Herbicide Handbook (1994) Seventh Edition. Ed. William H. Ahrens, Weed Science Society of America, Champaign, Illinois, USA.

Zoliar's activity is triggered by a rainfall or irrigation event. It is readily absorbed through plant roots when the soil is wet (near or above field capacity), but is not absorbed from a dry soil.

Zoliar acts on the plant's photosynthetic pathways and destroys chlorophyll and lipids in the cell membranes, and cell proteins. This has the effect of turning affected leaves white. The affected leaves and plants die if this effect lasts sufficiently long.

It is common under Australian conditions for Zoliar to become less active again within a few days of the triggering rainfall or irrigation event. When this happens, the plant recovers from the herbicidal effect and resumes growing. Sections of white along the length of a leaf can indicate Zoliar activity has occurred in the past. Some suppression of nutgrass does continue at lower soil moisture levels.

This grass plant has been affected by Zoliar, but will probably recover as some leaves are still photosynthesising.

Zoliar has the primary advantage that it needs to be applied only once for the season and is most effective during wetter conditions, when the nutgrass would otherwise be most actively growing, and other control measures are difficult or impossible to implement. Zoliar also has the advantage of being equally effective across both hills and furrows.

In addition to controlling nutgrass, Zoliar controls a broad range of grass and broadleaf weeds. Zoliar is relatively expensive, but the cost can be partly offset by substituting Zoliar for some of the other residual herbicides that would normally be used. For example, the grass herbicides such as trifluralin and pendimethalin should not be required in a field treated with Zoliar.

The wheat in this patch was killed by Zoliar that was applied in an earlier season.

Unfortunately, Zoliar is also active against a range of other crop plants. The plant-back period to cereal crops is 30 months after a single herbicide application; a longer plant-back period is required following multiple applications. Zoliar is best suited to heavily infested fields because of its cost and the limitations with rotation crops.

Imazapyr (eg. Arsenal®, Group B)

Arsenal is registered for controlling nutgrass (*Cyperus* spp.) in non-crop situations. It inhibits acetolactate synthase, a key enzyme in the plant's metabolic pathway. This inhibition rapidly leads to plant death. Arsenal is a residual soil sterilant, effective in controlling most plant species. It is both root and shoot absorbed, and can act as a contact herbicide as well as a residual herbicide.

Arsenal will kill cotton and rotation crops for years after application. It should never be applied in-crop or in an area where soil or water movement could carry the herbicide into a sensitive area.

Arsenal is highly persistent, with a half-life of up to 142 days. It can control weeds for up to 3 years when applied at the registered rate. It is ideal for controlling nutgrass patches on roadways, the outsides of channel banks, and other non-crop areas.

When applying Arsenal to a nutgrass patch, it is good practice to apply the herbicide to an area 1 or 2 metres larger than the obviously infested area. This ensures that all nutgrass plants are controlled by the application. All too often the Arsenal controls the nutgrass in the sprayed patch, but treatment fails because a few plants remain outside the sprayed area and the infestation re-develops from these plants.

Arsenal is weakly adsorbed to soil and can move many metres from the site of application. It should never be applied in-crop or in an area where soil or water movement can carry the herbicide into a sensitive area, such as in the rotobuck area, or on the inside of ditches and channels.

Contact herbicides

MSMA (eg. Daconate®,Group K)

Daconate can be a useful tool for nutgrass management, as it can be applied over-the-top of cotton, or as a directed spray. It is normally applied to small cotton in spring, although it can be applied up until flowering. Daconate can not applied after the crop commences flowering.

Daconate is readily absorbed into nutgrass foliage and rapidly affects plants. It does not necessarily kill nutgrass plants but will suppress nutgrass growth, allowing the cotton to establish and shade the weed. Daconate is also effective in controlling a range of other weeds.

Daconate is an arsenical compound (contains arsenic). It has little soil activity but has a half-life of about 180 days in soil. Arsenic build up in the soil is not a problem when it is used in accordance with the label directions.

Table 5. *Yield reduction in cotton sprayed over-the-top with Daconate® in November and December.*

Date	Yield reduction (%)
Late November	2
Early December	13
Late December	18

Daconate is not completely safe to cotton. It can burn cotton leaves and delay cotton growth. To reduce this crop damage, Daconate should be applied as a directed spray to young cotton where possible, rather than an over-the-top application. Daconate should be directed to avoid the growing terminal of the cotton plants.

Damage to older cotton can be more serious as shown in Table 5. Nevertheless, in a field heavily infested with nutgrass, Daconate when properly applied, does far more damage to the nutgrass than it does to the cotton, with the end result that a Daconate application helps the establishing cotton and ultimately improves cotton yields

Daconate should be applied during hot conditions, as the efficacy is temperature related. That is, Daconate is more effective under hotter rather than cooler conditions. Daconate is also more damaging to cotton as temperatures increase. Growers should consider using lower rates when spraying Daconate over-the-top of cotton under very hot conditions, especially later in the season. Label recommendations suggest that Daconate should be applied under hot, dry conditions, at temperatures above 25°C. This temperature, requirement means that Daconate should not be applied under cool, cloudy conditions, as it is unlikely to be effective under these conditions.

Temperature variation within a day, however, does not have much effect on the efficacy of Daconate as shown in Table 6. Daconate is absorbed into the plant and has its herbicidal effect over time, so that efficacy is more affected by the temperature over a number of hours following spraying, rather than the actual temperature at the time of spraying.

***Table 6**. Yield reduction on cotton sprayed over-the-top with Daconate® at different temperatures and times on the same days.*

	Time		
	6 am	10 am	3 pm
15 December Temperature (ºC)	14	22	26.5
Yield reduction (%)	20	22	26
22 December Temperature (ºC)	19.9	26	35
Yield reduction (%)	24	22	19

Sempra® applied through a shielded sprayer (foreground plot) controlled nutgrass in the furrow (sprayed area), but gave little control of the unsprayed plant-line.

Halosulfuron-methyl (Sempra®, Group B)

Sempra is registered for controlling nutgrass in cotton, but must be applied through a shielded sprayer, to avoid herbicide contact to the cotton. Sempra inhibits acetolactate synthase, a key enzyme in the plant's metabolic pathway. This inhibition stops plant growth and plant death occurs 14 to 21 days after application.

Sempra does not persist for long in the soil, with a half-life of up to 34 days. However, most rotation crops are very sensitive to Sempra and the recommended plant-back period to rotation crops is 24 months.

Sempra has the advantage that it kills nutgrass plants reasonably quickly and can be very effective early in the cotton season. However, Sempra does not tend to translocate through the nutgrass rhizomes. Consequently, Sempra does not give good control of tubers attached to sprayed plants and gives little control of unsprayed nutgrass in the plant-line when it is applied through a shielded sprayer, as shown in Table 7.

***Table 7.** Reduction in leaf number and tuber number of sprayed and unsprayed nutgrass plants attached to sprayed plants. Plants were grown in divided pots and sprayed 4 or 10 weeks after first shoot emergence. They had on average 59 and 153 leaves at spraying, respectively.*

Sempra rate (g/ha)	Nutgrass age	Sprayed	Unsprayed
Reduction in leaf number (%)			
70 g	4 weeks	12	0
	10 weeks	0	0
140 g	4 weeks	56	0
	10 weeks	56	0
Reduction in number of viable tubers (%)			
70 g	4 weeks	58	0
	10 weeks	39	0
140 g	4 weeks	92	0
	10 weeks	79	23

Glyphosate (various trade names, Group M)

Glyphosate is registered for controlling nutgrass in cotton. In conventional cotton and varieties with the Liberty Link® trait, glyphosate must be applied through a shielded sprayer, with the spray nozzles positioned so as to **avoid any spray contacting** the cotton foliage. Glyphosate can be applied pre-cotton emergence, in-crop as a shielded spray, at defoliation, or after picking. Up to 4 applications of Roundup Ready Herbicide® can be applied over-the-top of cotton varieties with the Roundup Ready Flex® trait up to 22 nodes of growth. If 3 or fewer applications are made up to the 22 node growth stage, a further application can be made at defoliation, between 60% open bolls and picking. For more information, refer to the Rondup Ready® herbicide label, Managing Roundup Ready® Cotton and SPRAYpak/ Spray Application in WEEDpak.

Note, most glyphosate formulations are not registered for over-the-top use in Roundup Ready Flex cotton, but Roundup Ready Herbicide is not the only glyphosate formulation registered for this use. Information in this document applies equally to the other registered products.

Glyphosate inhibits EPSP synthase, which prevents protein synthesis and kills the plant. Glyphosate is effective against most plants, but the herbicidal effect is quite slow, often taking 2 to 3 weeks. Glyphosate is far more effective when applied to rapidly growing plants. Spray failures can occur when glyphosate is applied to stressed plants. This is particularly true with nutgrass, where glyphosate applications to stressed plants are often ineffective.

Glyphosate is rapidly adsorbed and inactivated on contact with the soil. Consequently, it has no residual effect, although its breakdown in the soil is comparatively slow, with a half-life of approximately 47 days.

Glyphosate can be effective in controlling nutgrass. It translocates within the sprayed nutgrass plant and also to attached tubers and plants. This translocation means that glyphosate can kill the nutgrass plants it is sprayed on, but can also kill attached tubers and nutgrass plants in the cotton row that were not sprayed.

Glyphosate applied through a shielded sprayer controlled nutgrass in the furrow and controlled some nutgrass in the unsprayed cotton plant-line.

Glyphosate resistance

Nutgrass has a low risk of developing resistance to glyphosate as it primary reproduces vegetatively, with every daughter plant genetically identical to the parent. However, nutgrass does produce some viable seed and some seedlings establish, leading to some genetic variability in the species in Australia. This genetic variability opens the door for nutgrass to develop resistance to glyphosate and a nutgrass management strategy which relies exclusively on glyphosate places extremely high selection pressure on this weed. Consequently, even though the risk of nutgrass developing resistance to glyphosate is low, it isn't zero. There is a small, but real risk of resistance.

Given the lack of good alternative control options and very low risk of resistance developing to glyphosate, it is not unreasonable to continuing using glyphosate as the main tool for nutgrass control. Nevertheless, growers should always be on the lookout for nutgrass plants that have not been affected by a glyphosate application and could be resistant to glyphosate. If a patch of nutgrass remains green following a glyphosate application when all the surrounding nutgrass plants have been killed, assume the worst (resistance) and treat the patch as if it is resistant, controlling it with an alternative option, regardless of the cost. Physically removing a suspect patch of nutgrass with an excavator may be a very cheap option compared to the long-term havoc that glyphosate resistant nutgrass would cause to the industry.

Contact the author immediately if glyphosate resistant nutgrass is found or strongly suspected. For more information on herbicide resistance, refer to Herbicide Resistance, Section C of WEEDpak.

Herbicide efficacy on the major species

Zoliar is effective against all nutgrass species, as it is effective against both tubers and seedlings. Heavy rates of Zoliar are necessary to control plants growing from tubers, but much lighter rates of Zoliar should be adequate to control seedlings, with application timed to occur prior to expected weed germination. Much shallower soil incorporation should also be used for seedling control, as seedlings will not emerge from more than a few mm depth. Lighter rates, shallowly applied should give good control of species that only grow from seed such as dirty Dora, umbrella sedge and rice flatsedge.

Arsenal is equally effective against all nutgrass species, controlling seedlings and emerging shoots.

The three major species, nutgrass, Downs nutgrass and yelka have differing sensitivities to the contact herbicides. All herbicides are more effective on younger rather than older plants (Tables 8, 9 & 10).

Table 8. *Herbicide efficacy of the contact herbicides on nutgrass (C. rotundus) grown in pots. Plants were sprayed 4 or 8 weeks after first shoot emergence.*

Age	Herbicide	Rate/ha	% Kill
4 weeks	Daconate	1.4 L 2.8 L	0 25
	Sempra	70 g 140 g	46 100
	Roundup CTXtra	1 L 2 L	96 100
8 weeks	Daconate	1.4 L 2.8 L	0 0
	Sempra	70 g 140 g	8 0
	Roundup CTXtra	1 L 2 L	81 87

Daconate, which suppresses nutgrass, is much more effective on Downs nutgrass and yelka.

Sempra is effective on young nutgrass plants, especially at the higher rate, but is much less effective on older plants. Sempra is more effective on downs nutgrass and yelka, but the same trend occurs with age, being more effective on younger plants.

Glyphosate gave good control of all species at both growth stages, although results in the field are not always so consistent.

Table 9. *Herbicide efficacy of the contact herbicides on downs nutgrass (C. bifax) grown in pots. Plants were sprayed 4 or 8 weeks after first shoot emergence.*

Age	Herbicide	Rate/ha	% Kill
4 weeks	Daconate	1.4 L 2.8 L	29 50
	Sempra	70 g 140 g	67 75
	Roundup CTXtra	1 L 2 L	92 100
8 weeks	Daconate	1.4 L 2.8 L	44 50
	Sempra	70 g 140 g	11 25
	Roundup CTXtra	1 L 2 L	94 100

Table 10. *Herbicide efficacy of the contact herbicides on yelka (C. victoriensis) grown in pots. Plants were sprayed 4 or 8 weeks after first shoot emergence.*

Age	Herbicide	Rate/ha	% Kill
4 weeks	Daconate	1.4 L 2.8 L	100 75
	Sempra	70 g 140 g	69 100
	Roundup CTXtra	1 L 2 L	87 100
8 weeks	Daconate	1.4 L 2.8 L	42 50
	Sempra	70 g 140 g	0 37
	Roundup CTXtra	1 L 2 L	100 87

Factors that affect Zoliar efficacy

Zoliar is best suited to light, acid soils, where it is very effective at relatively light rates. In Arizona (USA), for example, Zoliar is very effective when applied post-cotton emergence at 1.5 kg/ha, but will kill cotton if applied pre-planting at this rate. Lighter rates should be used when applying Zoliar to light acid soils in Australia.

Cotton and nutgrass on a light, acid soil in Arizona severely affected by 1.5 kg of Zoliar.

Zoliar can behave quite unpredictably in alkaline, heavy clay soils, and must be applied at higher rates on these soils to be effective (4 kg/ha in the first season with lower rates used in subsequent seasons). In some situations, it appears that Zoliar is some how "bound-up" in the soil for some weeks after application, apparently becoming effective only six or so weeks after application. The length of this time period is influenced by soil moisture.

Consequently, it is recommended that Zoliar be applied to alkaline, heavy clay soils in about May, prior to a cotton crop. Thorough incorporation is essential for best results. This is most easily achieved by broadcasting Zoliar before listing. Zoliar is then thoroughly incorporated into the hills through listing, although the Zoliar rate in the furrows may be relatively low.

Good results have been achieved by applying very heavy rates of Zoliar to heavily infested nutgrass patches in fields, and on head and tail ditches. These rates could not be safely used on lighter soils.

Results from an experiment using very heavy rates of Zoliar are shown in Table 11. In this experiment Zoliar was applied over-the-top of 4-leaf cotton. Use of these rates is contrary to the pesticide label. To use higher than label rates, growers must first obtain a use permit from the NRA (National Registration Authority).

The combination of Zoliar applied pre-planting and glyphosate applied in-crop gave the most effective control of nutgrass in this experiment. The very high rates of Zoliar did cause significant leaf damage to the cotton (applied over-the-top of young cotton), but did not adversely affect crop yield.

***Table 11**. Shielded Roundup and heavy rates of Zoliar for nutgrass control applied over 2 seasons. The initial nutgrass infestation averaged 456 tubers/m^2. Specific permit permission must be obtained from the NRA before pesticides can be used outside the label recommendation.*

	Rate/ha	Tubers per m^2	Lint yield (kg/ha)
Untreated	-	1213	1467
Roundup CT	2.4	1076	1674
Zoliar	4	434	1564
Zoliar	16	133	1791
Roundup CT + Zoliar	2.4 + 4	152	1600
Roundup CT + Zoliar	2.4 + 16	35	1759

Factors that influence glyphosate efficacy

Glyphosate seldom gives 100% control of nutgrass in the field, even under the best conditions. One reason for this is that a nutgrass population includes plants at all stages of growth, including dormant tubers, shoots that have not emerged above the soil surface at the time of spraying, and newly emerging shoots. Dormant tubers and un-emerged shoots are effectively protected from glyphosate and newly emerged shoots are difficult or impossible to spray due to their small size and because they are often protected from the spray by other plant material. The problem of spray penetration can be a major limitation to control of a dense stand of nutgrass.

An apparent spray failure with glyphosate may not be caused by poor herbicide efficacy, but by the emergence of new nutgrass shoots from previously dormant tubers and from plants that were not sprayed. This is especially true with early season glyphosate applications, as new shoots may continue to emerge through to early summer. These shoots are connected to previously dormant tubers that were not previously susceptible to treatment. The emergence of new shoots after spraying should not be viewed as a spray failure but as an opportunity to treat a new portion of the nutgrass population. A dense nutgrass infestation can contain up to 14 000 tubers/m^2, but will have only about 2200 shoots/m^2 (only 16% of the population). This means that a high proportion of tubers may not be directly connected to live shoots.

Repeated treatments are the only sure way of controlling nutgrass with glyphosate.

Growers should always aim to apply at least two in-crop applications of glyphosate in cotton. These applications should be timed to occur after irrigation in about mid-December and mid-January, before the canopy closes. Ideally the second application should occur about four weeks after new shoots begin to emerge following the first glyphosate application.

Nutgrass age

Nutgrass plants are most susceptible to glyphosate when they are young, and become progressively more tolerant as they age. Freshly emerged shoots are much easier to kill than are mature plants. This is shown in the data in Tables 8 and 13. Flowering has little impact on glyphosate susceptibility, but flowering plants are much less susceptible than are younger plants.

However, except during early spring, or after cultivation or a successful herbicide application, a nutgrass population includes plants at all stages of plant maturity. Almost from the moment the first shoot appears in spring, nutgrass plants produce new tubers that produce new plants, that produce new tubers, and so on. These new tubers are initiated within days of the first shoot emergence. Viable new tubers and new plants can be formed within 4 to 6 weeks of the first shoot emerging. Consequently, at any point in the season, a nutgrass population includes freshly emerged shoots, through to mature plants.

The potentially rapid increase in a nutgrass population is shown in Figure 1. Competition from cotton can greatly reduce this rate of reproduction in the cotton row. Vigorously growing cotton may also shade the furrow and compete strongly with the nutgrass.

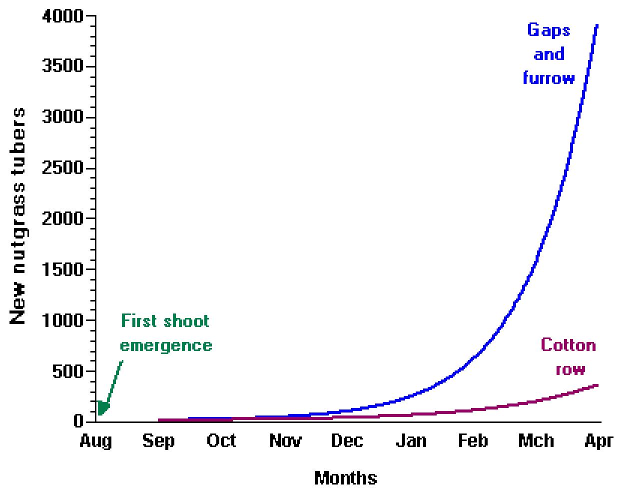

***Figure 1**. Nutgrass tuber production in cotton starting from a single tuber in spring. Nutgrass is intolerant of shading and produces fewer tubers in the cotton row.*

The glyphosate labels generally recommend that spraying be delayed until nutgrass plants reach at least 20% flowering, in about February. This recommendation is based on a misunderstanding of the need for nutgrass to be flowering before herbicide application. This misunderstanding assumes that older nutgrass plants are more sensitive to glyphosate and that nutgrass plants translocate assimilates to their attached tubers after flowering in autumn. Neither of these assumptions is correct.

Unlike many other perennial plants, nutgrass does not predominantly move assimilates (nutrients) down to its roots and tubers in autumn prior to plant dormancy. The movement of assimilates in nutgrass is a continuous process and is more apparent in younger plants than older plants. Almost from initial shoot emergence, nutgrass produces new tubers and assimilates are being continuously moved down to the roots and tubers, to provide for the production of these new roots and tubers. Consequently, glyphosate translocation to attached tubers occurs equally well at all stages of the season, although glyphosate is more effective in killing young plants and tubers than older plants.

Ideally, glyphosate should be applied to nutgrass within 4 to 6 weeks of first shoot emergence. This timing gives the best kill of plants and attached tubers, and ensures that plants are controlled before they reproduce, **provided that plants are not stressed at spraying**. Stressed plants are far less susceptible to glyphosate, and are unlikely to be killed by an application.

Stressed plants

Nutgrass is capable of very rapid growth, but is very easily stressed by factors such as low temperatures, low soil moisture, cultivation and other herbicides. Like most weeds, nutgrass is far more susceptible to glyphosate when the weed is rapidly growing. Even very high rates of glyphosate are likely to be ineffective in controlling nutgrass when it is stressed.

Moisture stressed plants are best controlled by cultivation. Where this is not possible or not practical, spraying should be delayed until after plants have resumed normal growth.

Low temperatures

While early spring may seem to be an ideal time to apply glyphosate to nutgrass, there have been many spray failures at this time caused by the nutgrass being stressed by low temperatures.

Glyphosate applications can be very effective in warm to hot conditions in October and November, but are likely to be ineffective when temperatures drop too soon after application. For effective control, hot conditions must continue for at least a week after spraying. A drop in temperature, or cool nights, may result in a spray failure.

Similarly, cool conditions in autumn are likely to result in spray failures.

Reliable control of nutgrass can generally be achieved from mid-November onwards, although this date will be earlier in the northern regions and can be much later in the cooler areas. Nevertheless, spraying earlier in the season can be very effective when conditions are favourable.

Low soil moisture

Nutgrass has a shallow, fibrous root system that makes it very prone to moisture stress in the cotton system. Experience has shown that nutgrass is most susceptible to glyphosate when the weed is rapidly growing, immediately after irrigation or rainfall. Ideally, glyphosate should be applied to the nutgrass as soon as possible after irrigation or rainfall.

The exception to this is that glyphosate can be very effective when applied to moisture stressed nutgrass, provided that rain or irrigation occurs within hours of the application. Applying glyphosate to nutgrass immediately before irrigation can be a practical way to overcome the difficulty of wet tail ditches etc.

Cultivation

One of the practical difficulties of controlling nutgrass with glyphosate can be the need to delay inter-row cultivation to allow nutgrass to grow sufficiently to be sprayed.

Nutgrass should be allowed to grow for at least four weeks between cultivation and spraying. Cultivation should then be delayed for at least one week after spraying and two weeks if possible. Cultivating within a week of spraying can reduce spray efficacy, as shown in Table 12.

Table 12. *Reduction in Roundup CT efficacy from simulated, post-spraying cultivation. Nutgrass plants were sprayed 6 weeks after first shoot emergence of plants growing in pots.*

Herbicide rate (L/ha)	Post-spraying cultivation	% Kill	Leaves per plant
-	-	0	125
2.4	-	75	0.3
2.4	2 days	25	7
2.4	4 days	50	3
2.4	8 days	25	14

Glyphosate rate

Most glyphosate labels recommend a split application of herbicide at 1 L active per ha per application. This rate has generally been adequate to control nutgrass in most situations, with the second application greatly improving the final result.

A range of other glyphosate rates has been used on nutgrass over the years with varying success. Half the recommended rate has been adequate to control nutgrass under ideal conditions, as shown in Tables 13 and 16, but has often lead to spray failures (also shown in Table 13). A higher rate (such as 2 L active/ha) will give better control in some situations, but is not generally needed and may not be cost-effective. Increasing the rate beyond 1 L active/ha will not generally overcome limitations such as the plant being stressed by cool temperatures or lack of soil moisture, but will greatly increase the risk of damage to the crop when applied as an inter-crop spray to conventional or Liberty Link varieties.

Water quality

One of the desirable characteristics of glyphosate is its ability to be rapidly adsorbed to soil particles and inactivated. This makes glyphosate ideal as a knockdown herbicide prior to planting or even between planting and crop emergence. Glyphosate can also be inactivated by metals and ions in the spray solution, and is very sensitive to zinc, which is present on galvanized surfaces.

These qualities make glyphosate very sensitive to water quality. Glyphosate efficacy can be reduced by dirty water, by hard water, by alkaline water and by metal ions. To avoid problems with water quality, it is important to use the best quality water available and to ensure that glyphosate remains in the spray tank for as short a time as possible.

Under most circumstances, however, water quality should not be a major factor reducing the efficacy of glyphosate on nutgrass, provided the spray mixture is not allowed to sit for an extended period.

A comparison of glyphosate efficacy using a range of water sources where the mixture was allowed to sit for 24 hours (Table 13) showed that poor water quality could have a large effect on herbicide efficacy, but that the effects were not consistent. Results from a second experiment where the spray was used 3 hours after mixing showed no reduction in efficacy due to water quality.

In both experiments, herbicide rate and nutgrass age had as much impact on herbicide efficacy as did water quality.

Table 13*. Herbicide efficacy of two rates of Roundup CT on nutgrass applied 3 or 6 weeks after first shoot emergence of plants grown in pots. The herbicide was applied in 100 L water/ha with 0.4% Turbo P (non-ionic surfactant) added. The spray mix was allowed to sit for 24 hours before spraying. Water quality is shown in Table 14.*

Age	Rate (/ha)	Source	% Kill
3 weeks	1.2 L	Distilled	82
		Bore A	98
		Bore B	76
		River	100
		Channel	58
	2.4 L	Distilled	88
		Bore A	99
		Bore B	77
		River	94
		Channel	100
6 weeks	1.2 L	Distilled	37
		Bore A	5
		Bore B	0
		River	1
		Channel	0
	2.4 L	Distilled	78
		Bore A	42
		Bore B	93
		River	0
		Channel	81

Table 14*. Water quality of the sources used in Table 13. The channel water was allowed to sit in storage for an extended period before use.*

Source	pH	Conductivity (dS/m)	Hardness (Ca + Mg)	Chloride (mg/L)
Distilled	6.65	0	0	10
Bore A	6.62	0.36	164	15
Bore B	8.18	0.57	157	48
River	9.48	2.59	98	370
Channel	9.21	0.18	67	25

Water rate

Most glyphosate labels recommend a maximum water rate at or below 100 L/ha. Common farm use is in the range of 40 to 60 L/ha, well below the maximum recommended rate.

Lower water rates improve spraying efficiency by increasing the area that can be covered by each tank load, but may also reduce the coverage of droplets on the target plant. Coverage and spray penetration into the plant canopy can be improved by using higher nozzle pressure, but this leads to the production of more small spray droplets and more spray drift.

Coverage can also be improved by using higher water volumes. Larger droplets and water volumes of around 100 L/ha should be used when spraying dense nutgrass patches to ensure adequate spray penetration. High water volumes and lower nozzle pressures are desirable when using an in-crop shielded application of glyphosate to reduce spray drift and thereby reduce damage to the crop.

Additives

A large range of wetters, surfactants and other additives is available for use with glyphosate and other herbicides. These additives can improve herbicide efficacy in some situations, but generally are not required with glyphosate. Some additives may have an inconsistent or negative affect in some situations, as shown in Table 15.

Table 15. *The effect of some spray additives on glyphosate efficacy on nutgrass, sprayed 8 weeks after first shoot emergence.*

	Treatment	% Kill	Leaves per plant
1	Untreated	0	234
2	Roundup 3 L	0	231
3	Roundup 3 L + 3% Agral 600	100	0
4	Roundup 3 L + Herbex 3 L	75	1
5	Roundup 3 L + Prep 0.3 L	0	50

The addition of Prep® (ethephon) to glyphosate for example, may improve control in some situations, but Prep is antagonistic to glyphosate, causing the chemicals to come out of solution and may reduce glyphosate efficacy.

Both percentage kill and leaves per plant data are shown in this and some other tables. Leaves per plant gives an indication of the suppression of plants that survived the treatment. A comparison of treatments 1 and 2, in Table 15 shows that the Roundup application (without additive) not only failed to kill the nutgrass, it failed to even suppress the weed. Treatment 5 (Roundup + Prep) also failed to kill the nutgrass, but did suppress the weed, causing a 79% reduction in leaf number.

Additives are often used to overcome poor application conditions, poor water quality, or antagonism from other tank-mixed herbicides. Generally, these additions do not fully overcome the problems. No additive will make stressed nutgrass plants receptive to glyphosate.

However, experience in the field has shown that the addition of a non-ionic surfactant at around 0.2% will often improve glyphosate efficacy, as shown with Agral 600 in Table 15. Data in Table 16 shows an improvement when using a non-ionic surfactant with low glyphosate rates, but no improvement when using the recommended rate of glyphosate.

***Table 16**. Nutgrass leaf production and % kill from three rates of Roundup CT with 4 rates of added non-ionic surfactant (Turbo-P).*

Roundup CT rate	Surfactant rate (%)	% Kill	Leaves per plant
-	-	0	110
0.6	-	0	133
	0.2	25	80
	0.5	25	43
	1.0	25	75
1.2	-	25	61
	0.2	100	0
	0.5	100	0
	1.0	100	0
2.4	-	100	0
	0.2	100	0
	0.5	100	0
	1.0	100	0

Additives should never be used with over-the-top glyphosate applications to Roundup Ready Flex cotton, except as directed on the product label. The use of other additives could affect the activity of glyphosate and cause damage to the Roundup Ready Flex cotton.

Tank-mixing

Glyphosate can be tank-mixed with a range of other herbicides. However, tank-mixing with some of the more commonly used cotton herbicides is likely to reduce glyphosate efficacy to some extent, as many of these herbicides contain clay that will inactivate the glyphosate. The amount of reduction of glyphosate efficacy will depend on water volume and quality, the amount of clay in the tank-mixed herbicide and the length of time the mixture stands in the spray tank.

Tank mixing with clay-based products should be avoided if possible. Ammonium sulfate should be added when tank-mixing with a clay-based product is necessary and higher glyphosate rates should be considered. Always ensure good agitation and that these mixtures remain in the spray-tank for as short a time as possible.

Re-spraying interval

Glyphosate is frequently used to control other weeds at a lighter rate than the 1 kg active/ha used for nutgrass. Ideally, nutgrass patches should be sprayed with a heavier rate at the same time by using a boom spray fitted with a second boom line with larger nozzles or by slowing the tractor to increase spray rate. The additional boom line is likely to give the better result of these two options as it is far easier for the operator to switch on or off an additional boom than to be constantly changing tractor speed.

***Table 17**. Effect of timing of a 1.4 L/ha (0.63 L active/ha) application of Roundup CT after a 1 L/ha (0.45 L active) application on nutgrass 3 or 6 weeks of age.*

Nutgrass age	Initial spray rate	Time to re-spraying with 1.4 L	% Kill	Leaves per plant
3 weeks	-	-	0	108
	1 L	-	50	49
		at spraying	100	0
		1 week after	75	7
		2 weeks after	100	0
		3 weeks after	75	1
		4 weeks after	25	71
6 weeks	-	-	0	166
	1 L	-	0	32
		at spraying	25	1
		1 week after	25	52
		2 weeks after	50	1
		3 weeks after	0	4
		4 weeks after	0	24

However, if the two applications can't occur on the same day, the second application should be delayed for around two weeks, as shown in Table 17.

Herbicide efficacy is reduced when the two sprays are too close together due to the stress on the plant caused by the first spray. Glyphosate applied to a plant with the second spray is unlikely to be readily translocated or to be very effective, as the plant is already stressed and damaged by the first spray. However, if the sprays are too far apart, the affect of the first spray is lost.

For best control, nutgrass should be resprayed approximately four weeks after green shoots emerge.

Herbicide combinations

The best control of nutgrass has been achieved using multiple applications of glyphosate on a field that previously received Zoliar. However, this can be a very expensive option, as unless the nutgrass patches are well defined, the Zoliar must be applied to most or all of the field. GPS mapping of the nutgrass patches may be used to greatly reduce this cost.

An alternative strategy for lighter infestations of nutgrass that has been successfully used by some growers is to apply a tank mix of Zoliar and Sempra as a spot application through a shielded sprayer in December, with a follow-up application of glyphosate in January. The combination of Zoliar and Sempra is very expensive on a per hectare basis, but the applications can be very cost-effective when applied through a weed-activated sprayer so that the herbicide is only applied to the weed infestation.

Spraying equipment

In-crop applications of glyphosate must be applied so as to avoid contact with the crop foliage. The only exception to this is Roundup Ready Flex cotton, which can be sprayed over-the-top with Roundup Ready herbicide up to 22 nodes of growth, in compliance with the product label.

Glyphosate can be applied in-crop to conventional or Liberty Link varieties as a directed spray or through a shielded sprayer. A range of equipment is available, at a range of prices, ranging from basic rubber or steel shields against the crop, to completely enclosed sprayers. The primary differences between these extremes of design is their ability to be safely operated in windy conditions, their ability to be adjusted to meet a range of requirements and crop size, and their ability to be used in a range of crop sizes without causing excessive physical damage to the crop.

It is essential when using any spray equipment to ensure that the equipment is properly set up and is used only under appropriate conditions. Generally, the more open the equipment design is, the more sensitive it is to windy conditions. Any air movement into the shield area will cause air movement back out of the shield area. This air is likely to carry fine spray droplets that may then be deposited onto the crop. Shields that have open fronts and tops are most prone to this movement, but some air movement is inevitable in even the best designed shields.

Nevertheless, even an open shield design can be used safely in the crop provided that it is used at low tractor speeds and low wind conditions, and with correctly set up and operated spray nozzles. Fine mesh, such as shade cloth, can be used to enclose the shields, greatly reducing air movement within the shield area and reducing the risk of crop damage from spray drift.

A range of nozzle designs is available, including low drift nozzles. Low nozzle pressure (pressures towards the bottom end of the recommended range for the nozzle) and high water volumes (allowing the use of larger nozzles) will also help reduce the production of fine spray droplets.

Once a shielded sprayer has been set up, it is important that it is regularly checked to ensure that nozzles are operating correctly, and that the operator is aware of the operating conditions. Operating a sprayer in windy conditions will inevitably lead to crop damage.

Crop competition

Although nutgrass can compete very strongly with cotton, nutgrass does not itself tolerate strong competition. Nutgrass has a fibrous, relatively shallow root system. This enables it to compete strongly early in the cotton season and to respond quickly after rain and irrigation, but it does not compete well with irrigated cotton later in the cotton season when soil moisture in the surface soil layers is limiting.

A section of a cotton crop severely infested with nutgrass. No harvestable cotton was present in this portion of the field.

Nutgrass is also relatively intolerant of shading and has a greatly reduced growth rate when shaded by a taller crop.

One of the keys to growing cotton and other crops in a field that is infested with nutgrass is to ensure that the crop establishes as quickly as possible and is able to shade-out the nutgrass. There are a number of management practices that can influence crop competitiveness, including:

- stubble management
- soil conditions
- crop species and variety selection
- sowing date, rate and depth
- seed dressings
- fertilizer type, rate and placement
- irrigation management (pre- and post planting)
- herbicides – residuals and knock-down pre-emergence and post-planting
- cultivations
- weed control (of nutgrass and other weeds)

These practices should be optimised to maximise crop competitiveness. The result of not optimising these factors can be that the crop does not establish vigorously on nutgrass infested areas and competes poorly, allowing the nutgrass to establish and spread. This worst-case scenario can result in a crop failure with no harvestable crop.

One of the most common problems with establishing rotation crops is inadequate soil moisture and nutrition in the nutgrass infested areas. The main part of a field may have good moisture and nutrition following a cotton crop, but both these inputs are likely to be lacking on nutgrass infested areas, as the weed has already used these resources during the cotton season. Consequently, crop establishment is comparatively poor on the nutgrass infested areas. Irrigation at planting and inclusion of a starter fertilizer with the crop can make a large difference to the crop's competitiveness and its impact on nutgrass.

Developing an IWM program for nutgrass

Nutgrass is a perennial weed that will not be controlled with any single treatment. Successful nutgrass management is built on using as many management tools as possible, at every available opportunity, over a number of years.

No one management program is suitable for every field and every season. The management tools can be successfully used in a variety of ways, depending on the extent of the problem and available resources.

The type of nutgrass program required for any individual field will depend on the extent of the problem and the management resources available.

Results from field experiments conducted over a number of seasons and a number of sites are shown in Tables 18 to 21. These results allow comparison of some treatments and treatment combinations.

Of the contact herbicides, multiple glyphosate applications have given the most reliable nutgrass control over a number of sites and seasons. However, glyphosate is only effective on actively growing nutgrass. The combination of glyphosate (applied on actively growing nutgrass) and cultivation (on moisture stressed nutgrass) can be used very effectively (Table 18).

The best results in cotton were achieved using a combination of Roundup and Zoliar (Table 19), with Zoliar incorporated pre-planting and two in-crop shielded applications of Roundup applied each season. This treatment (Treatment 8) resulted in an 88% decrease in the nutgrass population over two seasons, compared to a 5-fold increase in the nutgrass population where no treatment was imposed (Treatment 1).

The Roundup and Zoliar combination also resulted in the best cotton yield, 117% (3 bales/ha) higher than the untreated comparison (Treatment 1). This yield increase of 3 bales would have more than payed for the cost of treating the nutgrass. In addition, use of this treatment would result in a field starting the next season with a lower density of nutgrass than was initially present, potentially resulting in even better yields than were recorded over these two seasons.

Results using a range of herbicides and herbicide combinations on an initially much lighter nutgrass population were similar (Table 20), with the best nutgrass control (an 87% reduction in tuber density) from three in-crop Roundup applications (Treatment 4) and the best yield (a 47%, 1.7 bales/ha increase) from 2 in-crop applications (Treatment 3). The slight reduction in yield associated with the third Roundup application was probably caused by crop damage from the additional herbicide application, as the herbicide was applied through a poorly designed shield which allowed some herbicide drift to the conventional (not Roundup Ready Flex) crop.

The improvements in crop yields after treatment would probably have been even better if better designed equipment and/or Roundup Ready Flex cotton had been used. Generally, any damage to the cotton from the herbicide application is more than compensated for by the associated reduction in weed competition resulting from the reduction in the nutgrass population. Nevertheless, it is essential to only apply glyphosate through a well designed and properly set-up shielded sprayer, operating in appropriate conditions unless the variety includes the Roundup Ready Flex trait.

Results from a more extensive comparison of Roundup and Zoliar combinations are shown in Table 21. In this experiment, the best nutgrass control was achieved using a single Roundup application in early December (Treatment 4), which resulted in a 97% decrease in the nutgrass density.

However, results from a single Roundup application were highly variable (compare Treatments 2 to 7). This variability reflects the normal variability of results often achieved with glyphosate and was caused by a number of factors including the condition of the nutgrass at the time of spraying. On some occasions, the nutgrass was highly stressed at spraying, resulting in a poor kill. Growers should be able to achieve much better results by targeting conditions that are more suitable for glyphosate when nutgrass is actively growing.

***Table 18**. Changes in nutgrass density in a fallow with treatments over 2 seasons. The area initially had an average nutgrass infestation of 334 tubers/ m².*

Treatment	Rate (L or Kg /ha)	Applications	Tubers/m²
Untreated	-	-	3879
Cultivation	-	8	1114
MSMA	2.8	2	2895
MSMA	2.8	4	789
Roundup CT	2.4	2	668
Roundup CT	2.4	4	346
Roundup CT	4.8	4	150
Roundup CT	2.4	8	47
Cultivation + Roundup CT	2.4	4 + 4	118

***Table 19**. Changes in cotton lint yield and nutgrass density with in-crop and residual herbicide treatments over 2 seasons. The area initially had an average nutgrass infestation of 1348 tubers/ m².*

	Treatment	Rate (L or Kg /ha)	Applications	Tubers/m²	Lint yield (kg/ha)
1	Untreated			7194	582
2	Roundup CT	2.4	1	3728	547
3	Roundup CT	2.4	2	797	856
4	Roundup CT	2.4	3	611	891
5	MSMA + Roundup CT	1.8 + 2.4	1 + 1	741	987
6	MSMA + Roundup CT	1.8 + 2.4	2 + 1	1194	873
7	Zoliar + Roundup CT	3 + 2.4	1 + 1	786	660
8	Zoliar + Roundup CT	3 + 2.4	1 + 2	160	1262

Table 20. *Changes in cotton lint yield and nutgrass density with in-crop treatments over 2 seasons. The initial nutgrass infestation averaged 338 tubers/m²*.

	Treatment	Rate (L or Kg /ha)	Applications	Tubers/m²	Lint yield (kg/ha)
1	Untreated			1097	819
2	MSMA	1.8	2	577	871
3	Roundup CT	2.4	2	223	1206
4	Roundup CT	2.4	3	43	1173
5	MSMA + Roundup CT	1.8 + 2.4	1 + 1	385	930
6	MSMA + Roundup CT	1.8 + 2.4	2 + 1	231	1126
7	MSMA + Roundup CT	1.8 + 2.4	1 + 2	108	1018
8	Sempra	0.14	1	552	944
9	Sempra	0.07	1 + 1	367	1047
10	MSMA + Sempra	1.8 + 0.07	1 + 2	386	1061
11	MSMA + Sempra + Roundup CT	1.8 + 0.14 + 2.4	1 + 1 + 1	278	992
12	MSMA + Roundup CT + Sempra	1.8 + 2.4 + 0.14	1 + 1 + 1	278	1143

Table 21. *Changes in nutgrass density with in-crop treatments over 2 seasons and cotton lint yield in the first season. The initial nutgrass infestation averaged 456 tubers/m². The Zoliar was applied over-the-top of the cotton after crop emergence and the Roundup CTXtra was applied as a directed spray.*

	Treatment	Rate (L or Kg /ha)	Applications	Tubers/m²	Lint yield (kg/ha)
1	Untreated			1213	1467
2	Roundup CTXtra	2	early Nov	615	1588
3	Roundup CTXtra	2	late Nov	210	1661
4	Roundup CTXtra	2	early Dec	39	1486
5	Roundup CTXtra	2	late Dec	685	1532
6	Roundup CTXtra	2	early Jan	1076	1674
7	Roundup CTXtra	2	late Jan	410	1493
8	Roundup CTXtra	2 + 2	early Nov + late Dec	328	1371
9	Roundup CTXtra	2 + 2	late Nov + early Jan	667	1543
10	Roundup CTXtra	2 + 2	early Dec + late Jan	173	1532
11	Zoliar	4	Oct	434	1564
12	Zoliar + Roundup CTXtra	4 + 2	Oct + early Jan	152	1600
13	Zoliar + Roundup CTXtra	4 + 2 + 2	Oct + early Dec + early Jan	226	1573

A management program for heavy infestations

Cotton yields are reduced by nutgrass competition on a field heavily infested with nutgrass. Consequently, it is important to try to reduce the weed infestation as quickly as possible to improve crop yields. To do this, it is necessary to use a range of treatments in combination, using as many treatments as practical each season. Examples of intensive management plans for conventional and Roundup Ready cotton are shown in Tables 22 and 23. It may not be practical or appropriate to use all of these treatments each season, but it is important to use as many treatments as possible, until the nutgrass population is reduced to a more manageable level.

Table 22. *A management plan for back-to-back conventional or Libery Link cotton in a heavy nutgrass infestation. Treatments directly used for nutgrass control are shown in bold green type. An additional glyphosate application could replace the deep ripping operation if the soil is wet and the nutgrass is actively growing.*

	Operations	Crop
September	cultivation planting	
October		
November	MSMA application inter-row cultivation	
December	glyphosate application	Cotton
January	glyphosate application lay-by herbicide	
February		
March	glyphosate application at defoliation	
April	picking slashing	
May	deep ripping Zoliar application incorporation	
June	listing	Fallow
July	herbicide or cultivation	
August		

A management program for lighter infestations

A less intensive nutgrass management program can be used once the weed density on a field has been reduced to a level where the nutgrass is not reducing cotton yield. This program needs to be responsive, allowing for additional treatments should they become necessary, and must include regular field inspection. Failure to adequately treat nutgrass can result in a field becoming rapidly reinfested.

Such a management program would probably not include broadcast applications of Zoliar but may include a spot application of Zoliar to nutgrass patches. The main component of the management program should be in-crop shielded applications of glyphosate, with at least one application each season. Ideally, a second application will be allowed for in case the first application is not effective.

Table 23. *A management plan for back-to-back Roundup Ready Flex cotton in a heavy nutgrass infestation. Treatments directly used for nutgrass control are shown in bold green type.*

	Operations	Crop
September	cultivation planting	
October		
November	Roundup application inter-row cultivation	
December	Roundup application	Cotton
January	Roundup application lay-by herbicide	
February		
March	Roundup application at defoliation	
April	picking slashing	
May		
June	listing	Fallow
July	herbicide or cultivation	
August		

Summary

Eight different nutgrass species are commonly found in or around cotton fields. These species are quite different in their ability to spread from seed or rhizomes, and consequently require specific management strategies. Positive identification of the problem species is essential as the first step in a management program.

A range of management tools is available to manage these weeds. These tools include residual and contact herbicides, cultivation, and crop competition. There are also some management practices that can exacerbate a nutgrass problem and should be avoided whenever possible.

Management of nutgrass needs a long-term approach, as these weeds will not be eliminated by any single management input. A successful management program will include all the management tools, used in combination as opportunity arises.

Glyphosate and Zoliar® herbicides have given the most effective control of nutgrass over time. Glyphosate should ideally be applied in-crop at least twice each season. It must be applied through a well constructed, properly set up shielded sprayer, operating under favourable conditions, when applied in conventional or Liberty Link cotton varieties. Roundup Ready Herbicide can be applied with much greater safety in Roundup Ready Flex cotton varieties.

Zoliar is a residual herbicide that must be applied in consecutive seasons to be fully effective. It has a long plant-back period to most rotation crops.

Farm machinery can be a major contributor to spreading nutgrass around a farm. Attention to machinery hygiene can be pivotal in a successful management program.

Case studies of grower experiences with nutgrass

Nutgrass on Kilmarnock

John Watson

I remember nutgrass starting to be noticeable on channels in 1975; it was endemic in the dryland cropping paddocks and grazing country. The local pharmacist and then chemical supplier gave me a few mLs of something in a small plastic bottle. It was to be the answer to our potential problem and think it was probably Roundup! I was overseas for three years and by 1978 there were now small patches in some of the fields. Despite all our efforts it got progressively worse.

Many chemical products were tried, all of which gave variable and inconsistent results. Zoliar was effective if thoroughly incorporated on the flat before hilling up. It's extended use lead to problems in rotation crops. Cotton grown in a field with a relatively low population of nutgrass at planting could see it so thick after three months that yield would be affected if no action was or had been taken.

Graham Charles commenced trial work in the 1990's on our worst block, which, at the time, was on the leased property "Nandewar". He tested a number of products over three years and the best results indicated multiple applications of one or more chemicals. Overall, the trials showed that a cost effective result could be obtained from an early application of Zoliar and single in crop spray of Roundup using shielded sprayers.

The nutgrass control program is now largely based on control in the fallow phase, Roundup or chisel ploughing dry soil; rotations, cereal every second or third year; and in crop shielded spraying. It can sometimes be advantageous to do a broadacre application of Roundup after planting but before crop emergence. The result is quite variable, probably because of low temperatures especially here in the upper Namoi.

Roundup Ready® cotton will allow an over the top application after emergence and should therefore give better control as temperatures should be higher. Other than this obvious advantage, we will use much the same practices with Roundup Ready cotton, but will be looking to alternate some of the non-crop sprays with other chemistry to delay the onset of resistance of weeds to Roundup.

Case studies of grower experiences with nutgrass

Nutgrass Control at Norwood

Peter Glennie and Kylie May

Nutgrass has always been present on "Norwood". Years of flood inundation (prior to development), grazing and cultivation led to the gradual spread of the weed around the farm.

Early control methods consisted of cultivation and herbicides such as MSMA and glyphosate – all to varying degrees of success. The late 80's saw the introduction of Zoliar, which was incorporated into the control program. The worst areas were attacked first. The cost of Zoliar prohibited full field sprays in all but the worst fields, so various methods of spot spraying were tried, including manually turning small tractor mounted booms on and off, a spray boom on the back of a slasher at picking time and spraying with a quad. Zoliar was applied both at planting and picking and it was discovered that it wasn't until about the third year into the Zoliar program, that the nutgrass really started to respond to the applications. The patches were still there, but they were getting smaller and thinner.

The early 90's saw little or no irrigation water from Copeton and not much more rain. Water was conserved in the soil by preparing the hills early then leaving them to sit until planting time. Although this was a good drought strategy, the reduced disturbance saw nutgrass areas increase again.

A very dry winter in 1994 resulted in no winter crops being planted. This left an opportunity to grow a green manure crop the following summer. A lablab/forage sorghum mix was planted in December and left to grow for three months before being rolled and ploughed back into the ground. The following summer saw a marked reduction in the amount of nutgrass in those fields, probably due to a combination of the competition from the lablab/forage sorghum, and the extra cultivations needed to work the high amount of dry matter back into the soil. This result has been repeated in other years with lucerne and again this season with another lablab/forage sorghum mix that was planted last summer. Although this did reduce the amount of nutgrass in the field, other methods of control are necessary to keep the patches from increasing.

Zoliar still forms part of the nutgrass control program on "Norwood", although it is now mostly applied with a GTS sprayer, which has allowed more accurate targeting of the weed. Other methods of control are continually being trialled, both for better control and to hopefully reduce the amount of Zoliar in the soil, which limits rotation crop choice. Increased seed bed preparation, particularly deep cultivation, is having an affect, although more work still needs to be done.

This season (2001/02), saw the first commercial use of Roundup Ready cotton and herbicide. The herbicide had a dramatic effect on nutgrass patches, at a time of the season, when control is most important. It has allowed the cotton to out compete the nutgrass, without the need for extra cultivations. The wet November possibly helped contribute to the good result, by keeping the nutgrass fresh and more receptive to the Roundup Ready herbicide. It will be interesting to see if the result can be repeated over the next few seasons – here's hoping it will.

Currently we are trialling a more aggressive approach with the use of a large ripper with a wire cable connecting all the tynes. This cable is situated at the back of the tyne and is pulled by a D9N bulldozer, about 1 foot into the ground. The thought is that it will cut off the nuts from below and dry out the nuts above. So far the results are promising.

Case studies of grower experiences with nutgrass

Nutgrass control on Auscott Narrabri

David Wood

Nutgrass has been a problem on Auscott for a long time, but the issue came to a bottleneck over the last couple of years. Some fields were becoming so heavily infested that it was no longer economical to continue growing cotton.

The increase in the nutgrass populations was due to number of factors,
1. Succession of wet winters
2. Lack of effective in crop control options
3. Reduced tillage at depth

The run of wet winters reduced opportunities to use tillage as a control method, and resulted in operations for seedbed preparation being undertaken in less than ideal conditions. This made it very difficult to uproot and expose the tubers to desiccation as the nuts remained in moisture. Consequently, this simply spread the nutgrass from head ditch to tail drain.

In the past Zoliar was used as a broad acre spray across heavy infestations, however, its use was limited because of the restrictions that it imposed on future rotation crops. Due to the rotation issue Roundup was than used as an in crop control through shields. This also provided challenges with drift onto susceptible plants. MSMA was then used because of the greater crop safety, though unfortunately it success was variable. Sempra was also tried but was relatively ineffective. Together they gave reasonable control to continue cotton production, but were unable to stop the population from steadily increasing.

The situation took a turn for the better with the onset of Roundup Ready cotton. The Roundup Ready technology provided the opportunity to attack the nutgrass in the plant line early season, allowing the cotton to grow away and out compete the weed. The results from the Roundup spray are still sometimes variable, however, the successive applications achieve good brown off of the shoots more regularly, which is then followed by cultivation. In some cases it was taking the nutgrass 3-4 weeks to come back.

Zoliar is still an important part of the program on Auscott. Fields with light infestations are spot sprayed with a row weeder to prevent patches from spreading. It is also now sprayed through all rotobuck and tail drains in an attempt to stop cultivators from dragging the nuts down the field.

In combination with the chemical approach, rotation and tillage play an important role. The use of deep rooted crops, such as lucerne or safflower, dry out the soil profile and allow for deep ripping to expose nuts to desiccation. The advantage of lucerne over other crops is that if rains just prior to tillage, then it can be left to continue growing and draw the moisture out again, which is something that safflower or wheat cannot do if they have reached maturity.

At the end of the cotton season a Roundup spray at 2-3L/ha straight after harvest has shown signs of significantly reducing nutgrass populations in the following year. We are not sure if it will work each year, however, the results are encouraging.

MANAGING POLYMERIA (TAKE-ALL) IN COTTON

Graham Charles and Stephen Johnson

NSW Dept. of Primary Industries

Contents

Polymeria is a member of the bindweed family and has prominent, pink flowers. Polymeria plants grow in dense patches.

The polymeria plant

Polymeria (*Polymeria longifolia*) is a member of the *Convolvulaceae* (bindweed) family. Polymeria, also known as polymeria take-all and Peak Downs curse, is a native Australian plant, that occurs through much of the Queensland and New South Wales cotton growing area. It was present in many cotton fields before they were developed, and persists after development.

Polymeria is a deep-rooted, rhizomatous, perennial weed that tends to grow in dense patches. Its rhizomes can extend to 1.5 metres depth in the soil, with roots extending below the rhizomes. Shoots can emerge from 20 cm depth. Once established, its rhizomes form a dense mat that spreads throughout the soil under a polymeria patch. Polymeria spreads from these rhizomes and can rapidly re-establish from the rhizomes if the above ground plant material is removed by cultivation, chipping or knock-down herbicides.

Polymeria is an erect plant, 7 – 25 cm tall. Its leaves are green to grey or silver in colour and are covered in fine hairs. Polymeria has a prominent pink or white trumpet-shaped flower, with a yellow centre, 2 – 2.5 cm in diameter. It produces large, brown, velvety seeds, 3 – 5 mm across, with one or two viable seeds per seed capsule. Polymeria spreads from both seeds and rhizomes.

Polymeria was established on this area in the Moree watercourse prior to the development of the road.

NO HERBICIDES ARE REGISTERED FOR CONTROLLING POLYMERIA. A PERMIT MUST BE OBTAINED FROM THE NATIONAL REGISTRATION AUTHORITY BEFORE USING A HERBICIDE TO CONTROL POLYMERIA IN ANY SITUATION.

Polymeria can grow all year round in warmer areas, but is frost sensitive and is burnt off by frosts. Some shoots may persist through winter and new shoots will emerge early in spring. Plants grow rapidly over the warmer months. Flowering normally commences in mid-summer.

Polymeria patches are relatively stable, but spread slowly year after year. Once polymeria becomes established, it competes strongly with cotton, and is resistant to most management approaches. Patches of polymeria with a density of 100 stems/m^2 or more can reduce cotton yield by at least 50%. This, and higher densities, are common in many patches. Polymeria competes strongly for soil water and nutrients, depleting the cotton crop of these resources.

Cotton generally establishes poorly on polymeria patches, often resulting in islands of solid green (polymeria) amongst cotton rows. If unchecked, these islands can easily grow to 50 or 100 m across. Eventually, polymeria can spread from small patches to cover a significant proportion of a field. On one field at Twynam North, the area of polymeria increased by approximately 1% per year over an 8-year period, rising from 5.6% of the field area in 1988 to 14% in 1996. No cotton grew to maturity on these patches. In 1996, this represented a yield loss of 158 bales or $94 000 on this field alone. A number of other fields had smaller infestations.

It is estimated that dense infestations of polymeria are established on over 2500 ha of cotton country. Lighter infestations occur on a much greater proportion of the cotton area. These lighter infestations are more easily managed, and should be managed to prevent them becoming major problems. Special care should be taken to avoid spreading this weed when developing country infested with polymeria.

Polymeria forms dense patches. Cotton generally doesn't grow to maturity in these patches.

Inter-row cultivation delays polymeria growth, but shoots re-emerge from underground rhizomes. Inter-row cultivation doesn't control the weed in the plant row.

Cultivation

Polymeria has been regularly subjected to cultivation operations ranging from light inter-row cultivation in moist fields, through to deep cultivation under dry conditions. Polymeria is not controlled by normal cultivation practices, but cultivation in dry conditions may set polymeria back. Heavy cultivation in dry conditions may assist with controlling polymeria.

Cultivation in moist conditions can spread polymeria, as polymeria can establish and grow from small pieces of rhizome spread by the cultivator. Cultivators can inadvertently carry polymeria pieces into new fields where they may establish.

Polymeria's tolerance to cultivation is probably due to its deep rooting habit, with rhizomes penetrating well over a metre into the soil. Standard cultivation is at best only trimming surface growth, allowing plants to re-establish from the rhizomes below the cultivated zone.

NO HERBICIDES ARE REGISTERED FOR CONTROLLING POLYMERIA. A PERMIT MUST BE OBTAINED FROM THE NATIONAL REGISTRATION AUTHORITY BEFORE USING A HERBICIDE TO CONTROL POLYMERIA IN ANY SITUATION.

Herbicides for managing polymeria

A range of herbicides has been trialled for controlling polymeria, over a number of seasons, with mixed and often poor results. In the field, these poor results may be related on occasions to poor spraying conditions, stressed plants and the extensive mat of polymeria rhizomes present in polymeria patches. Herbicides are generally far less effective on stressed plants and the extensive rhizome mats may well mean that plants present on the surface in adjoining plots are attached to the same rhizomes, potentially reinfesting treated plots from rhizomes in untreated plots, diluting the herbicide effect from untreated plants or controlling untreated plants through the connected plants in treated plots.

Many herbicides burn-off the above-ground plant material, but the weed rapidly reinfests from the large mass of rhizomes present under the polymeria patches. These rhizomes act as a continuous source of reinfestation.

Consequently, it is likely that growers treating a whole patch of polymeria will get better results than is indicated from the plot experiments in this article.

Nevertheless, the results reported here have been highly variable even in small pot experiments where spraying conditions are favourable, plants are not moisture stressed and no rhizome mat is present.

No herbicides are registered for controlling polymeria.

Best results for controlling polymeria have been obtained with applications of Arsenal, atrazine, Basagran, Grazon, Roundup, Starane and 2,4-D. A range of other herbicides, including Ally, dicamba, diuron, Express, Garlon, Glean, Staple and Tordon have been trialled, but do not satisfactorily control polymeria.

A permit must be obtained from the National Registration Authority before using a herbicide to control polymeria in any situation.

Imazapyr (eg. Arsenal®)

Arsenal is a residual soil sterilant, effective in controlling most plant species. Arsenal is both root and shoot absorbed, acting as both a contact herbicide and a residual herbicide. Arsenal is highly persistent, with a half-life of up to 142 days. It can control weeds for up to three years when applied at the registered rate. It is ideal for controlling weeds on roadways, the outsides of channel banks, and other non-crop areas.

Arsenal is weakly adsorbed to soil and can move many metres from the site of application. It should never be applied in-crop or in an area where soil or water movement can carry the herbicide into a sensitive (crop) area.

Arsenal inhibits acetolactate synthase, a key enzyme in the plant's metabolic pathway. This inhibition rapidly leads to plant death.

Arsenal gave short-term control of polymeria when applied at 2 L/ha or more (Table 1). Better control was achieved with higher rates (Table 2). However, some polymeria persisted in areas sprayed with Arsenal, even when applied at rates as high as 6 L/ha (Table 2).Thabks Tony

Table 1. *Polymeria control in cotton using over-the-top applications. The treatments were assessed 63 days after the initial treatment on December 20, 1996.*

Treatment	Application(s)		% control
	20 Dec	15 Jan	after 63 days
Untreated	-	-	0
Arsenal	0.5 L/ha	-	50
Arsenal	1 L/ha	-	53
Arsenal	2 L/ha	-	83
Roundup CT	2.4 L/ha	-	20
Roundup CT	-	2.4 L/ha	43
Roundup CT	2.4 L/ha	2.4 L/ha	53
Staple	-	240 g/ha	0
Staple	120 g/ha	120 g/ha	7

Table 2. *Polymeria control in fallow, sprayed on October 10, 1996. Treatments were assessed at 97 and 376 days.*

Treatment	% control	
	97 days	376 days
Untreated	0	10
Ally 10 g/ha	29	64
Ally 30 g/ha	30	24
Arsenal 2 L/ha	79	83
Arsenal 6 L/ha	92	99
Express 30 g/ha	22	24
Express 90 g/ha	36	46
Garlon 100 mL/ha	17	24
Garlon 300 mL/ha	44	27
Glean 20 g/ha	52	53
Glean 60 g/ha	6	0
Starane 2 L/ha	58	36
Starane 6 L/ha	70	65

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A dark patch of dead plants from arsenal used to control polymeria on a channel bank.

Arsenal must never be used in a crop area.

Triclopyr & picloram (eg. Grazon™)

Grazon is a mixture of picloram and triclopyr. It is effective on a wide range of difficult-to-kill, broad leaf weeds. Grazon is a residual herbicide, with both shoot and root activity. It is not safe to apply to cotton, and has a plant-back to cotton of many months. Grazon can be used in non-cotton areas and fallow fields. It has a plant-back to wheat and barley of 2 to 4 months (depending on the application rate). Always check the product label before using a herbicide.

Triclopyr is moderately persistent, with a half-life of about 30 days. Picloram is more persistent, with a half-life of around 90 days, although it can break down much more quickly under warm, moist conditions, and more slowly under cool, dry conditions. Picloram is highly leachable. Both chemicals have the same mode of herbicidal action, acting on the plant's cell walls, causing cell elongation, and affecting cell division, causing plant death.

Grazon gave good control of polymeria when applied at 2 L/ha, with applications in December and February (Table 3), reducing the polymeria population to negligible levels after 3 seasons of application. Nevertheless, six years of applications were required to eradicate a polymeria patch. Grazon is suited to spot-applications in fallow fields and non-cotton areas.

Interestingly, a single application of Grazon in March each season gave no control of this weed, highlighting the importance of repeated applications for polymeria management.

Table 3. *Polymeria control in a fallow. Herbicides have been applied at the nominated time each season since December 1999. Herbicides were applied regardless of the condition of the polymeria (stressed or actively growing). Polymeria rated from 0 (bare ground) to 100% ground cover of plants.*

Treatment	Visual assessment of weed rating at: Initial 10 Dec 99	1 year 19 Dec 00	2 years 6 Dec 01	2.3 years 19 Apr 02	3.6 years 11 Jun 03	5 years 19 Jan 05	6 years 22 Dec 05
Untreated	33	35	60	77	73	50	50
Grazon 2 L/ha (Mch)*	-	-	43	53	30	40	40
Grazon 2 L/ha (Dec & Feb)	80	17	5	2	3	1	0
Roundup CTXtra 6 L/ha (Sept)	47	38	50	77	53	14	5
Roundup CTXtra 6 L/ha (Sept & Dec)	87	33	43	43	30	17	3
Roundup CTXtra 6 L/ha (Nov & Jan)	53	28	25	17	10	10	0
Roundup CTXtra 6 L/ha (Mar)	70	53	73	77	25	22	12
Roundup CTXtra 6 L/ha (Sept, Dec & Mar)	47	2	1	1	0	0	1
Roundup CTXtra 18 L/ha (Nov)	23	34	63	53	60	37	10
Roundup CTXtra 18 L/ha (Nov & Jan)	60	27	5	0	0	1	1
Starane 2 L/ha (Mar)	50	60	60	63	60	20	6
Starane 2 L/ha (Dec & Feb)	33	4	4	5	2	5	0
Tordon 2G 10 kg/ha (Nov & Feb)	47	53	22	43	9	13	34
Tordon 75D 3 L/ha (Mar)	33	33	25	43	4	10	5
2,4-D amine 2.5 L/ha (Mch)*	-	-	73	90	28	30	37
2,4-D amine 5 L/ha (Mch)*	-	-	10	17	10	7	18
2,4-D amine 10 L/ha (Mch)*	-	-	60	60	60	33	30

Note. These treatments were established in spring 2002. Hence the December 2001 assessment is the initial rating for these treatments*

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Triclopyr (eg. Garlon™)

Triclopyr has a much shorter soil half-life than picloram and a much shorter plant-back to cotton, but by itself was ineffective for controlling polymeria at the rates used in the field when compared to the tricolpyr and picloram combination (Table 2).

Picloram (eg. Tordon 2G™)

Surprisingly, picloram at the rate used was also relatively ineffective for controlling polymeria in the field when compared to the tricolpyr and picloram combination (Table 3), possibly due to limited plant uptake of this granular formulation which is relatively insoluble in water.

Glyphosate (eg. Roundup)

Glyphosate kills most plants, including conventional and Liberty Link® cotton plants. It can be applied to fallows, but must be applied through a shielded sprayer, set up to avoid any contact with cotton foliage when applied to conventional or Liberty Link® cotton. Glyphosate can be applied pre-cotton emergence, in-crop as a shielded spray, at defoliation, or after picking.

Roundup Ready herbicide can be applied over-the-top of cotton varieties including the Roundup Ready Flex trait up to 22 nodes of crop growth.

Glyphosate inhibits EPSP synthase, which prevents protein synthesis and kills the plant. Glyphosate is effective against most plants, but the herbicidal effect is quite slow, often taking 2 to 3 weeks. Glyphosate is far more effective when applied to rapidly growing plants. Spray failures can occur when glyphosate is applied to stressed plants.

Glyphosate is rapidly adsorbed and inactivated on contact with the soil. Consequently, it has no residual effect, although its breakdown in the soil is comparatively slow, with a half-life of 47 days.

Glyphosate can be effective in controlling polymeria, with 100% kill observed in some situations. However, the result observed in the field is generally not this good, as:

- glyphosate may not fully translocate throughout the polymeria rhizome mat, leaving some rhizomes alive. Translocation appears to improve as herbicide rates are increased. Polymeria will rapidly regrow from unaffected rhizomes.
- glyphosate is less effective against stressed plants. Moisture and temperature stresses reduce herbicide efficacy.
- thorough spray penetration into a thick polymeria patch is difficult to achieve. Inevitably some plants and shoots are not sprayed.
- polymeria can re-establish from seed.

Glyphosate can be an effective tool for in-crop management of polymeria. Glyphosate must be applied using spray shields to prevent the herbicide contacting the crop foliage unless it is applied to cotton varieties including the Roundup Ready Flex trait.

Glyphosate rate

Glyphosate was often ineffective in controlling polymeria in pots when applied at rates of 1 or 2 L/ha (Tables 1, 5, 9 and 18), although good control was observed on one occasion (Table 14). The level of control was generally, but not always improved as rates were increased to 4 L/ha or more (Tables 5 and 18). Similarly good results were observed in the field, where Roundup CT was applied as an in-crop, directed spray (Table 6), and on actively growing polymeria in a fallow (Table 7).

However, 4, 8 or even 12 L/ha of glyphosate were relatively ineffective in controlling polymeria on some occasions (Tables 4, 9 and 10).

Table 4. *Polymeria control using contact herbicides at standard and heavier rates on plants grown in pots. Dry matter regrowth was recorded from 42 to 168 days after treatment.*

Treatment	Dry matter regrowth (kg/ha)	% control
Untreated	5972	0
Roundup CT 4 L/ha	6646	0
Roundup CT 8 L/ha	8916	0
Starane 2 L/ha	6438	0
Starane 4 L/ha	7028	0
2,4-D amine 2 L/ha	3254	46
2,4-D amine 4 L/ha	2369	60

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Table 5. *Polymeria control using contact and residual herbicides at standard and heavy rates on plants grown in pots. Dry matter regrowth was recorded from 25 to 86 days after treatment.*

Treatment	Dry matter regrowth (kg/ha)	% control
Untreated	1773	0
Atrazine 5 L/ha	1015	43
Atrazine 10 L/ha	585	77
Basagran 2 L/ha	898	49
Basagran 6 L/ha	551	69
Roundup CT 2 L/ha	1320	26
Roundup CT 4 L/ha	556	69
Roundup CT 8 L/ha	178	90
Roundup CT 16 L/ha	0	100
Starane 2 L/ha	2099	0
Starane 6 L/ha	102	94

Table 6. *Polymeria control in cotton using directed spray applications of Roundup CT. Weed density was assessed 19 and 60 days after treatment.*

Treatment (applied Jan 17, 1997)	% control 19 days	% control 60 days
Untreated	0	0
Roundup CT 4 L/ha	37	57
Roundup CT 8 L/ha	67	63
Roundup CT 16 L/ha	93	83

Glyphosate rates between 3 and 6 L/ha generally have been effective in the field when other factors such as low temperatures and moisture stress have not been limiting.

Glyphosate is generally ineffective when applied to stressed polymeria and is not well suited to treating polymeria in fallows, unless the weed is actively growing after good rain (as was the case in Table 7).

Results from repeated applications in fallow have also been very variable, with multiple applications often giving the best results (Table 3). A strategy of multiple glyphosate applications, applied after rain and as required, seems to be the best approach when using this herbicide in a fallow.

Table 7. *Control of polymeria in a fallow using increasing rates of glyphosate. Percentage control was visually estimated relative to an unsprayed treatment, 64 days after spraying. Work by Scarsbrick, Auld and Milne, 1979.*

Treatment	Rate	% control at 64 days
Glyphosate	1 L/ha	23
	2 L/ha	60
	4 L/ha	73
	6 L/ha	77
	8 L/ha	80

Repeated applications of glyphosate in crop can also be effective. In one experiment, where multiple applications of Roundup CT at 4 and 8 L/ha were compared, the best result was from a repeated application of 4 L/ha in November and January, with similar, but inferior results from three applications of 4 or 8 L/ha (Table 8).

The reason for the reduction in control from the additional herbicide application may have been that the polymeria was stressed in October due to cool temperatures, reducing the effectiveness of this application, and plants were further stressed by the herbicide application, making them less receptive to the November application.

Table 8. *Control of polymeria using in-crop directed spray applications of Roundup CT. The results were assessed 104 and 364 days after the first herbicide application on October 24, 1997.*

Treatment	Application(s) (L/ha) 24 Oct	20 Nov	17 Jan	% control 104 days	364 days
Untreated	-	-	-	3	25
Roundup CT	4	-	-	0	15
Roundup CT	8	-	-	0	15
Roundup CT	-	4	4	57	78
Roundup CT	4	4	4	47	57
Roundup CT	8	8	4	67	63

Repeated in-crop applications appeared to be less effective in a second field experiment, possibly due to the length of the experiment (time) and the size of the rhizome mat under the large polymeria patch used in the experiment allowing reinfestation of the treated plots from the surrounding area (Table 9).

Repeated applications of glyphosate in a pot experiment were very effective, espically at the higher rate of glyphosate (Table 10).

Aside from the direct effect on the polymeria, the glyphosate treatments had an added benefit, in that cotton established on the sprayed plots and was estimated to yield around 5 bales/ha on the best treatments. This result was in marked contrast to previous seasons, when no cotton lint was harvested from the polymeria patches. The additional yield on these plots easily justified the expense of the herbicide application. The degree of polymeria control with glyphosate was primarily limited by the need to apply the herbicide as a shielded spray (in conventional cotton), to actively growing plants, leaving unsprayed polymeria in the cotton row.

Table 9. *Control of polymeria using repeated shielded applications of Roundup CTXtra in a cotton crop. Applications were made in December 1998 and 1989, and January and February 1999 and 2000. Weed density was assessed 64, 372 and 483 days after the December 1998 treatment.*

Treatment	Application date(s)			% control		
	Dec	Jan	Feb	64 days	372 days	483 days
Untreated	-	-	-	0	0	0
Roundup CTXtra	-	-	3 L/ha	0	34	26
Roundup CTXtra	-	3 L/ha	3 L/ha	0	0	0
Roundup CTXtra	3 L/ha	3 L/ha	3 L/ha	9	27	18
Roundup CTXtra	-	-	6 L/ha	0	30	23
Roundup CTXtra	-	6 L/ha	6 L/ha	47	56	59
Roundup CTXtra	6 L/ha	6 L/ha	6 L/ha	23	0	16
Roundup CTXtra	-	-	12 L/ha	0	27	53
Roundup CTXtra	-	12 L/ha	12 L/ha	24	41	45
Roundup CTXtra	12 L/ha	12 L/ha	12 L/ha	23	18	28

Table 10. *Polymeria control using repeated applications of Roundup Ready herbicide applied to plants grown in pots. Plants were assessed 1 week after each spray application and 5 weeks after the final spray.*

				% control of alive shoots				
Spray 1	Spray 2	Spray 3	Spray 4	Spray 1	Spray 2	Spray 3	Spray 4	Final
-	-	-	-	0	0	0	0	0
1.5 kg/ha	-	-	-	5	81	88	86	54
1.5 kg/ha	1.5 kg/ha	-	-	27	86	84	59	38
1.5 kg/ha	-	1.5 kg/ha	-	29	84	76	77	69
1.5 kg/ha	1.5 kg/ha	1.5 kg/ha	-	41	94	88	95	100
1.5 kg/ha	1.5 kg/ha	1.5 kg/ha	1.5 kg/ha	49	95	76	36	100
3 kg/ha	-	-	-	21	93	96	95	100
3 kg/ha	3 kg/ha	-	-	25	94	92	95	100
3 kg/ha	-	3 kg/ha	-	32	98	100	100	100
3 kg/ha	3 kg/ha	3 kg/ha	-	42	92	96	100	100
3 kg/ha	3 kg/ha	3 kg/ha	3 kg/ha	45	95	92	95	85

Timing of glyphosate applications

Glyphosate applications during December and January have generally been the most effective (Table 9), with poorer results from earlier applications (Tables 8 and 19).

Commercial applications in early spring, before cotton planting, have given variable results. Rates between 3 and 6 L/ha were applied to a number of patches on a large property over a one-week period in one spring, with good control observed from about half the applications. There was no obvious correlation between the glyphosate rate and the variable results achieved, with poor control observed on some patches sprayed at 6 L/ha, and good control on some other patches sprayed at 3 L/ha.

Variable results were observed from an in-crop experiment, were plots were sprayed over two seasons (Table 9). Best results were from applications of 6 L/ha in January and February, and from a single application of 12 L/ha in February. A single application of 3 L/ha in February gave limited benefit.

Overall, polymeria density was substantially reduced on the trial area over the two seasons, with some evidence of glyphosate translocating well beyond the treated areas.

One of the main difficulties encountered in these experiments was unacceptable damage to the cotton (conventional variety), due to imprecise application of the high herbicide rates through a shielded, hand-held sprayer. Even with better spray equipment, the potential risk of damage to the crop from very high rates of glyphosate is too high to be acceptable. Results from applications of 3 L/ha show that useful levels of control of polymeria could be achieved with this rate, without unacceptable risk of damage to the crop. A polymeria management strategy using one or two in-crop glyphosate applications of 1.5 kg/ha of Roundup Ready herbicide should achieve much improved cotton yields and a year-by-year reduction in the polymeria infestation in varieties utilizing the Roundup Ready Flex trait.

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Additives to enhance glyphosate efficacy

Anecdotal evidence suggested that the use of a spray additive with glyphosate may improve its efficacy for polymeria control. Polymeria has a very hairy leaf surface, which may be a factor contributing to the poor control results observed with lighter rates of glyphosate (3 L and below). A wide range of spray additives was available for use with glyphosate, some of which it was thought may have improved spray efficacy when used on polymeria.

A small range of spray additives was tested at various rates. The addition of PULSE® Penetrant at 1% improved control (Table 11), while the addition of Turbo® Plus at 5% improved control in a second experiment (Table 12). The control from Roundup CTXtra without additive was also very good in both experiments.

Table 11. *Polymeria control in a pot trial using Roundup CTXtra with additional spray additive. Spray was applied at 100 L/ha. Regrowth was measured from 31 to 164 days after treatment.*

Treatment	Dry matter regrowth (kg/ha)	% control
Untreated	5080	0
Roundup CTXtra @ 3 L/ha	294	94
Roundup CTXtra @ 3 L/ha + 1% Bond	3425	33
Roundup CTXtra @ 3 L/ha + 1% Pulse	0	100
Roundup CTXtra @ 3 L/ha + 1% Turbo Plus	898	82

Table 12. *Polymeria control in a pot trial using Roundup CTXtra and additional spray additive. Spray was applied at 100 L/ha. Regrowth was measured from 42 to 126 days after treatment.*

Treatment	Dry matter regrowth (kg/ha)	% control
Untreated	6718	0
Roundup CTXtra @ 3 L/ha	208	97
Roundup CTXtra @ 3 L/ha + 5% Bond	292	96
Roundup CTXtra @ 3 L/ha + 0.2% Pulse	426	94
Roundup CTXtra @ 3 L/ha + 1% Pulse	104	
Roundup CTXtra @ 3 L/ha + 5% Pulse	145	98
Roundup CTXtra @ 3 L/ha + 5% Turbo Plus	0	100
Roundup CTXtra @ 6 L/ha + 1% Turbo Plus	544	92

A lower rate of glyphosate was used in a third experiment (Table 13), where Roundup CT was used at 3 L/ha rather than Roundup CTXtra at 3 L/ha. This gave an 8% reduction in active ingredient and a change in the product surfactant. Turbo Plus at 1% gave a large improvement in spray efficacy in this experiment, although efficacy was further improved by increasing the Roundup rate without including the additive.

Table 13. *Polymeria control in a pot trial with Roundup CT and Turbo Plus spray additive. Spray was applied at 100 L/ha. Regrowth was recorded from 42 to 167 days after treatment.*

Treatment	Dry matter regrowth (kg/ha)	% control
Untreated	9672	0
Roundup CT @ 3 L/ha	2465	75
Roundup CT @ 3 L/ha + 1% Turbo Plus	406	96
Roundup CT @ 3 L/ha + 5% Turbo Plus	542	94
Roundup CT @ 6 L/ha	0	100
Roundup CT @ 6 L/ha + 1% Turbo Plus	0	100
Roundup CT @ 6 L/ha + 5% Turbo Plus	0	100

Extreme care should be taken with in-crop applications of glyphosate, as the herbicide can damage conventional cotton plants, as in this photo (crop plants yellow and stunted).

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Glyphosate formulations

A range of commercial glyphosate formulations is available, with differing types and concentrations of wetters. There is little evidence that these formulations vary in their efficacy for controlling polymeria (Table 14).

Table 14. *Comparison of a range of glyphosate formulations for controlling polymeria in a pot trial. Applications were at 1.0 and 1.5 kg a.e./ha, giving equivalent rates of the various formulations. Dry matter regrowth was recorded from 43 to 173 days after treatment.*

Treatment	Rate	Dry matter regrowth (kg/ha)	% control
Untreated	-	10529	0
Roundup CT	2.2 L/ha	542	95
	3.3 L/ha	0	100
Roundup Max	2.0 L/ha	100	99
	2.9 L/ha	0	100
Roundup Ready	1.4 kg/ha	0	100
	2.2 kg/ha	0	100
Credit & Bonus	1.9 L/ha	339	97
	2.8 L/ha	0	100

Using glyphosate in the field

Based on these results, glyphosate was applied to polymeria patches on commercial fields, with applications at planting and shielded applications in crop. While the results were not outstanding, there was a general reduction in polymeria density on treated fields and cotton was picked from polymeria patches where there previously was no harvestable cotton. The main lessons learned from these trials were:

- polymeria must be actively growing to achieve effective control. Results have been generally poor from applications to moisture stressed polymeria and in cool spring conditions,
- at-planting applications of glyphosate are not always effective but can enabled cotton to establish in polymeria patches,
- in-crop glyphosate applications in conventional and Liberty Link cotton varieties must be through well constructed shielded sprayers, with competent operators. High rates of glyphosate can cause unacceptable damage,
- spot-spraying is the preferred in-crop option, minimising the risk of accidental damage to cotton conventional and Liberty Link varieties, and
- attention to crop agronomy is important to enable satisfactory cotton establishment and growth in polymeria patches.

Glyphosate can be effective in controlling polymeria in-crop, enabling the crop to establish and yield even in thickly infested patches.

Fluroxypyr (eg. Starane®)

Starane is a contact herbicide, effective on a range of harder-to-kill broadleaf weeds. Starane is primarily shoot absorbed, but there can be some root absorption. Starane is moderately persistent, with a half-life of up to 55 days. Starane is moderately leachable. It is not safe to apply on or near cotton.

Starane's mode of action is not clear, but it has a hormone-like action, altering the integrity of the plant's cell walls and affecting cell division. Starane is most effective on actively growing plants.

Starane has been widely trialled by growers, generally at 2 L/ha, but with variable results. Starane has been useful for controlling smaller infestations of polymeria, but is less satisfactory for controlling larger patches. Applications under optimal (glasshouse) growing conditions gave poor results, with no control with Starane at 2 L/ha (Table 5) or 4 L/ha (Table 4). Control improved to 94% when Starane was applied at 6 L/ha (Table 5).

Poor results in the field were observed with Starane at 1 and 2 L/ha sprayed in December (Table 15), and at 2 and 6 L/ha sprayed in October (Table 2). A single application of Starane at 2 L/ha in March repeated over a number of years initially gave poor results, but good control was achieved by the 6th year (Table 3). Repeated applications of Starane at 2 L/ha in December and February gave good results after only the 1st season (Table 3). Growers report that best results have generally been achieved with applications in February and March.

Nevertheless, some viable polymeria rhizomes remain after treatment. As with the other herbicides, a polymeria management plan based

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on Starane will require repeated strategic applications and spot treatments over many seasons.

Table 15. *Polymeria control in fallow, sprayed on December 22, 1987, and assessed after 65 days. This trial was conducted by Max McMillan.*

Treatment	% control
Untreated	10
Basta 3 L/ha	6
MCPA Amine 1 L/ha	22
Starane 1 L/ha	54
Starane 2 L/ha	62
2,4-D Amine 1 L/ha	22
2,4-D Amine 2 L/ha	44
2,4-DB 1.7 L/ha	12
2,4-D Amine 1 L/ha + Ally 10 g/ha	14

2,4-D amine

2,4-D amine has been widely trialled for controlling polymeria. It is generally applied in autumn, after cotton is defoliated and no longer susceptible to the herbicide. 2,4-D must never be applied during the cotton season, as cotton plants are extremely sensitive to the herbicide. Drift onto cotton from an application of 2,4-D can cause a big reduction in cotton yield.

There have been reports of good control of polymeria using 2,4-D, but these reports have not been repeated when using standard rates. 2,4-D applied in autumn burns-off the polymeria foliage, which then dies off over winter. The 2,4-D appears to have given very good control at this point, as in Table 16.

Table 16. *Polymeria control in a fallow using 2,4-D and other herbicides, applied on March 14, 1983 and assessed in July, 112 days after spraying. Work by Neville Strachan.*

Treatment	% control
Untreated	0
2,4-D Amine 2 L/ha	100
2,4-D Ester 1.25 L/ha	96
Dicamba 1.4 L/ha	0
Glean 30 g/ha	0
Roundup 2 L/ha	43
Tordon 50-D 1.4 L/ha	96
Dicamba 1.4 L/ha + 2,4-D Amine 2 L/ha	96
Roundup 2 L/ha + 2,4-D Ester 1.5 L/ha	100
Tordon 50-D 1.4 L/ha + 2,4-D Amine 2 L/ha	96
Tordon 50-D 1.4 L/ha + Dicamba 1.4 L/ha	96
Weedazol TL Plus 5.6 L/ha	43

However, the weed will often re-emerge in spring with little apparent affect from the treatment. 2,4-D amine at 4 L/ha applied in June gave some short-term control, but had no longer-term benefit (Table 19). 2,4-D amine applied at 1 or 2 L/ha earlier in the season also gave little long-term control of polymeria (Table 15).

Nevertheless, a very good result was observed from 2,4-D amine applied at a double rate in autumn following rain and followed by cultivation (Table 20).

The value of this herbicide may be primarily limited by the need for the weed to be actively growing and the relatively short application window available in autumn.

2,4-D ester

There was no indication that 2,4-D ester was any more effective for controlling polymeria than was 2,4-D amine, when applied at the same rate of active ingredient (Tables 16 and 19). Given that 2,4-D ester has even more issues and usage limitations as 2,4-D amine, there seems to be no

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justification to using this formulation for polymeria management.

Using 2,4-D or fluroxypyr in the field

The opportunity to apply 2,4-D and fluroxypyr to cotton fields and fallows is limited by factors including:

- applications in the cotton area can only safely occur in autumn, after defoliation. Applications earlier in the season are not possible due to the extreme sensitivity of cotton to these herbicides,
- 2,4-D and fluroxypyr must be applied to actively growing polymeria. Polymeria growing in cotton will often be moisture stressed, and not likely to respond to herbicide unless rain occurs at or after picking, and,
- 2,4-D and fluroxypyr must be applied before frosts in autumn burn off the foliage, again stressing the plants.

Polymeria is a native plant that occurs through much of the cotton industry. Uncontrolled infestations, such as the plants established on this channel bank, produce seed that can spread the weed into cotton fields.

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Glufosinate (eg. Liberty Link® herbicide)

Glufosinate appeared to have no efficacy on polymeria at the rate used (Basta @ 3 L/ha, Table 15).

Dicamba

There was no indication that dicamba had any efficacy on polymeria at the rate used (Table 16).

Group B herbicides

There are a range of Group B herbicides, some of which have been trialled for use on ploymeria.

None of the Group B herbicides trialled had any activity against polymeria at the rates used. Results with these herbicides can be found in:

- Ally (metsulfuron-methyl) Tables 2 and 15,
- Glean (chlorsulfuron) Tables 2 and 16,
- Express (tribenuron methyl) Table 2, and
- Staple (pyrithiobac-sodium) Table 1.

Other herbicides

Anecdotal evidence in the field suggested that some of the residual herbicides had activity on polymeria.

High rates of atrazine appeared to substantaiily reduce the polymeria growth rate (Tables 5 and 17), indicating the use of atrazine in sorghum or maize crops may have benefit for managing polymeria in these crops. However, cotton growers need to be cautious of the re-cropping interval back to cotton following the use of atrazine, especially if dry conditions occur during the fallow period, potentially slowing the breakdown rate of atrazine.

High rates of basagran also appeared to have some efficacy on polymeria (Table 5), indicating the use of basagran in suitable rotation crops may have benefit for managing polymeria.

Diuron appeared to have little or no efficacy on polymeria at the rates used (Table 17).

Table 17. *Polymeria control using residual herbicides at standard and heavier rates on plants grown in pots. Dry matter regrowth was recorded from 41 to 166 days after treatment.*

Treatment	Dry matter regrowth (kg/ha)	% control
Untreated	1531	0
Atrazine 2 kg/ha	1396	9
Atrazine 4 kg/ha	1149	25
Atrazine 6 kg/ha	538	65
Diuron 2 kg/ha	1293	16
Diuron 4 kg/ha	1310	14
Diuron 5 kg/ha	1155	25

Herbicide combinations

It is unlikely that combinations of herbicide with different modes of action will improve control of this weed, as the different herbicides generally stress the plant, reducing herbicide efficacy.

Nevertheless, glyphosate is commonly used in combination with a Group I herbicide such as 2,4-D or Starane when applied to weeds in winter fallows and could be considered as an option for polymeria control.

Combinations of glyphosate and 2,4-D, or glyphosate and Starane gave no consistent improvement in polymeria control in three experiments. There was evidence of antagonism between Roundup CT and 2,4-D amine in one experiment (Table 18) and no useful improvement in control in a second experiment (Table 19).

Table 18. *Polymeria control using Roundup CT and 2,4-D amine combinations at standard and heavier rates on plants grown in pots. Dry matter regrowth was recorded from 41 to 130 days after treatment.*

Treatment		Dry matter regrowth (kg/ha)	% control
Untreated		638	0
Roundup CT 2 L/ha		1247	0
Roundup CT 4 L/ha		2	100
-	2,4-D 1.1 L/ha	1001	0
Roundup CT 2 L/ha	2,4-D 1.1 L/ha	459	28
Roundup CT 4 L/ha	2,4-D 1.1 L/ha	338	47
-	2,4-D 2.2 L/ha	1282	0
Roundup CT 2 L/ha	2,4-D 2.2 L/ha	510	20
Roundup CT 4 L/ha	2,4-D 2.2 L/ha	85	87
-	2,4-D 4.4 L/ha	1006	0
Roundup CT 2 L/ha	2,4-D 4.4 L/ha	1139	0
Roundup CT 4 L/ha	2,4-D 4.4 L/ha	266	58

Table 19. *Polymeria control using a range of herbicide combinations in a fallow, sprayed on June 26, 1995.*

Treatment	% control	
	104 days	340 days
Untreated	1	0
2,4-D Amine 4 L/ha	21	0
Roundup 4 L/ha	41	0
Starane 2 L/ha	4	0
Roundup CT 1.5 L/ha + 2,4-D Amine 2 L/ha	0	0
Roundup CT 3 L/ha + 2,4-D Amine 2 L/ha	0	0
Roundup CT 1.5 L/ha + 2,4-D Ester 1.5 L/ha	30	0
Roundup CT 2 L/ha + Goal 0.75 L/ha	0	0
Roundup CT 1.5 L/ha + Starane 1 L/ha	19	17

The best result was achieved where combinations of 2,4-D, Starane and Roundup Ready herbicide were applied in a wheat stubble fallow in autumn where cultivation followed soon after the herbicides. The initial control was assessed before the cultivation and final control was assessed 20 months later in the following cotton crop (Table 20).

Best results were achieved with combinations of Roundup Ready herbicide and Surpass, Roundup Ready herbicide and Starane and one combination of Surpass and Starane. The combinations generally but not always gave better control than the herbicides alone, with the single application of 2,4-D amine alone at 4 L/ha giving one of the better results.

Nevertheless, the results were highly variable, showing that a range of herbicides can be useful for managing polymeria takeall, but that growers shouldn't expect to achieve good results from every application. Managing polymeria isn't about a silver bullet, but about a dedicated, long-term approach, with multiple treatments.

Table 20. *Polymeria control using a range of herbicide combinations in a fallow, sprayed on 19th March 2004.*

Treatment	% control	
	14 days	594 days
Untreated	0	0
Roundup Ready 4 kg/ha	25	22
Surpass 4 L/ha	58	61
Roundup Ready 4 kg/ha + Surpass 0.5 L/ha	35	21
Roundup Ready 2 kg/ha + Surpass 1 L/ha	49	73
Roundup Ready 1 kg/ha + Surpass 2 L/ha	53	78
Roundup Ready 0.5 kg/ha + Surpass 4 L/ha	79	83
Starane 2 L/ha	61	40
Roundup Ready 4 kg/ha + Starane 0.25 L/ha	28	25
Roundup Ready 2 kg/ha + Starane 0.5 L/ha	23	72
Roundup Ready 1 kg/ha + Starane 1 L/ha	33	70
Roundup Ready 0.5 kg/ha + Starane 2 L/ha	70	53
Surpass 4 L/ha + Starane 0.25 L/ha	60	66
Surpass 2 L/ha + Starane 0.5 L/ha	45	82
Surpass 1 L/ha + Starane 1 L/ha	38	28
Surpass 0.5 L/ha + Starane 2 L/ha	65	5
Roundup Ready 2 kg/ha + Starane 0.25 L/ha + Ally 3 g	28	38
Roundup Ready 2 kg/ha + Surpass 2 L/ha + Ally 3 g	88	49
2,4-D Amine 4 L/ha	89	76

NO HERBICIDES ARE REGISTERED FOR CONTROLLING POLYMERIA. A PERMIT MUST BE OBTAINED FROM THE NATIONAL REGISTRATION AUTHORITY BEFORE USING A HERBICIDE TO CONTROL POLYMERIA IN ANY SITUATION.

Summary

Polymeria is a deep rooted, rhizomatous, perennial weed that spreads from seeds and rhizomes. It tolerates and can be spread by floods and cultivation practices.

No herbicides are registered for controlling polymeria. A permit must be obtained from the National Registration Authority before using a herbicide to control polymeria in any situation.

There are a range of herbicides with some efficacy on polymeria, including Arsenal, Basagran, diuron, Grazon, glyphosate, Starane and 2,4-D. However, most of these herbicides can't be safely used in cotton and some have long plant-back periods to cotton.

Polymeria can be managed in cotton with repeated applications of glyphosate on actively growing polymeria, applied prior to- or at-planting, and to cotton varieties including the Roundup Ready Flex trait or through well constructed shields, used under appropriate conditions to conventional and Liberty Link varieties. Glyphosate can be spot-applied to polymeria patches to improve crop safety.

Good crop agronomy is important to ensure cotton establishes in polymeria patches, resulting is competitive, strong cotton.

Polymeria growing in fallow can be controlled with glyphosate on actively growing patches and with Starane or 2,4-D in autumn if opportunity arises. The addition of Pulse Penetrant or a non-ionic surfactant to the glyphosate may improve spray efficacy for some formulations but is not necessary when using Roundup Ready herbicide.

Grazon may be useful for controlling polymeria in fallows that are not going back to cotton. Atrazine and Basagran may have some benefit in the appropriate rotation crops. Arsenal may be useful for controlling polymeria on non-cropping and waste areas.

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A grower's experience with polymeria

Polymeria (Take-all) control in Cotton

David Moore (Formerly Senior Agronomist, Colly Farms Ltd)

My experiences refer to the control of this weed in the western Gwydir/Collarenebri area. Having seen this weed grow rapidly as a cotton acre utiliser over a number of seasons, I can say its control is not easy to achieve and involves having a large amount of patience and deep pockets.

The key to controlling polymeria revolves around attacking it when it is actively growing, has a large enough leaf mass, and warm temperatures – not unlike controlling nutgrass. The critical time, therefore, is from early December, through to the end of the irrigation cycle in irrigated cotton. In this period, the weed grows very well, being well fed by both nutrients and water. The leaf surface is covered with tiny hairs that can make uptake of any herbicide very difficult. This is why treatment in times of higher temperature/relative humidity is better than in cooler periods.

The aim with all these treatments has been to reduce the number of shoots/m^2 so that the current, or following crop has a greater chance of producing economically viable cotton yield.
Treatments I have tried are;

1. **Phenoxy herbicides in the Autumn.**

   I have found these applications (of up to 5 L/ha of 2,4-D amine) to be ineffective.

2. **Fluroxypr (Starane) herbicide applied in summer**

   Have seen very good results with this product at rates of around 2 L/ha. The drawback is this products volatility and propensity to volatilise and effect nearby crops. It may be an option in a fallow with adequate buffer.

3. **Deep ripping/cultivation in a fallow situation.**

   The mass of rhizomes that are under a patch of polymeria is incredible, as is the depth to which they can be found. Shallow cultivation that minimally disrupts the growth is ineffective, with smaller pieces of rhizomes being transplanted and growing with the next rainfall.

   Therefore, any cultivation must be aggressive and the transplanted rhizomes need to dry out for a long time before any water is added to the system.

   Unfortunately, when these fields come back into irrigated production, the frequency of watering and warm summers mean that the weed is back with two seasons.

4. **Glyphosate in the fallow**

   Again needs to be actively growing with adequate leaf mass - using rates of applied 450 g/L product need to be around 6 L/ha.

   Have seen good reductions in numbers from these applications.

5. **Shielded applications of glyphosate in crop.**

   Have seen up to two applications of high rates of glyphosate in crop via a shielded sprayer give very good results. Again the rate needs to be around 6 L/ha.

6. **Industrial residual herbicides in field**

   Have seen a Imidazolinone product (Arsenal) used in field on heavily infested patches of polymeria. While there was a dramatic decrease in shoots per square metre, there was no total reduction. This accompanied with the fact that these areas will not yield cotton for the following two seasons and the fact that treated soil may move through the field makes this option an unfavoured one.

   However, it may be an option in controlling patches in head ditches, roadsides etc. with a back pack application. Needless to say, care in application is critical.

Summary

I favour applications of glyphosate in the fallow or shielded applications in crop. These applications, timed when the weed is actively growing under high humidity, have given good results. These applications followed up by an application of Fluroxypr in early autumn also help to reduce the numbers of shoots per metre in the following crop.

The ability to use GPS to accurately record patches of polymeria and assess the degree of control achieved is advantageous.

The key is to not let your fields get to the stage that areas of your fields are unproductive and require such treatments as mentioned above. If you have some infested fields, isolate them and make rig hygiene a priority.

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MANAGING BELLVINE IN COTTON

Graham Charles
(NSW Dept of Primary Industries)

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The morning glory family in cotton

The morning glory family includes over a dozen weedy species that can be found in the cotton growing area of Australia. A number of morning glory species are also major problem weeds in parts of the US cotton industry.

The most commonly found morning glories in Australian cotton are cowvine (also called peachvine, *Ipomoea lonchophylla*), bellvine (*Ipomoea plebeia*), common morning glory (*Ipomoea purpurea*) and desert cowvine (*Ipomoea diamantinensis*). These plants have many similarities but can be distinguished by leaf shape in seedling and older growth stages as shown.

They are aggressive, highly competitive weeds that can grow through and over a cotton crop, tangling inter-row and harvesting machinery. This climbing habit is more apparent in bellvine and common morning glory, which can emerge above even a dense cotton crop later in the season.

Cotyledon and adult leaf shapes can be used to distinguish the morning glory species most commonly found in Australian cotton crops. The plants are (top to bottom): bellvine, peachvine, common morning glory and desert cowvine.

Bellvine (top) and common morning glory (bottom) can climb up through a cotton crop and emerge above the crop later in the season.

The bellvine plant

Bellvine is found throughout much of the Queensland cotton area, and is spreading in northern NSW.

It is an annual weed that emerges following rainfall and irrigation events in spring and summer, and grows rapidly over the warmer months. Bellvine plants are not frost tolerant and are killed by frosts.

Bellvine seeds appear to have little seed dormancy. Seeds germinate readily and high densities of seedlings can establish with cotton in spring. Seedlings grow rapidly after emergence during warm weather and develop long, twining branches. Large plants may be 3 to 4 m in diameter and can form dense clumps, potentially growing over the top of other plants.

Bellvine plants grow vegetatively through spring and early summer and commence flowering when day-length begins to decrease in late summer. Bellvine flowers prolifically over late summer and autumn, each plant producing masses of seed capsules, with 4 seeds per capsule.

Large numbers of bellvine seeds may be present in the soil seedbank. Soil cores from heavily infested cotton fields detected bellvine seed densities in the range of 100 - 3000 seeds/m^2, with 8800 seeds/m^2 the highest recorded density. Bellvine seed densities in the soil fluctuated greatly within a small distance, indicating both the tremendous seed production capacity of this species and its relatively short seedbank life.

Bellvine seeds do not readily germinate from the soil surface, but seedlings are able to emerge from down to 10 cm soil depth, with seedlings most freely emerging from down to 4 cm (Figure 1). Emergence from 1 and 2 cm depth commenced within 4 days of planting, with most seeds emerging from the shallower depths within 5 weeks of planting.

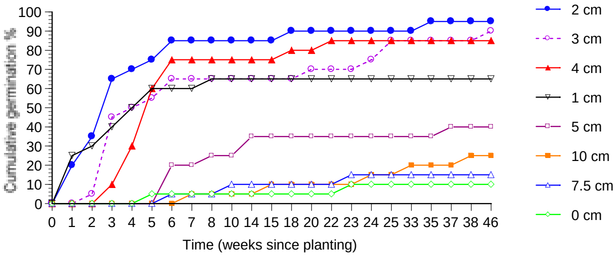

Figure 1. *Emergence over time of bellvine seeds planted at 0 – 10 cm depth. No emergence was observed for seeds planted at 15 and 20 cm.*

Bellvine, another weedy member of the morning glory family, can be troublesome in Australian cotton. It is a vine weed that can choke cotton plants and cause problems for cultivation and harvesting machinery.

Bellvine plants may form dense clumps and can grow over the top of other plants.

Strategies for managing bellvine

Bellvine is most susceptible to control in fallows and rotation crops such as cereals and sorghum crops. Plants are easily controlled with shallow cultivation to 5 cm. Bellvine seedlings can also be controlled using heavy applications of glyphosate in fallows and with phenoxy herbicides in fallows, cereal and sorghum crops.

Bellvine is difficult to control in cotton and other broadleaf crops. Consequently, this weed is best managed using an integrated weed management approach, managing the weed in cotton using multiple tools and reducing the problem over time by preventing weed set in fallows and rotation crops. Care must be taken to ensure these herbicides do not drift onto susceptible crops such as cotton.

Effective control of bellvine in fallows, cereal and sorghum crops is a practical solution for this weed because the bulk of seed production occurs in late summer and autumn, giving a wide window of opportunity for control, and bellvine seeds don't have a long seedbank life. Consequently, it should be possible to deplete the seedbank and achieve a large reduction in weed pressure within 2 or 3 seasons if all bellvine plants can be prevented from setting seed for this period. This strategy assumes favourable conditions and a large germination of bellvine seedlings each season.

Nevertheless, it is important to manage bellvine in cotton so that cotton yields are not compromised, and to ensure minimal return of weed seed to the seedbank in each cotton crop.

Pre-emergent control of bellvine in cotton

Of the residual herbicides tested, trifluralin at 2.8 L/ha gave the best residual control of bellvine, reducing emergence 1 week after herbicide application by 77%, and by 67% at 4 weeks (Table 1). Diuron at 3.5 L/ha gave some suppression of bellvine emergence for the first 2 weeks after application, and a small reduction at 8 weeks.

The bellvine seedlings that emerged through these herbicides grew normally, except on the Zoliar treatments, where a high rate of post-emergence seedling mortality was observed (Table 1). Consequently, the high rates of trifluralin and Zoliar both caused reductions in the number of established bellvine seedlings present 8 weeks after treatment, but in both cases, some bellvine seedlings were still able to establish through these treatments. Diuron at 3.5 L/ha and Zoliar at 2 kg/ha also caused small reductions in seedling establishment.

Table 1. Bellvine control (emergence% and establishment) with pre-emergence herbicides applied in pots.

Herbicide	% Cumulative seedling emergence				% establishment	
	1 week	2 weeks	4 weeks	8 weeks	4 weeks	8 weeks
Trifluralin 1.4 L/ha	43	51	52	57	41	43
Trifluralin 2.8 L/ha	10	17	18	22	13	18
Stomp 1.5 L/ha	57	64	66	69	52	59
Stomp 3 L/ha	42	55	62	63	43	46
Dual 1 L/ha	38	50	55	57	45	47
Dual 2 L/ha	42	51	59	62	45	46
Diuron (500 g/L) 1.75 L/ha	40	55	58	60	54	56
Diuron (500 g/L) 3.5 L/ha	22	34	45	46	37	39
Cotoran (500 g/L) 2.8 L/ha	38	56	62	64	53	58
Cotoran (500 g/L) 5.6 L/ha	35	46	55	57	45	49
Cotogard (250+250 g/L) 2.5 L/ha	55	56	66	70	58	61
Cotogard (250+250 g/L) 5 L/ha	38	55	57	59	50	52
Gesagard (500 g/L) 2.25 L/ha	46	58	62	63	56	59
Gesagard (500 g/L) 4.5 L/ha	48	54	55	58	50	51
Zoliar 2 kg/ha	53	55	58	63	39	39
Zoliar 4 kg/ha	40	48	52	53	28	28
Untreated	44	52	55	56	52	53

Better results for these herbicides were observed in the field, although some bellvine seedlings still established in even the best treatments.

Pre-planting applications of Zoliar and diuron gave good control of bellvine in a Roundup Ready cotton crop at Theodore (Table 2). These treatments reduced bellvine densities by 99 and 93% respectively in December, compared to the untreated plots.

Table 2. Bellvine control with pre-emergence herbicides applied in a Roundup Ready cotton crop at Theodore. Roundup was applied over-the-top after the October survey, and the site was inter-row cultivated after the November survey.

Herbicide	Bellvine plants/m²		
	22 Oct	27 Nov	20 Dec
Zoliar 4 kg/ha	0.0	0.1	0.1
Diuron (800 g/kg) 2 kg/ha	0.4	0.5	0.5
Cotoran (500 g/L) 5.6 L/ha	1.7	2.0	1.0
Convoy DF (440+440 g/kg) 2.9 kg/ha	2.5	3.3	3.2
Prometryn 900 DF 2.5 kg/ha	4.4	8.0	3.5
Untreated	7.5	9.6	6.5

Nevertheless, densities of 0.5 bellvine/m^2 are still sufficient to cause problems in cotton and need to be controlled. The Convoy, prometryn and untreated plots maintained very high densities of bellvine plants in this experiment and became unmanageable by mid-season.

Residual herbicides applied prior to planting suppressed bellvine seedling growth and reduced bellvine numbers by 50-60% compared to an untreated plot in the foreground, but 5-10 seedlings/m row still established and required control early in crop life.

The residual herbicides were much more effective in a Roundup Ready cotton crop at Emerald, where multiple Roundup Ready Herbicide applications were made during the season (Table 3). The relatively low bellvine density (0.3 plants/m^2) on the untreated plots in December showed the importance of using glyphosate as part of a bellvine management system. A high bellvine density had been present on these plots at the start of the season, but was managed by the glyphosate applications even in the absence of residual herbicides. However, bellvine numbers increased by mid-January in the absence of a lay-by residual herbicide, showing the importance of using a combination of weed management tools to manage this weed.

Table 3. Bellvine control with pre-emergence herbicides applied in a Roundup Ready cotton crop at Emerald. Roundup Ready Herbicide was applied twice over-the-top after the October survey, and as a shielded application in early December.

Herbicide	Bellvine plants/m²			
	23 Oct	26 Nov	20 Dec	21 Jan
Diuron (800 g/kg) 2 kg/ha	0.3	0.3	0.1	0.1
Convoy DF (440+440 g/kg) 2.9 kg/ha	0.4	0.5	0.1	0.1
Zoliar 4 kg/ha	0.5	0.4	0.1	0.1
Prometryn 900 DF 2.5 kg/ha	0.5	0.5	0.1	0.2
Cotoran (500 g/L) 5.6 L/ha	2.1	2.0	0.2	0.4
Untreated	11.2	3.5	0.3	1.1

Non-residual herbicides for post-emergence control of bellvine in cotton

A series of glasshouse experiments was conducted to examine a range of herbicide options and combinations for post-emergence control of bellvine in cotton.

None of the post-emergence herbicides tested gave acceptable and repeatable levels of control (kill) of bellvine seedlings and plants, with results varying between experiments. Nevertheless, many of the herbicide options did consistently suppress bellvine growth for at least 4 to 5 weeks post-spraying. This level of suppression is far from ideal but could be useful as part of an integrated bellvine management program.

Roundup Ready Herbicide at 1.5 kg/ha and Envoke at 30 g/ha gave the best control of bellvine seedlings and the best suppression of plant growth as indicated by bellvine leaf number 4 weeks after spraying (Table 4). These herbicides were effective in suppressing the growth of small plants (3 and 13 leaves), but were less effective on much larger plants (68 leaves at spraying).

Table 4. Bellvine control with non-residual herbicides applied post-emergence to plants with 3, 13 and 68 leaves growing in pots. The number of live leaves per plant was recorded 4 weeks after spraying.

Herbicide	% Weed kill			Leaf number after 4 weeks		
	3 leaves	13 leaves	68 leaves	3 leaves	13 leaves	68 leaves
Roundup Ready Herbicide 0.75 kg/ha	50	0	37	4	64	120
Roundup Ready Herbicide 1.5 kg/ha	75	0	12	3	10	110
Basta 1 L/ha	12	0	0	57	128	278
Basta 2 L/ha	37	0	25	47	136	115
Staple 30 g/ha	12	0	0	18	149	283
Staple 60 g/ha	12	0	0	11	133	211
Envoke 15 g/ha	25	0	0	3	83	209
Envoke 30 g/ha	75	0	0	0	28	111
Untreated	0	0	0	106	171	184

Similar results were observed on smaller bellvine plants (Table 5). Roundup at 1.5 kg/ha, Staple at 120 g/ha and Envoke at 15 g/ha all killed some seedlings and gave good suppression of bellvine plants up to 5 weeks after spraying.

Staple and Envoke also have residual activity on some plants, although they are used as non-residual herbicides in cotton. Bellvine seeds were planted into these pots 5 weeks after spraying to test for residual control, but these herbicides had no detectable effect on seedling emergence or growth.

Envoke was less effective in suppressing larger bellvine plants, except at the highest rates, and had little effect on very large plants (Table 6).

These bellvine seedlings were suppressed but not killed by herbicide applied 4 weeks earlier.

Table 5. Bellvine control with non-residual herbicides applied post-emergence to plants with 2, 4, 9 and 17 leaves growing in pots. The number of live leaves per plant was recorded 4 weeks after spraying.

Herbicide	% Weed kill				Leaf number after 4 weeks			
	2 leaves	4 leaves	9 leaves	17 leaves	2 leaves	4 leaves	9 leaves	17 leaves
Roundup Ready 1.5 kg/ha	25	100	37	12	6	0	0	1
Staple 120 g/ha	50	0	12	12	1	3	3	3
Envoke 15 g/ha	0	0	25	12	1	3	9	10
Untreated	0	0	0	0	69	83	123	192

Table 6. Bellvine control with Envoke applied post-emergence to plants with 2, 7, 51 and 143 leaves growing in pots. The number of live leaves per plant was recorded 4 weeks after spraying.

Herbicide	% Weed kill				Leaf number after 4 weeks			
	2 leaves	7 leaves	51 leaves	143 leaves	2 leaves	7 leaves	51 leaves	143 leaves
Envoke 5 g/ha	0	25	0	0	18	67	199	276
Envoke 10 g/ha	0	0	0	0	22	68	169	397
Envoke 15 g/ha	0	0	0	0	7	37	125	313
Envoke 20 g/ha	0	0	0	0	6	12	75	270
Untreated	0	0	0	0	82	155	177	336

A range of herbicide combinations were tested with Roundup Ready Herbicide to improve post-emergence control of bellvine. Combinations of Roundup Ready and Envoke, and Roundup Ready and Staple gave the best control on a field population of actively growing bellvine seedlings (Table 7). Both combinations gave improved control compared to Roundup Ready Herbicide alone, although some seedlings grew through the treatments and required an additional control input.

Table 7. Bellvine control with non-residual post-emergence herbicide combinations applied to bellvine seedlings. % kill was determined by the difference in population prior to and 2 weeks post-spraying.

Herbicide	% kill
Roundup Ready 1 kg/ha + Envoke 30 g/ha	79
Roundup Ready 1 kg/ha + Staple 120 g/ha	50
Daconate 2.8 L/ha + Harvade 450 ml/ha	6
Roundup Ready 1.5 kg/ha	5
Roundup Ready 1 kg/ha + Harvade 450 ml/ha	4
Roundup Ready 1 kg/ha + Daconate 2.8 L/ha	3
Roundup Ready 1 kg/ha	3

Post-emergence control of bellvine with combinations of Roundup Ready and Envoke herbicides was further evaluated in a glasshouse experiment, but did not give consistent improvements over Roundup Ready Herbicide alone (Table 8). Best control was achieved with Roundup Ready Herbicide alone at 1.5 kg/ha.

Bellvine control generally improved as Roundup Ready rates increased, and as Envoke rates increased, but the trend was not consistent through the combinations. Bellvine control was relatively poor with Roundup Ready Herbicide alone at 0.5 kg/ha, and was improved with the addition of Envoke to this Roundup rate. Roundup Ready Herbicide alone at 1.5 kg/ha gave much better bellvine control, with no improvement from the addition of Envoke to this higher Roundup rate.

As previously observed, Roundup Ready Herbicide at 1.5 kg/ha was reasonably effective in controlling bellvine seedlings in this experiment, and effectively suppressed plant growth for 4 weeks post-spraying.

A tank-mix of Roundup Ready and Envoke herbicides gave the best control of bellvine (foreground), but some seedlings survived this treatment

Table 8. Bellvine control with combinations of Roundup Ready and Envoke herbicides applied post-emergence to plants with 4, 8 and 14 leaves growing in pots. The number of alive leaves per plant was recorded 4 weeks after spraying.

Herbicide		% Weed kill			Leaf number after 4 weeks		
		4 leaves	8 leaves	14 leaves	4 leaves	8 leaves	14 leaves
	Envoke 5 g/ha	0	0	0	63	29	128
	Envoke 10 g/ha	0	0	0	66	18	100
	Envoke 20 g/ha	12	0	0	24	7	52
Roundup Ready 0.5 kg/ha		0	0	0	162	50	203
Roundup Ready 0.5 kg/ha	Envoke 5 g/ha	12	0	25	42	45	27
Roundup Ready 0.5 kg/ha	Envoke 10 g/ha	37	12	25	13	38	26
Roundup Ready 0.5 kg/ha	Envoke 20 g/ha	37	0	0	18	40	58
Roundup Ready 1 kg/ha		12	25	12	13	17	24
Roundup Ready 1 kg/ha	Envoke 5 g/ha	87	25	50	2	10	7
Roundup Ready 1 kg/ha	Envoke 10 g/ha	62	50	12	5	11	30
Roundup Ready 1 kg/ha	Envoke 20 g/ha	87	25	50	1	19	4
Roundup Ready 1.5 kg/ha		62	62	62	3	6	12
Roundup Ready 1.5 kg/ha	Envoke 5 g/ha	87	12	25	1	14	8
Roundup Ready 1.5 kg/ha	Envoke 10 g/ha	87	12	50	1	21	6
Roundup Ready 1.5 kg/ha	Envoke 20 g/ha	62	62	37	2	5	9
Untreated		0	0	0	176	235	301

Combinations of Staple and Envoke herbicides at lower rates were also examined in an attempt to find a more cost-effective combination for bellvine control and to broaden the spectrum of weeds controlled by a single application (Table 9). Weed control and suppression improved with increasing rates of both herbicides and with increasing rates of the combinations, although the best control was achieved with the 120 g/ha rate of Staple alone. There was no strong evidence of synergism with these combinations, but the use of a Staple and Envoke combination might be a practical option where a range of other weeds in a field indicate this use.

Table 9. Bellvine control with combinations of Staple and Envoke herbicides applied to bellvine seedlings at 4, 8 and 15 leaves. The number of alive leaves per plant was recorded 4 weeks after spraying.

Herbicide		% Weed kill			Leaf number after 4 weeks		
		4 leaves	8 leaves	15 leaves	4 leaves	8 leaves	15 leaves
	Envoke 5 g/ha	0	0	0	244	116	308
	Envoke 10 g/ha	0	0	0	150	98	444
	Envoke 20 g/ha	12	0	0	84	115	55
Staple 30 g/ha		0	0	0	95	126	364
Staple 30 g/ha	Envoke 5 g/ha	0	0	0	42	111	263
Staple 30 g/ha	Envoke 10 g/ha	0	37	0	68	52	120
Staple 60 g/ha		37	25	0	24	77	90
Staple 60 g/ha	Envoke 5 g/ha	50	0	0	19	68	108
Staple 60 g/ha	Envoke 10 g/ha	75	37	0	1	35	133
Staple 120 g/ha		100	27	100	0	32	0
Untreated		0	0	0	255	251	372

Non-residual herbicides for post-emergence control of bellvine in fallows

A range of herbicide combinations with Roundup Ready Herbicide that might be used to control bellvine and other weeds in fallows were tested on small bellvine plants (Table 10). Good levels of weed suppression were achieved with all combinations, although some reduction in bellvine control was apparent with some combinations. No combination improved on the result from Roundup Ready Herbicide alone. The poor level of control with Roundup + Harvade and Roundup + Daconate combinations was consistent with the poor results seen earlier in Table 7.

Table 10. Bellvine control with Roundup Ready Herbicide combinations applied to bellvine seedlings at 4, 8 and 15 leaves. The number of alive leaves per plant was recorded 4 weeks after spraying.

Herbicide	% Weed kill			Leaf number after 4 weeks		
	4 leaves	8 leaves	15 leaves	4 leaves	8 leaves	15 leaves
Roundup Ready 1.5 kg/ha	75	100	87	0	1	1
Roundup Ready 1.5 kg/ha + Pledge 30 g/ha	87	100	75	0	0	2
Roundup Ready 1.5 kg/ha + Oust 500 g/ha	0	62	0	0	1	2
Roundup Ready 1.5 kg/ha + Hammer 75 ml/ha	62	75	37	0	0	3
Roundup Ready 1.5 kg/ha + Goal 75 ml/ha	12	50	0	0	1	2
Roundup Ready 0.5 kg/ha + Harvade 450 ml/ha	0	0	0	1	1	2
Roundup Ready 0.5 kg/ha + Daconate 2.8 L/ha	0	12	0	1	1	2
Untreated	0	0	0	9	17	31

Residual herbicides for post-emergence control of bellvine in cotton

Prometryn and Convoy at maximum label rates were relatively effective in controlling bellvine seedlings in a glasshouse experiment, but were less effective on older plants (Table 11). The residual herbicides also suppressed seedling growth, but had less effect on older plants.

Diuron was less effective than prometryn in this experiment but gave similar or better results when compared to prometryn in two other experiments, effectively controlling bellvine seedlings at 4 - 16 leaves.

Inter-row cultivation is effective in controlling bellvine seedlings in the furrow but can't control weeds in the plant-line.

Table 11. Bellvine control with residual herbicides applied post-emergence to plants with 3, 13 and 68 leaves growing in pots. The number of alive leaves per plant was recorded 4 weeks after spraying.

Herbicide	% Weed kill			Leaf number after 4 weeks		
	3 leaves	13 leaves	68 leaves	3 leaves	13 leaves	68 leaves
Diuron (900 g/ka) 1 kg/ha	0	0	0	63	93	177
Diuron (900 g/ka) 2 kg/ha	25	0	25	54	93	191
Prometryn (900 g/ka) 1.25 kg/ha	75	0	12	8	104	187
Prometryn (900 g/ka) 2.5 kg/ha	100	12	37	0	48	61
Convoy (440 + 440 g/kg) 1.45 kg/ha	25	0	25	30	86	108
Convoy (440 + 440 g/kg) 2.9 kg/ha	87	0	0	2	87	158
Cotoran (500 g/L) 2.7 L/ha	0	0	0	54	98	255
Cotoran (500 g/L) 5.4 L/ha	12	0	0	59	94	200
Untreated	0	0	0	106	171	184

Herbicide combinations for the control of bellvine in cotton

A range of pre- and post-emergence herbicides and herbicide combinations for bellvine control were assessed in 6 field experiments in commercial cotton fields over 3 seasons. No single herbicide or herbicide combination was able to completely control bellvine in any of these experiments, nor did any single system give consistently superior results.

These inconsistencies were partly a product of biological variation, but were also contributed to by the effectiveness of herbicide incorporation, which varied between fields and seasons, and the soil persistence of the herbicides, which was influenced by soil moisture content, water solubility, soil mobility and large rainfall events.

However, some general principles did emerge from the data sets. It is clear that an effective bellvine management system using the currently available inputs must include multiple management inputs over the cotton season. A treatment that is effective in controlling bellvine seedlings at one point in the season is unlikely to prevent new seedlings from emerging later in the season and may not control older plants that emerged earlier in the season. Consequently, multiple management inputs are required to manage this weed.

Of the pre-planting residual herbicides, diuron and Zoliar gave the most consistent control of bellvine establishment up to the 4 leaf stage of crop development (Tables 2, 3, 12, and 14, Site 4). These herbicides were less effective on the remaining sites (Tables 13 and 14, Site 3). These poor results were associated with poor herbicide incorporation and heavy rainfall events that occurred after the herbicides were applied, probably washing much of the herbicide from the target area.

Table 12. Bellvine control at the 4-leaf crop stage with pre-planting residual herbicides in the 02/03 season.

Herbicide	Emerged bellvine seedlings per m row	
	Site 1	Site 2
Zoliar 4 kg/ha	0	0.5
Diuron (800 g/kg) 2 kg/ha	0.3	0.6
Zoliar 2 kg/ha	1.0	0.7
Diuron (800 g/kg) 1.3 kg/ha	1.0	1.0
Prometryn 900 DF 2.5 kg/ha	2.6	0.3
Cotoran (500 g/L) 5.6 L/ha	2.8	2.4
Cotoran (500 g/L) 2.7 L/ha	3.3	0.4
Convoy DF (440+440 g/kg) 2.9 kg/ha	4.8	0.9
Prometryn 900 DF 1.7 kg/ha	6.5	0.5
Convoy DF (440+440 g/kg) 1.4 kg/ha	9.6	0.9
Untreated	4.4	5.2

Table 13. Bellvine control at the 4-leaf crop stage with pre-planting residual herbicides in the 03/04 season.

Herbicide	Emerged bellvine seedlings per m row Site 3	Site 4
Trifluralin (480 g/L) 2 L/ha + Zoliar 1 kg/ha	24	12
Trifluralin (480 g/L) 2 L/ha + Diuron (800 g/kg) 2 kg/ha	24	14
Trifluralin (480 g/L) 2 L/ha + Zoliar 1 + Convoy (440+440 g/kg) 2 kg/ha	26	16
Trifluralin (480 g/L) 2 L/ha + Zoliar 1 kg/ha + Diuron (800 g/kg) 1 kg/ha	27	14
Zoliar 2 kg/ha	41	9
Untreated	56	17

Table 14. Bellvine control at the 4-leaf crop stage with pre-planting residual herbicides in the 04/05 season.

Herbicide	Emerged bellvine seedlings per m row Site 3	Site 4
Zoliar 1 kg/ha + Diuron (800 g/kg) 2 kg/ha	0.7	2.6
Diuron (800 g/kg) 2 kg/ha + Prometryn (800 g/kg) 2 kg/ha	1.0	4.2
Diuron (800 g/kg) 2 kg/ha	1.2	2.7
Zoliar 2 kg/ha	1.2	3.2
Prometryn (800 g/kg) 2 kg/ha	3.3	4.9
Untreated	4.4	4.5

The over-the-top application of Roundup Ready Herbicide used during the emergence to 4 leaf growth window was very effective and controlled most bellvine seedlings that had emerged with the cotton crop. This good result occurred regardless of the presence or absence of pre-planting residual herbicides, removing nearly all emerged bellvine seedlings from all treatments. Consequently, the Roundup application substantially reduced the benefit gained from the pre-planting residual applications.

The effectiveness of Roundup applied at this stage was related to the generally favourable growing conditions at the time, the uniformly small size of the weeds and the ability to get 100% spray coverage on these weeds. Roundup applications later in the season tended to be less effective for bellvine control, as the bellvine plants were generally larger, full spray coverage was not always achieved, and weeds were often stressed.

Bellvine seedlings continued to emerge following irrigation and rainfall events. A second in-crop herbicide application was required in mid-December to control bellvine seedlings that emerged following the over-the-top Roundup application at the 4-leaf crop stage.

Good results were achieved with both diuron and prometryn applied as directed sprays at this stage, but poorer results were achieved with only a direct Roundup Ready Herbicide application (Table 15). There was no strong relationship between the bellvine density in mid-January and the pre-planting herbicide used, but a much stronger relationship between bellvine density and the use of a residual spray in the early-season application.

Table 15. Bellvine control with herbicide combinations applied pre- and post-emergence to Roundup Ready cotton in the 03/04 season (Table 13, Site 4). The formulations used were: Convoy 440 + 440 g/kg, Diuron 900 g/kg, Roundup Ready Herbicide (RR), Prometryn 900 g/kg and Trifluralin 480g/L.

Pre-planting incorporated	Over-the-top 4 leaves	Directed Mid-Dec	Bellvine plants/m^2 4 leaves	Mid-Dec	Mid-Jan
Trifluralin 2 L/ha + Zoliar 1 kg+ Convoy 2 kg/ha	RR 1.5 kg/ha	Diuron 2 kg/ha	10.7	11.9	1.0
Zoliar 2 kg/ha	RR 1.5 kg/ha	Prometryn 2 kg/ha	9.7	9.8	1.2
Zoliar 2 kg/ha	RR 1.5 kg/ha	Diuron 2 kg/ha	8.6	9.7	1.2
Trifluralin 2 L/ha + Diuron 2 kg/ha	RR 1.5 kg/ha	Prometryn 2 kg/ha	11.2	11.3	1.5
Trifluralin 2 L/ha + Zoliar 1 kg/ha	RR 1.5 kg/ha	Prometryn 2 kg/ha	13.9	15.9	1.5
Trifluralin 2 L/ha + Zoliar 1 kg/ha	RR 1.5 kg/ha	Diuron 2 kg/ha	11.9	14.4	2.6
Zoliar 2 kg/ha	RR 1.5 kg/ha	RR 1.5 kg/ha	8.8	8.2	2.7
Trifluralin 2 L/ha + Zoliar 1 kg/ha + Diuron 1 kg/ha	RR 1.5 kg/ha	Prometryn 2 kg/ha	14.6	16.7	3.1
Trifluralin 2 L/ha + Zoliar 1 kg/ha	RR 1.5 kg/ha	RR 1.5 kg/ha	10	11.5	3.4
Trifluralin 2 L/ha + Diuron 2 kg/ha	RR 1.5 kg/ha	RR 1.5 kg/ha	16.6	15.8	3.5
Trifluralin 2 L/ha	RR 1.5 kg/ha	RR 1.5 kg/ha	15.4	11.5	4.3
Trifluralin 2 L/ha + Zoliar 1 kg/ha + Diuron 1 kg/ha	RR 1.5 kg/ha	RR 1.5 kg/ha	11.8	14.5	5.3
Trifluralin 2 L/ha + Diuron 2 kg/ha	RR 1.5 kg/ha	RR 1.5 kg/ha	23.8	23.5	8.3
Trifluralin 2 L/ha + Zoliar 1 kg + Convoy 2 kg/ha	RR 1.5 kg/ha	RR 1.5 kg/ha	20.4	20.8	8.6
Untreated	RR 1.5 kg/ha	RR 1.5 kg/ha	17	19.1	7.3

Bellvine seedlings continued to emerge following the first directed herbicide application and were again controlled by a directed lay-by spray (Table 16).

Bellvine density at canopy closure was lowest on treatments receiving an early-season residual herbicide, with a smaller influence from the lay-by directed herbicide application. This result occurred because the lay-by herbicide was not able to adequately control relatively large bellvine plants that had survived the early-season spray where no residual herbicide was used. Conversely, a non-residual herbicide application at lay-by was adequate on treatments where a residual herbicide had controlled all bellvine seedlings in the early-season directed spray.

The pre-planting residual herbicide had no influence on the bellvine density at canopy closure, given that nearly all bellvine seedlings were killed by the Roundup Ready Herbicide application at 4 leaves. In an earlier experiment (Table 2), treatments where the bellvine was not managed by the early-post-emergence spray had become unmanageable by lay-by.

The highest bellvine densities were on plots that had received only Roundup Ready Herbicide or Roundup Ready Herbicide + Envoke as both the early season and lay-by directed spray applications.

Table 16. Bellvine control with herbicide combinations applied pre- and post-emergence to Roundup Ready cotton in the 04/05 season (Table 14, Site 4). The formulations used were: Convoy 440 + 440 g/kg, Diuron 900 g/kg, Roundup Ready Herbicide (RR), Prometryn 900 g/kg and Trifluralin 480g/L.

Pre-planting	Over-the-top (kg/ha)	Directed	Directed	Bellvine plants/m^2	
Incorporated	2 leaves	Mid-Dec	Layby	Lay-by	Late-Jan
	RR 1.5	RR 1.5 + Zoliar 1 + Diuron 2	RR 1.5 kg/ha	0.2	0.0
Zoliar 2 kg/ha	RR 1.5	Diuron 2 kg + Envoke 5 g/ha	Diuron 2 kg + Envoke 5 g/ha	0.0	0.1
	RR 1.5	RR 1.5 + Diuron 2 + Prometryn 2	RR 1.5 kg/ha	0.1	0.1
Diuron 2 kg/ha	RR 1.5	Diuron 2 kg/ha	Diuron 2 kg/ha	0.5	0.1
	RR 1.5	RR 1.5 kg + Diuron 2 kg/ha	RR 1.5 kg + Diuron 2 kg/ha	0.5	0.1
	RR 1.5	Diuron 2 kg/ha	Diuron 2 kg/ha	0.2	0.1
Zoliar 2 kg/ha	RR 1.5	Diuron 2 kg/ha	Diuron 2 kg/ha	0.5	0.1
	RR 1.5	RR 1.5 kg + Zoliar 2 kg/ha	RR 1.5 kg + Diuron 2 kg/ha	0.7	0.1
Zoliar 1 + Diuron 2 kg/ha	RR 1.5	RR 1.5 kg/ha	RR 1.5 kg + Diuron 2 kg/ha	1.1	0.2
Prometryn 2 kg/ha	RR 1.5	RR 1.5 kg + Diuron 2 kg/ha	RR 1.5 kg/ha	0.3	0.2
Diuron 2 kg/ha	RR 1.5	RR 1.5 kg/ha	RR 1.5 kg + Diuron 2 kg/ha	1.2	0.3
	RR 1.5	RR 1.5 kg + Envoke 20 g/ha	RR 1.5 + Envoke 20 g/ha	0.2	0.5
Diuron 2 kg/ha	RR 1.5	RR 1.5 kg/ha	RR 1.5 kg/ha	0.9	0.7
Zoliar 1 kg + Diuron 2 kg	RR 1.5	RR 1.5 kg/ha	RR 1.5 kg/ha	2.0	0.8
Diuron 2 + Prometryn 2 kg	RR 1.5	RR 1.5 kg/ha	RR 1.5 kg + Diuron 2 kg/ha	2.4	0.9
Zoliar 2 kg/ha	RR 1.5	RR 1.5 kg/ha	RR 1.5 kg + Diuron 2 kg/ha	2.6	1.0
	RR 1.5	RR 1.5 kg/ha	RR 1.5 kg/ha	1.8	1.1
Zoliar 2 kg/ha	RR 1.5	RR 1.5 kg/ha	RR 1.5 kg/ha	1.6	1.4
	RR 1.5	RR 1.5 kg + Envoke 5 g/ha	RR 1.5 + Envoke 5 g/ha	1.6	1.7
Diuron 2 + Prometryn 2 kg	RR 1.5	RR 1.5 kg/ha	RR 1.5 kg/ha	2.7	1.8

Herbicides systems for managing bellvine in cotton

A herbicide program for managing bellvine in cotton will include multiple inputs throughout the season. These inputs must be targeted against bellvine seedlings, as the weed is most easily controlled at the seedling stage, and must ensure that bellvine seedlings are not able to establish and develop into large plants in the cotton crop. The timing of these inputs will be determined by the number of bellvine seedlings present at any one time.

The 4-leaf over-the-top Roundup Ready Herbicide application is an important component of a bellvine management program in Roundup Ready cotton. Pre-planting residual herbicides may also be used with Roundup Ready cotton, but may not be essential as long as the 4-leaf spray is able to be applied, depending on the spectrum of other weeds that may be present.

Acceptable bellvine control may be achieved later in the season with inter-row cultivation, chipping and directed Roundup applications in Roundup Ready cotton where only a light population of bellvine emerges. However, if a heavy infestation of bellvine is present, early season and lay-by applications of residual herbicide will be required.

Bellvine is more difficult to manage in non-Roundup Ready cotton. An application of pre-planting residuals herbicides is essential in this situation, and early-season and lay-by directed applications of residual herbicides will also probably be required along with inter-row cultivation and chipping passes to control this weed.

Bellvine plants that emerge late in the season should have little impact on the crop and can be controlled at defoliation or after picking.

Pre-harvest glyphosate

A pre-harvest application of glyphosate can be effective in controlling a low to moderate density of bellvine plants which has survived through to harvest, provided the bellvine is actively growing at the time of application. When a pre-harvest glyphosate is applied to an early crop, it should be possible to prevent bellvine from setting seed; any immature seeds already produced will be rendered sterile by the glyphosate.

This strategy will greatly reduce the return of bellvine seed to the seed bank, allowing the bellvine population to be reduced to a more manageable level over 2 or 3 seasons.

It is equally important that any bellvine plants that are not killed by this treatment are controlled soon after picking before they are able to set viable seed.

Alternative residual herbicides for managing bellvine in fallows and rotation crops

Tordon 242 was the only alternative residual herbicide tested which resulted in a long-term reduction in the germination of bellvine seeds (Table 17). Tordon 242 can be applied to cereal and linseed crops, but picloram, one of the constituents of Tordon 242, is toxic to cotton and has a long residual life in the soil (can be up to 300 days half-life). Consequently, there is a minimum 12 month plant-back period to cotton for Tordon 242.

Bellvine germination was also slightly delayed by Atrazine, but the remaining herbicides had no residual effect on this weed.

Pre-planting residual herbicides give little benefit for bellvine control in Roundup Ready cotton where Roundup Ready Herbicide is applied at the 4-leaf crop stage, but may be required to control other weeds, such as the grass weeds in this Roundup Ready crop.

An effective in-crop bellvine management program over 3 season using Roundup Ready cotton and including a pre-harvest glyphosate greatly reduced the bellvine density in this field resulting in a 4-bale crop almost free of bellvine.

Table 17. Bellvine seedling emergence following applications of residual herbicides.

Herbicide	% Cumulative bellvine germination			
	1 week	2 weeks	4 weeks	1 year
Ally 7 g/ha	69	87	89	89
Atrazine (900 g/ka) 3.3 kg/ha	57	77	80	81
Harmony M 45 g/ha	71	87	87	87
Lontrel (300 g/L) 500 ml/ha	90	91	92	93
Sencor (750 g/kg) 470 g/ha	78	83	83	83
Simazine (900 g/kg) 2.2 kg/ha	75	88	88	89
Spinnaker 400 ml/ha	88	88	89	89
Tordon 242 1 L/ha	11	20	21	22
Untreated	82	88	89	90

Summary

Bellvine is an annual weed that is a major problem in cotton. It is an aggressive, highly competitive weed that can grow through and over a cotton crop and can tangle inter-row and harvesting equipment.

Very high densities of bellvine seedlings can emerge with the cotton crop, and successive germinations may occur throughout the season. Bellvine plants do not flower and set seed until late summer and autumn, but are capable of producing very large numbers of seeds per plant.

Bellvine has few hard seeds, and seeds readily germinate in favourable conditions. Consequently, bellvine is not a plant that has a large, long-term seedbank, and should not necessarily be a long-term weed problem. The bellvine population in a given season will largely reflect the amount of seed produced over the past 1 or 2 seasons. A bellvine problem should be able to be greatly reduced by good management over a couple of seasons, provided that no plants are allowed to set seed. Summer fallows and rotation crops such as sorghum may give the best opportunity to manage bellvine.

Bellvine is readily controlled by cultivation and herbicides in fallows, but is very difficult to control in cotton.

None of the pre-emergence residual herbicides were effective in controlling bellvine. Best results were achieved with trifluralin, diuron and Zoliar. Roundup Ready Herbicide applied over-the-top of Roundup Ready cotton at the 4-leaf stage was very effective in controlling bellvine seedlings. Moderate infestations of bellvine can be managed with the combination of pre-planting residuals and in-crop applications of Roundup.

Directed applications of diuron and prometryn are relatively effective in controlling bellvine later in the season in-crop. Both mid-season and lay-by applications of residuals may be required to control bellvine in a heavy infestation. Directed applications of Roundup are not as effective in controlling bellvine at this stage.

An effective bellvine management system will use all the available control options (cultivation, chipping, herbicides, rotations and fallows) in combination.

MANAGING CAUSTIC WEED IN COTTON

Graham Charles
(NSW Dept of Primary Industries)

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Caustic weed, also known as doily weed, is an annual weed that most cotton growers have, but ignore.

Background

Caustic weed (*Chamaesyce drummondii*), also known as doily weed, is an annual weed that most cotton growers have, but ignore. Seedlings emerge throughout the season and can establish at high densities, sometimes resulting in a 'green carpet' in fields, with plants covering much of the furrow and hill. It has a tap root and prostrate growth habit, and individual plants may exceed 50 cm in diameter. Due to its habit and density, it is expensive to chip, and is not normally controlled in cotton; chippers generally 'fail' to see it. However, some growers have found that if caustic weed germinates at sufficient densities early in the season, it can reduce cotton yields. Caustic weed can also be problematic in dryland cotton, competing for moisture and nutrients.

Caustic weed can occur at high densities, sometimes resulting in a 'green carpet' in fields. Individual plants may exceed 50 cm in diameter. Due to its growth habit and density, it is expensive and impractical to hand chip.

Herbicides for pre-emergent control of caustic weed in cotton

Dual and Stomp both gave some level of control of caustic weed when applied and incorporated prior to cotton planting (Table 1). A high rate of Stomp was very effective in controlling caustic weed when surface applied and not incorporated.

Table 1. Control of caustic weed with residual herbicides incorporated pre-planting in an irrigated cotton crop at Narrabri. Control was assessed 5 weeks after application.

Herbicide	% Control
Incorporated	
Dual (720 g/L) 2 L/ha	64
Stomp (330 g/L) 3 L/ha	46
Treflan (400 g/L) 2.8 L/ha	0
Surface applied	
Dual (720 g/L) 2 L/ha	50
Stomp (330 g/L) 4.5 L/ha	90
Cotoran (500 g/L) 4.5 L/ha	23
Untreated	0

Of the other residual herbicides that might be applied pre- or post- cotton planting, Diuron gave the best control 35 days after application (Table 2). These herbicides were applied at layby and were not incorporated.

Table 2. Pre-emergence control of caustic weed with residual herbicides applied at lay-by in an irrigated cotton crop at Warren. Control was assessed after 35 days.

Herbicide	% Control 35 days
Diuron (500 g/L) 2 L/ha	43
Diuron (500 g/L) 3 L/ha	67
Cotogard (250 + 250 g/L) 2 L/ha	20
Gesagard (500 g/L) 2.2 L/ha	7
Cotoran (500 g/L) 2.8 L/ha	0
Untreated	0

Herbicides for post-emergence control of caustic weed in cotton

A range of herbicides were applied post-emergence in January to a heavy infestation of caustic weed growing in cotton (Table 3). Roundup CT, higher rates of Diuron, and Daconate all gave good control of caustic weed 35 days after spraying. The control with Diuron was improved by the addition of DCTron oil at 1%.

Table 3. Caustic weed control with post-emergence herbicides applied over-the-top of an irrigated cotton crop at Warren in January. Control was assessed 18 and 35 days after application.

Herbicide	% Weed kill 18 days	% Weed kill 35 days
Roundup CT 1.2 L/ha	93	100
Roundup CT 1.2 L/ha + Goal 75 ml/ha	100	100
Diuron (500 g/L) 2 L/ha	23	44
Diuron (500 g/L) 2 L/ha + 1% DCTron	65	70
Diuron (500 g/L) 3 L/ha	73	100
Daconate 2.8 L/ha	27	90
Diuron (500 g/L) 1.4 L/ha + Daconate 1.4 L/ha	53	83
Cotoran (500 g/L) 2.8 L/ha	0	3
Cotogard DF (250 +250 g/L) 2 L/ha	10	29
Gesagard (500 g/L) 2.2 L/ha	42	30
Untreated	0	0

The results of a second experiment on a dryland site were similar (Table 4), although the caustic weed was moisture stressed following application and the herbicides were less effective than in the previous experiment. Higher rates proved more effective than lower chemical rates in all cases. Diuron again gave the best level of control, with the addition of DCTron oil improving the efficacy of the Diuron treatments. Roundup CT was less effective on stressed caustic weed, but higher rates could be expected to give a better result. The addition of Goal reduced efficacy rather than improving it in this instance. It is likely that the Goal killed the foliage of the stressed caustic weed before the glyphosate was able to translocate throughout the plant, resulting in the observed reduction in control with the addition of Goal. Daconate was also ineffective in stressed conditions.

Table 4. Caustic weed control with post-emergence herbicides applied on a dryland site at Narrabri in January. Control was assessed 34 days after application.

Herbicide	% Weed kill 34 days
Roundup CT 1.2 L/ha	57
Roundup CT 1 L/ha	53
Roundup CT 0.6 L/ha	42
Roundup CT 1.2 L/ha + Goal 75 ml/ha	24
Diuron (500 g/L) 3 L/ha	92
Diuron (500 g/L) 2.5 L/ha	57
Diuron (500 g/L) 1.5 L/ha	32
Diuron (500 g/L) 3 L/ha + 2% DCTron	100
Diuron (500 g/L) 2.5 L/ha + 2% DCTron	79
Diuron (500 g/L) 1.5 L/ha + 2% DCTron	63
Daconate 3 L/ha	0
Gesagard (500 g/L) 3 L/ha	10
Untreated	0

Summary

Caustic weed is a minor weed of cotton that competes for nutrients and water, and at high densities can reduce cotton yields. It is relatively easily controlled and is often ignored, but it is a persistent weed that may become more problematic in reduced input systems.

Stomp and diuron gave the best control of the residual herbicides, with diuron giving good post-emergence control as well as some pre-emergence control of caustic weed. Glyphosate (Roundup CT) also gave good post-emergence control of caustic weed in an irrigated field.

An integrated weed management system including inter-row cultivation, residual herbicides and glyphosate should effectively control this weed. A mid-season directed application of diuron may be a useful tool in fields where no pre-planting residual herbicides are used.

MANAGING MINTWEED IN COTTON

Graham Charles and Grant Roberts
(NSW Dept of Primary Industries)

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Mintweed is a minor annual weed of cotton. It develops a compact bush and is a prolific seed producer. A single plant can produce up to 180 000 seeds in a season.

Background

Mintweed (*Salvia reflexa*), is generally a minor annual weed of cotton, but has the potential to become a serious pest in some situations. Mint weed has in the past been a major problem weed on some fields in the Macquarie and Upper Namoi valleys, requiring additional inputs of residual herbicides and hand-chipping for control.

Mintweed has a distinctive cotyledon shape and texture and the leaves have a strong mint smell when crushed.

Mintweed is easily identified. It has a distinctive cotyledon shape and texture and the leaves of seedlings and plants have a strong mint smell when crushed.

A large flush of mintweed seedlings can emerge with or soon after the cotton crop and lesser numbers of seedlings may continue to emerge throughout the season. Seedlings grow rapidly in warm spring conditions (more rapidly than the cotton crop) and can quickly smother establishing cotton seedlings, competing strongly for light, water and nutrients. Mintweed seedlings may begin to flower and set seed within 50 - 60 days of emergence and will continue to set seed throughout the season. Later emerging seedlings grow even more rapidly and may begin flowering as soon as 32 days after emergence.

A mature plant can produce up to around 180 000 seeds during the season, but these seeds initially have strong dormancy and will not germinate before the following season. This dormancy is broken over winter, often resulting in a flush of mintweed seedlings in spring.

Mintweed has been problematic in some of the cooler cotton growing areas and may also be problematic in dryland cotton, competing for moisture and nutrients. The first flush of seedlings

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has often been controlled with inter-row cultivation and chipping, but this option is labour-intensive and expensive.

A flush of mintweed seedlings may emerge with the cotton crop and grow rapidly in the warm conditions, quickly smothering establishing cotton seedlings.

Herbicides for pre-emergent control of mintweed in cotton

Dual and diuron both gave some level of control of mintweed when applied and incorporated prior to cotton planting, with the best control coming from a combination of the two herbicides (Tables 1 & 2).

Good soil incorporation and good soil moisture are essential to the success of these pre-planting treatments. Poor incorporation, a cloddy seedbed or rapidly falling soil moisture are all likely to result in poor control of mintweed with pre-planting incorporated residual herbicides.

Stomp, Gesagard, Cotogard and Cotoran were all relatively ineffective in controlling mintweed, but are valuable for controlling a range of other weeds. Trifluralin was not included in the experiments.

Table 1. *Control of mintweed with residual herbicides incorporated pre-planting in an irrigated cotton crop at Carroll. Control was assessed 8 weeks after application.*

Herbicide	% Control
Dual (720 g/L) 4 L/ha	60
Zoliar 4 kg/ha	40
Dual (720 g/L) 2 L/ha	38
Gesagard (500 g/L) 6 L/ha	30
Stomp (330 g/L) 3 L/ha	10
Cotoran (500 g/L) 6 L/ha	7
Diuron (500 g/L) 2 L/ha + Cotogard (250 + 250 g/L) 4 L/ha	40
Dual (720 g/L) 2 L/ha + Cotogard (250 + 250 g/L) 4 L/ha	20
Diuron (500 g/L) 4.7 L/ha *	0
Untreated	0

Note - this diuron treatment was not incorporated.*

Table 2. *Pre-emergence control of mintweed with residual herbicides incorporated pre-planting in an irrigated cotton crop at Carroll (2nd season). Control was assessed 8 weeks after application.*

Herbicide	% Control
Dual (720 g/L) 4 L/ha	73
Dual (720 g/L) 2 L/ha	75
Diuron (900 g/kg) 2.5 kg/ha	65
Cotogard (250 + 250 g/L) 3.5 L/ha	12
Dual (720 g/L) 2 L/ha + Diuron (900 g/kg) 2.5 kg/ha	90
Dual (720 g/L) 2 L/ha + Cotogard (250 + 250 g/L) 3.5 L/ha	46
Diuron (900 g/kg) 2.5 kg/ha + Cotogard (250 + 250 g/L) 3.5 L/ha	41
Untreated	0

Contact herbicides for post-emergence control of mintweed in cotton

Glyphosate and heavy rates of Daconate gave the best post-emergence control of mintweed with contact herbicides (Table 3), although Daconate was less effective in a second experiment (Table 5). Shielded applications of glyphosate should be effective in controlling mintweed in conventional cotton, but may leave an unacceptably large population of mintweed in the cotton plant-line. Roundup Ready Herbicide should be effective in removing the early flush of mintweed in Roundup Ready cotton and Roundup Ready Flex cotton crops. However, later germinations will require additional treatments.

Table 3. *Post-emergence control of mintweed with broadcast herbicides applied to 1 – 5 leaf mintweed seedlings in an irrigated cotton crop at Carroll. There was a population of around 10 mintweed seedlings per m² when the herbicides were applied.*

Herbicide	% Weed kill
Glyphosate 450 2 L/ha	100
Daconate 1 L/ha	10
Daconate 2 L/ha	85
Daconate 3 L/ha	100
Basta 5 L/ha	88
Staple 60 g/ha	60
Staple 90 g/ha	75
Staple 120 g/ha	65
Daconate 1 L/ha + Staple 90 g/ha	83
Daconate 2 L/ha + Staple 60 g/ha	80
Dual (720 g/L) 4 L/ha	10
Dual (720 g/L) 2 L/ha	5
Untreated	0

Dual, which gave good pre-emergence control of mintweed, was ineffective for post-emergence control. Staple appears to have some activity on mintweed, but even at 120 g/ha (the maximum use rate) did not give effective control of this weed. Combinations of Staple and Daconate were included in order to explore a more cost effective way of using Staple, but gave no better control than either herbicide alone.

Alternative herbicides for pre-emergence control of mintweed

Excellent mintweed control was achieved with Atrazine, Simazine and Primextra (a mixture of atrazine and metolachlor). These herbicides are not safe to apply to cotton, but can be used with rotation crops such as maize and sorghum (Atrazine and Primextra (plus Concept for sorghum)), chick peas and faba beans (Simazine).

An option for cotton growers with a heavy infestation of mintweed is to rotate to one of these alternative crops for one or two seasons until the mintweed seedbank is reduced. However, there is an extended plant-back period before it is safe to grow cotton following the use of these residual herbicides, depending on the application rate, soil type and pH and soil moisture (rainfall and irrigation pattern).

Table 4. *Control of mintweed with residual herbicides incorporated pre-planting in an irrigated cotton crop at Carroll. Control was assessed 8 weeks after application.*

Herbicide	% Control
Atrazine (500 g/L) 5.4 L/ha	100
Simazine (900 g/kg) 3 kg/ha	100
Primextra (227 + 223 g/L) 4 L/ha	90
Untreated	0

Fallow herbicides for post-emergence control of mintweed

Although a wide range of herbicides and herbicide combinations are available for controlling weeds in fallows, spray drift can be a major issue with many of these options as most are not safe on other crops, including cotton, and can cause unacceptable levels of damage to crops or pastures if spray drift does occur.

Glyphosate, bromoxynil and atrazine were all effective in controlling mintweed when applied over-the-top of 1 - 4 leaf seedlings (Table 5). However, plant-back issues may occur with atrazine, as previously discussed. Plant-back problems can also occur with some of the other options, although the plant-back periods are much shorter than with atrazine.

Spray.Seed and Basta also gave reasonable control of mintweed, but some seedlings survived these treatments and would have needed to be controlled with a follow up treatment.

Table 5. *Mintweed control with post-emergence herbicides applied over-the-top to 1 – 4 leaf mintweed seedlings in an irrigated cotton crop at Carroll in January.*

Herbicide	% Weed kill
Glyphosate 450 2 L/ha	100
Bromicide 3 L/ha	100
Atrazine (500 g/L) 5.4 L/ha	100
Spray.Seed 4 L/ha	88
Basta 5 L/ha	88
Daconate 3 L/ha	60
Banvel 200 2 L/ha	53
Express 30 g/ha	0
Glyphosate 450 0.6 L/ha + Express 15 g/ha	48
Untreated	0

Summary

Mintweed is a minor annual weed of cotton that can emerge in large numbers at or soon after crop emergence. Mintweed seedlings grow more rapidly than cotton seedlings in spring conditions and can compete for sunlight, nutrients and water.

A pre-planting combination of Dual and Diuron gave the best residual control of mintweed. Atrazine and simazine also gave excellent residual control of mintweed, although these herbicides can not be safely used in cotton.

Glyphosate gave good post-emergence control of mintweed in cotton, and should be an effective management option for this weed in Roundup Ready Flex crops.

MANAGING LIPPIA IN THE COTTON FARMING SYSTEM

Graham Charles
(NSW Dept of Primary Industries)

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Lippia is an aggressive perennial weed that is rapidly spreading through the inland river system.

Background

Lippia (*Phyla nodiflora*), is a highly invasive weed which is rapidly spreading in the Murray Darling Basin, and currently infests over 5 million ha. It is seriously degrading the riparian and floodplain environments in this region, reducing biodiversity and threatening valuable ecosystems.

As well as its major environmental impact, lippia has serious negative implications for the grazing industry. Lippia competes very strongly with all native and introduced pasture species, establishing on what is often the most valuable grazing areas. Once established, lippia out-competes other pasture species, resulting in almost pure lippia stands with little grazing value.

Lippia spreads until it forms an almost continuous mat, out competing other species. Note the lack of any vegetation bulk in this infestation in the Gwydir valley.

Lippia flowers prolifically, establishes readily from seed, and also spreads from vegetative parts that are carried in mud and flood waters. It is a perennial plant that grows rapidly in wet conditions, but can survive prolonged dry periods.

Lippia is extremely tolerant of grazing, but has little grazing value. Neither heavy grazing nor the exclusion of grazing appear to restrict the spread of this weed.

However, lippia doesn't tolerate cultivation, and so isn't normally a problem in conventional farming systems. Yet, lippia has the potential to directly impact the cotton industry in a number of ways.

Lippia and irrigation structures

Lippia has an extensive and well developed root system that enables it to dry the soil to depth. This drying can result in severe cracking in heavy clay soils, opening the soil to erosion. Lippia infested creek and river banks are often unstable and heavily eroded. The same effect could occur on irrigation structures, reducing bank stability, leading to erosion and bank failures.

Lippia could easily establish above the water level in a turkey's nest dam and grow over the banks. If this happens, lippia will eventually cause extensive cracking of the banks, and will inevitably lead to bank failure.

Turkey's nest dams with lippia established on the walls are predisposed to fail.

It is critical that lippia not be allowed to establish on irrigation structures.

Lippia can cause severe cracking, destabilizing banks and causing slumping. (Photo: Mike Lucy)

Lippia and water movement

Heavy infestations of lippia result in a great reduction in the bulk of vegetation on the ground, potentially increasing the rate of water movement and the potential for erosion and soil movement.

Continuing expansion of the lippia infested areas in the river valleys is likely to result in an increase in the rate of water flow in these valleys during flood times, increasing erosion and soil movement problems.

Lippia and farming

Lippia is not a problem in conventional farming systems, as it doesn't tolerate cultivation. However, lippia is likely to become problematic in zero-tillage systems, where it does tolerate the herbicides commonly used.

Inclusion of strategic cultivation into a zero-tillage system may become a necessary management input where lippia becomes a problem.

Lippia and grazing

The spread of lippia in pastures can be reduced by good grazing management, encouraging other pasture species. Competitive pasture species may need to be introduced to degraded areas, and over-grazing and set-stocking should be avoided.

Nonetheless, research from Queensland indicates that lippia is likely to out compete any and all pasture species in the long-term. Careful grazing management is essential to ensure the longevity of pastures in susceptible areas.

Lippia and the riparian zone

Moves by the cotton industry towards better management of the riparian zone are being hampered by heavy lippia infestations where these occur. Re-establishment of native species into areas degraded by lippia will be very difficult and will probably necessitate short-term control of lippia with cultivation and/or herbicides.

Herbicides for controlling lippia

Lippia doesn't tolerate cultivation, but cultivation isn't a desirable option in easily erodible areas, in pastures or treed areas, or in close proximity to water, the areas where lippia is most frequently found.

A range of herbicides that control lippia is available, although repeated applications are always necessary, as lippia rapidly re-establishes from seed and surviving plants and plant pieces.

Lippia is also likely to reinvade clean areas after flood inundation. Management must make allowances for the movement of this weed in flood water, and in high-flow water pumped from rivers during flood events.

A table-drain uniformly infested with lippia was used for a herbicide screening experiment.

Lantana 600®, an Agricrop product, is registered at 5 L/ha for use on lippia on non-crop areas.

The Australian Pesticides & Veterinary Medicines Authority (APVMA) has also approved the use of 2 and 3 way mixtures of glyphosate (450 g/L) at 2.6 - 5.4 L/ha plus 2,4-D amine (225 g/L) at 2.4 L/ha and/or metsulfuron (600 g/kg) at 15 - 30 g/ha for lippia control on fallows in NSW and Qld. Effective control of this weed requires 2 applications over summer when possible. For more information on the permits and herbicide use, refer to the APVMA Permit web site at: www.apvma.gov.au. The current permits also allow for the use of 2,4-D amine (500 g/L) at 2 - 4 L/ha for controlling lippia in pastures.

However, 2,4-D can not be safely used around cotton, and metsulfuron has a long plant-back to cotton and some other species, especially when applied to alkaline soils.

So how effective are glyphosate and Lantana 600 alone?

The best control over a 2 year period from a field experiment in the Namoi valley was observed with Roundup CT® at 20 L/ha and Arsenal® at 6 L/ha (Table 1). Roundup CT at 5 L/ha was also still giving a reasonable level of control after 1 year. This result suggests that repeated applications of Roundup CT at around 5 L/ha are necessary to give effective long-term control of lippia, and are allowed under the current APVMA permit.

Table 1. The long-term control of lippia following a single herbicide application in autumn 2000 in the lower Namoi Valley. Weed kill was assessed 60 days, 1 and 2 years after application.

Herbicide	% Weed kill		
	60 days	1 year	2 years
Arsenal 6 L/ha	67	77	40
Arsenal 2 L/ha	30	10	10
Roundup CT 20 L/ha	100	80	37
Roundup CT 5 L/ha	70	60	27
Lantana 600 6 L/ha	63	43	27
Lantana 600 3 L/ha	53	33	23
Tordon 75D 5 L/ha	97	13	10
Starane 6 L/ha	57	3	10
Starane 2 L/ha	80	3	7
Tordon 242 5 L/ha	30	7	10
Garlon 2 L/ha	77	7	10
Grazon 2 L/ha	47	7	10
Untreated	0	0	3

Note Lantana 600® is the only herbicide registered for the control of lippia. Glyphosate may be used under an APVMA permit.*

Given the high cost of a 6 L/ha rate of Arsenal, the lack of registration of this product for this use and the problems sometimes associated with the use of this herbicide, the results from this experiment don't justify the use of Arsenal to control lippia.

None of the other herbicides that might be used in a fallow over summer, Tordon®, Starane®, or Grazon® were effective in controlling lippia. These results are supported by the findings of Mike Lucy (QDPI&F) and others who recorded similarly poor results from a range of fallow herbicides.

Lippia control was improved by repeated applications of Lantana 600 and Roundup CT (Table 2). Both herbicides gave good results, and better control from a repeated application of a lower rate than was achieved with a single application at a higher rate. Lantana 600 at 5 L/ha (twice) gave very good control after 1 year (90%). Two applications of Roundup CT at 5 L/ha also gave good results on a difficult-to-control weed.

Clearly, both these herbicides gave good levels of control with repeated applications at their label/permit rates and would be suitable for controlling lippia in fallows.

Lantana 600 has an advantage over Roundup CT for spot applications in that it acts extremely quickly when applied to flowering lippia, rapidly dulling the flowers. This readily distinguishes sprayed and unsprayed patches, simplifying spot applications.

Lower rates of Arsenal didn't give control comparable with the results of Lantana 600 or Roundup CT and should not be used for the reasons previously stated.

Table 2. The long-term control of lippia following herbicide applications in summer and autumn 2000/2001. Weed kill was assessed 60 days and 1 year after the initial herbicide application. The % ground cover of other species 1 year after the initial herbicide application is also shown.

Herbicide		% Weed control		% Other species
		60 days	1 year	1 year
Lantana 600 5 L/ha	Lantana 600 5 L/ha	95	90	83
Roundup CT 10 L/ha	Roundup CT 10 L/ha	95	70	57
Roundup CT 5 L/ha	Roundup CT 5 L/ha	95	70	63
Roundup CT 15 L/ha		80	47	60
Roundup CT 10 L/ha		70	55	50
Roundup CT 5 L/ha		57	40	57
Lantana 600 10 L/ha		53	33	73
Lantana 600 5 L/ha		80	47	60
Arsenal 2 L/ha	Arsenal 2 L/ha	100	37	23
Arsenal 1 L/ha	Arsenal 1 L/ha	93	20	37
Arsenal 2 L/ha	Roundup CT 5 L/ha	79	7	27
Arsenal 4 L/ha		93	33	43
Arsenal 2 L/ha		67	10	27
Arsenal 1 L/ha		72	57	60
Untreated		3	7	23

Note Lantana 600® is the only herbicide registered for the control of lippia. Glyphosate may be used under an APVMA permit.*

Combinations of glyphosate + 2,4-D amine and glyphosate + Ally appeared to give some improvement in lippia control compared to these herbicides alone but the onset of drought conditions made it impossible to determine the long-term effect of these treatments (Table 3). None of the combinations gave improved control compared to Lantana 600 but some did give better control than Roundup CT alone.

2,4-D and 2,4-D or metsulfuron combinations with glyphosate could be useful in fallow applications where there is no risk of herbicide drift to sensitive crops such as cotton, and where there is sufficient time between the herbicide application and the following cotton crop.

Table 3. The control of lippia following a single herbicide application in November 2001 in the lower Namoi Valley. Weed kill was assessed 60 days after application.

Herbicide	% Weed kill 60 days
Lantana 600 10 L/ha	82
Lantana 600 5 L/ha	67
Tordon granules 20 kg/ha	52
Roundup CT 5 L/ha	41
2,4-D amine 4 L/ha	28
2,4-D amine 2 L/ha	15
Ally 30 g/ha	15
Roundup CT 2.5 L/ha	7
Ally 15 g/ha	7
Tordon granules 20 kg/ha	4
Roundup CT 5 L/ha + Ally 30 g/ha	67
Roundup CT 5 L/ha + Tordon 20 kg/ha	63
Roundup CT 5 L/ha + 2,4-D amine 4 L/ha	56
Roundup CT 5 L/ha + 2,4-D amine 4 L/ha + Ally 30 g/ha	44
Roundup CT 2.5 L/ha + 2,4-D amine 2 L/ha + Ally 15 g/ha	33
Roundup CT 2.5 L/ha + 2,4-D amine 2 L/ha	30
Roundup CT 2.5 L/ha + Tordon 10 kg/ha	26
Roundup CT 2.5 L/ha + Ally 15 g/ha	15
Untreated	0

Note Lantana 600® is the only herbicide registered for the control of lippia. Glyphosate, 2,4-D amine and metsulfuron may be used under an APVMA permit.*

Roundup CT® at 5 L/ha gave good short and medium-term control of lippia in a table-drain, but also removed all other species..

Management of lippia not only involves the control of the lippia, but also the re-establishment of other competitive species. Lantana 600 is the herbicide of choice where other species are present as it is relatively soft on most other species, leaving more of these species to compete with any re-establishing lippia. This feature is important to the success of a lippia management program, as lippia is likely to reinvade clean areas. Areas treated twice with Lantana 600 at 5 L/ha (Table 2) had the best recovery of other species with 83% ground cover of other species 1 year after the first herbicide application. Lantana 600 will control some other species including galvanised burr, spear thistle and harrisia cactus.

For the same reasons, lower rates of glyphosate should be used where possible to allow for the retention of other species.

Summary

Lippia is a highly undesirable weed and should not be allowed to establish in the cotton industry. Particular care must be taken to ensure that lippia doesn't establish on irrigation structures as its presence is likely to lead to the failure of these structures.

Lippia should be controlled with cultivation where appropriate, or repeated applications of Lantana 600 on non-crop areas, or glyphosate on fallows. Glyphosate plus metsulfuron is the preferred option on fallows on non-alkaline soils, where cotton will not be a following crop.

2,4-D amine may be used to control lippia in pastures provided that there is no risk of spray drift to sensitive crops such as cotton.

MANAGING FLAXLEAF FLEABANE IN COTTON

Jeff Werth, Todd Green, Michael Widderick & HanWen Wu

(Qld. Department of Employment Economic Development and Innovation, University of New England, & NSW Dept. Primary Industries)

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The fleabane family

Flaxleaf or hairy fleabane (*Conyza bonariensis*) is a member of the Asteraceae, or daisy family of plants. The Asteraceae is the largest of the plant families and includes many weedy species, most notably the thistle family.

The Conyza genus (the part of the Asteraceae family including the fleabanes) contains 60 species, found throughout the temperate zones of the world. There are seven *Conyza* or fleabane species in Australia, the three most important species being flaxleaf fleabane, Canadian fleabane (*C. canadensis*) and tall fleabane (*C. sumatrensis*). Flaxleaf fleabane is native to South America and is the most weedy and the most common of the fleabane species in cropping systems in New South Wales and Queensland.

Tall fleabane tends to be the more problematic species elsewhere in the world, but is of minor importance in Australia, where it is most commonly found on roadsides and in pastures.

Flaxleaf fleabane is a member of the daisy family. It has become a major problem in the conservation farming systems of northern NSW, and southern and central Queensland. It is easily confused with tall fleabane and Canadian fleabane.

The flaxleaf fleabane plant

Flaxleaf fleabane is an annual or short-lived perennial weed that is now common right across the cotton industry.

Flaxleaf fleabane germinates between temperatures of 10°C and 30°C, with optimal emergence occurring from 20 - 25°C (Figure 1).

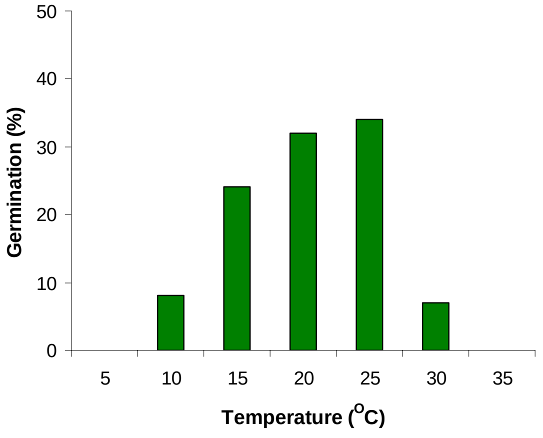

Figure 1*. Temperature range for flaxleaf fleabane germination.*

In the field, this correlates to mild conditions, generally in autumn, early winter and spring. However, there can be some emergence during mid-winter and summer when conditions are right. The likely times for emergence are illustrated in the lifecycle and management tables (Tables 8 and 9).

Flaxleaf fleabane rosettes in mature cotton. These plants are likely to have emerged during mild/wet conditions in mid-summer.

The growth rate of flaxleaf fleabane is affected by the time of its emergence. Plants that emerge in autumn and early winter grow slowly above ground, however below ground the roots continue to grow. This provides the plant with the ability to grow to flowering quickly in warmer spring temperatures. Plants that emerge in spring grow relatively more quickly, putting more resources into above-ground growth, but mature later in summer compared to the plants that established in autumn.

Due to the larger root system, the over-wintered plants are harder to control than plants of the same size that have emerged in spring.

A single fleabane plant is capable of producing over 100 000 seeds. Therefore, even at a low germination percentage (say, 5%), there is potential for 5000 seedlings to emerge at 30°C from just a single, uncontrolled plant.

Each seed has a pappus, or light hairs attached, which enable the seed to be easily dispersed by wind.

Flaxleaf fleabane plants have multiple flowers and can produce a large number of small seeds. The pappus (hairs attached to the end of the seed) assist in wind dispersal.

Most fleabane seeds lose their viability within 12-18 months on the soil surface. However, when buried, fleabane seeds can persist for several years (Figure 2).

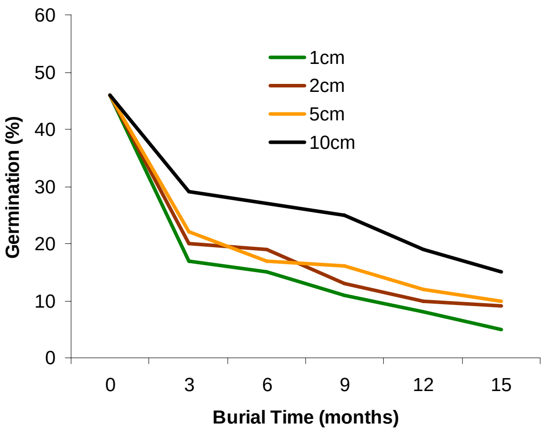

Figure 2. *The persistence of flaxleaf fleabane increases as the depth of seed burial increases.*

Flaxleaf fleabane requires light to germinate. Experiments have shown the even when temperature and moisture conditions are right, fleabane seeds will not germinate in the absence of light. This is illustrated in Figure 3, where no germination occurred under 100% shade, even though conditions were otherwise suitable for germination. However, some germination did occur on 90% shade, indicating that although flaxleaf fleabane requires light, it may not need much light to germinate.

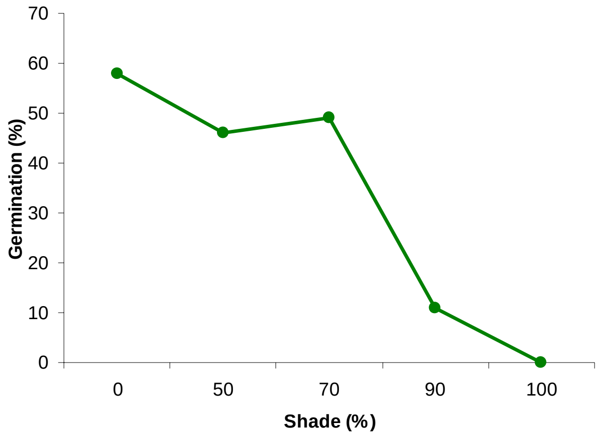

Figure 3. *Effect of partial and complete shading under shade cloth on flaxleaf fleabane germination.*

This is further illustrated in Figure 4, which shows the effect of stubble load and soil type on flaxleaf fleabane germination. Germination was highest on grey soil, followed by red soil with no stubble. In general, as the stubble load increased, flaxleaf fleabane germination decreased. However, even under the highest stubble load of 3.6 t/ha (which equated to approximately 86% shade), approximately 10 - 20% of seeds were still able to germinate, dependant on soil type.

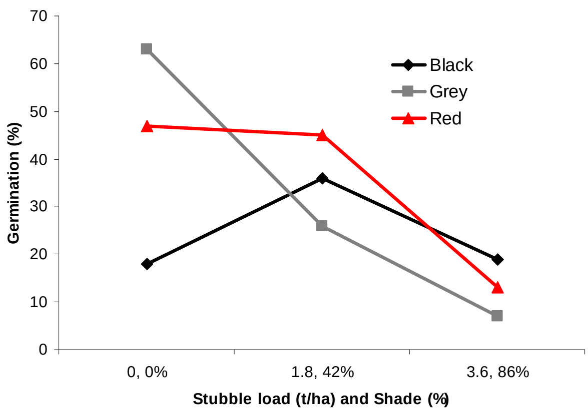

Figure 4. *Effect of shading on flaxleaf fleabane germination, using stubble and three soil types.*

Flaxleaf fleabane seedlings can establish at any time of the year, potentially adding to the seed bank and future problems. (Photo G. Charles).

Strategies for managing flaxleaf fleabane

Successful management of flaxleaf fleabane requires an IWM program centred on reducing the seed bank replenishment. That is, the easiest way of controlling flaxleaf fleabane is to not have it in the first place, or to exhaust the seed bank.

A number of components will be central to any fleabane management program. These include:

- knowing the field history,
- monitoring seedling emergence,
- using a variety of IWM tools, and
- preventing survivors from setting seed.

Field history

It is important to know previous herbicide history, as fleabane populations that have been exposed to glyphosate over a number of years are likely to be more difficult to control with glyphosate compared to populations that have no previous history of glyphosate. In fact, some flaxleaf fleabane populations have had an extensive history of glyphosate exposure have been found to be resistant to glyphosate. Larger fleabane plants from these populations will be almost impossible to kill using glyphosate.

Monitoring seedling emergence

Be aware of when flaxleaf fleabane is likely to emerge. Generally, it is more likely to emerge following rain in late autumn, early winter and early spring. However, flaxleaf fleabane will emerge whenever there are moist and mild conditions, and this could be at any time of year, ever mid-summer. Plants are much easier to control when they are young, so it is important to closely monitor potential fleabane emergence throughout the cropping system, including the fallow period.

Using a variety of IWM tools

It is important to use a variety of chemical and non-chemical tactics to manage flaxleaf fleabane. When herbicides are used as the primary management tools, it is important to rotate herbicide groups. Robust herbicide rates must be used in order to get maximum effectiveness to keep weed numbers low. Keeping weed numbers low is important for resistance management, as resistance is less likely to develop in fields with fewer weeds than in heavily infested fields.

Preventing survivors from setting seed

Control of survivors is vitally important; flaxleaf fleabane's prolific seed production means that even if very few plants are left, they will produce very large numbers of seeds, with the potential for a large, future weed problem. This will considerably reduce the effectiveness of previous control measures and perpetuate the problem.

Controlling flaxleaf fleabane in fallows

Flaxleaf fleabane has emerged as a problem weed largely due to the prevalence of no-till, glyphosate based farming systems. It is obvious in the trial results of Table 1 that glyphosate is much less effective on larger plants. A number of tank-mix partners were trialled for their effectiveness to improve control in fallow. A number of tank-mixes were relatively successful. The most successful in this case was glyphosate mixed with Tordon 75-D, which is now registered for control of flaxleaf fleabane seedlings and young rosette plants.

Table 1. *Effects of post-emergent treatments on flaxleaf fleabane in winter fallow in 2003. Weed kill was assessed nine weeks after application.*

Treatment	Rate (L or g/ha)	% Weed kill
Spray.Seed	2.4	57
Paraquat (rosette < 8 cm)	1.5	53
Roundup CT (rosette < 8 cm)	1.5	88
Roundup CT (rosette > 10 cm)	1.5	13
Roundup CT fb Spray.Seed*	1.5 fb 2.4*	96
Roundup CT + Amitrole T	1.5 + 2.5	93
Roundup CT + Ally	1.5 + 7	90
Roundup CT + Amicide 500	1.5 + 2	97
Roundup CT + Ally + Amicide 500	2.5 + 7 + 1	93
Roundup CT + Tordon 75-D	2.5 + 1	99
Roundup CT + Grazon DS	2.5 + 0.75	98
Roundup CT + Cadence	2.5 + 0.7	96
Roundup CT + Garlon + Ally	2.5 + 0.12 + 7	96
Amicide 500 + Amitrole T	2 + 2.5	94
Amicide 500 + Ally	2 + 7	95

Note. Fb – indicates the first herbicide application was followed by the 2nd herbicide. Other herbicide combinations in this table were tank-mixed.*

Herbicide performance depends largely on weed size and growing conditions at spraying. In general, responses from herbicide applications can be quite slow, with some visual symptoms not becoming apparent till nearly a month after application.

It is interesting to note that none of the treatments in Table 1 provided 100% control of flaxleaf fleabane, although the Tordon 75D and Grazon DS treatments came close. It was also noted that in practice, the results that growers have been experiencing have been quite variable. Due to its very high seed production, even very small numbers of escapes of flaxleaf fleabane can have considerable consequences.

As a result, it was decided to trial the "double-knock" herbicide tactic on fleabane. "Double-knock" is the sequential application of knock down herbicides from different herbicide mode of action groups. This technique, developed to control glyphosate resistant ryegrass, involves applications up to 2 weeks apart, where it is assumed that the 2nd herbicide application will control potential survivors of the 1st application. Therefore, it is assumed that the 1st application will also be relatively effective on the weeds sprayed, and it is important the both applications contain robust herbicide rates of herbicides which are effective against the target weed.

Table 2. Percentage kill of flaxleaf fleabane plants using the "double-knock" tactic at Dalby in 2006. The second knock was applied 7 days after the initial knock.

Initial knock	Second knock	% Weed kill
No herbicide (Control)		0
Roundup CT 2 L/ha	na	55
Roundup CT 2 L/ha	Spray.Seed 1.6 L/ha	95
Roundup CT 2 L/ha	Spray.Seed 2.4 L/ha	97
Roundup CT 2 L/ha + Surpass 1.5 L/ha	Spray.Seed 1.6 L/ha	99
Roundup CT 2 L/ha + Surpass 1.5 L/ha	Spray.Seed 2.4 L/ha	99
Roundup CT 2 L/ha + Surpass 3 L/ha	Spray.Seed 2.4 L/ha	100
Roundup CT 2 L/ha	Amicide 625 1.5 L/ha	94
Roundup CT 2 L/ha	Amicide 625 3 L/ha	91

The effect of the double-knock is shown in Table 2. Note that this fleabane population was not well controlled by the single application of glyphosate, with 2 L/ha of Roundup CT only controlled 55% of weeds sprayed. The double-knock significantly improved fleabane control, but a combination of glyphosate+ 2,4-D followed by Sprayseed, all at robust rates was required to achieve 99 - 100% control.

Using the double-knock tactic of glyphosate followed by paraquat (right side) greatly improved the control of flaxleaf fleabane compared to the result from glyphosate alone (left side).

Further experiments were conducted to determine the best time between applications using the double-knock tactic. The effectiveness of paraquat was also examined compared to Spray.Seed®, which contains both paraquat and diquat. The time between treatments ranged from separate applications on the same day, to 14 days for paraquat and Spray.Seed, and 5 days for 2,4-D (Figure 5).

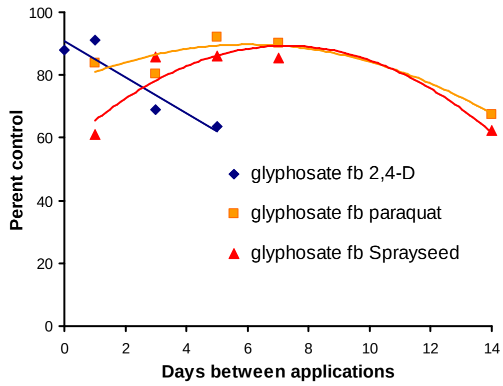

Figure 5. Effect of timing between glyphosate and follow-up applications of 2,4-D, paraquat and Spray.Seed on flaxleaf fleabane control.

The control of flaxleaf fleabane with applications of glyphosate followed by either Spray.Seed or paraquat were similar, with the optimum timing between applications being between 5 -10 days. However, as the time increased between applications of glyphosate and 2,4-D, control decreased, with the best results achieved by applying the 2,4-D within one day of the glyphosate.

Residual herbicides for controlling flaxleaf fleabane

Flaxleaf fleabane seedlings often emerge in the field in dense populations, such that the rosettes are often overlapping, with larger plants shading the smaller plants, making it very difficult to achieve good herbicide coverage on all plants. The high density of seedlings places pressure on post-emergent herbicides to provide effective control, particularly where poor coverage occurs due to the shading of smaller plants. Residual herbicides, therefore, have an important role in minimising the number of seedlings that emerge and sunsequently need to be controlled using a post-emergence herbicide.

A number of residual herbicides have been trialled for their effectiveness at minimising flaxleaf fleabane emergences. An experiment combining residual herbicides with the 2nd herbicide application in a double-knock tactic was conducted at Dalby in 2009. The aim of this experiment was to simulate controlling existing fleabane rosettes, while minimising future emergences.

All herbicides had a significant effect on fleabane emergences, with atrazine, Balance, and Sharpen performing the best (Table 3).

Table 3. *Residual control of flaxleaf fleabane when combined with a double-knock treatment. Trial was conducted at Dalby in 2009.**

Herbicide	Emergences per 100m² (126 DAT)
Glyphosate CT 1.5 L/ha + Surpass 475 1.0 L/ha fb Spray.Seed 1.6L/ha combined with…	
No residual	1543
Atrazine 4 L/ha	0
Diuron 1.5 kg/ha	58
Sharpen 200 ml/ha	5
Glean 20 g/ha	13
Balance 100 g/ha	2

Note Refer to herbicide labels for plant-back periods to cotton.*

The residual control significantly improved when Surpass 475 was replaced by Tordon 75D as the mix partner with glyphosate in the first application (Table 4). The addition of picloram in the Tordon 75D considerably reduced fleabane emergence even when no further residual herbicides were applied.

Table 4. *Residual control of flaxleaf fleabane when combined with a double-knock treatment. Trial was conducted at Dalby in 2009.**

Herbicide	Emergences per 100m² (126 DAT)
Glyphosate CT 1.5 L/ha + Tordon 75D 0.7 L/ha fb Spray.Seed 1.6L/ha combined with…	
No residual	178
Atrazine 4 L/ha	0
Diuron 1.5 kg/ha	0
Sharpen 200 ml/ha	0
Glean 20 g/ha	12
Balance 100 g/ha	8

Note Refer to herbicide labels for plant-back periods to cotton.*

All the herbicides trialled in Tables 3 & 4 have significant plant-back periods to cotton, although diuron can be used as a pre-emergent and post-emergent (lay-by). Therefore, another experiment was conducted to determine the effectiveness of the residual herbicides more commonly used in cotton.

The results in Table 5 are from one field experiment. These preliminary results have been backed up by two glasshouse experiments. The group C herbicides, prometryn and Convoy (prometryn + Fluometuron) were both effective at reducing fleabane emergence. Norflurazon, actually registered for nutgrass at a rate of 5 kg/ha, also reduced fleabane emergence when used at 1 kg/ha in this trial.

Table 5. *Residual control of flaxleaf fleabane with residual herbicides used in cotton. Trial was conducted in 2010 at Millmerran.*

Herbicide	Plants/m²	
	36 DAT	51 DAT
Nil	4.2	7.0
Pendimethalin 3.3 L/ha	3.5	7.5
Convoy 2.9 kg/ha	0.0	0.3
Prometryn 2 kg/ha	0.0	0.2
Metolachlor 2 L/ha	0.5	1.2
Norflurazon 1 kg/ha	0.5	1.2

Control of flaxleaf fleabane in cotton

The herbicide options for controlling flaxleaf fleabane in cotton are limited. The use of pre-emergent herbicides such as diuron (not specifically registered for fleabane control, but registered for broadleaf control) or Convoy will aid to reduce fleabane emergence in crop. The application of a lay-by, such as diuron or prometryn, will reduce possible emergences that may occur later in the season. However, there are likely to be some escapes and plants which establish will continue to grow throughout the season and by the time of picking, will be large, mature and setting seed. Any control measures applied at this time will prevent further seed set, but are generally too late and are ineffective in managing the weed population.

Heavy flaxleaf fleabane infestations have become all too common on many fallow fields. These fleabane plants emerged in the previous wheat crop and are now very difficult to control with herbicides. (Photo G. Charles).

Knowing that glyphosate is not likely to be effective in controlling flaxleaf fleabane in Roundup Ready Flex cotton crops, a useful strategy may be to apply a band of residual herbicide to the plant-line to reduce emergences in the plant-line of these crops. This could then be followed by a partial double-knock, consisting of a robust rate of Roundup Ready herbicide over-the-top of the crop, with a shielded paraquat or Spray.Seed application in the inter-row area, or inter-row cultivation between the rows 5-10 days after the glyphosate.

The use of non-chemical methods, such as inter-row cultivation and hand hoeing, can be very valuable to control plants between rows and escapes from previous control measures.

Managing flaxleaf fleabane in the farming system

Flaxleaf fleabane populations need to be monitored and managed in the whole farming system, all year round, in order for effective control to be maintained. How fleabane is managed in one crop or fallow, is likely to have a large impact on the following crop or fallow.

Flaxleaf fleabane plants can produce large quantities of seed, potentially creating a heavy penalty when escapes mature. However, seed persistence is relatively short and a few years of consistent and effective management will significantly reduce numbers.

Control in winter cereals can be quite variable, as is shown in Table 6. However, winter cereals can also be effective in competing with fleabane for light and nutrients. Wheat and barley crops that have been grown with high plant populations and relatively narrow rows (25 cm) have been shown to be very competitive with sowthistle. The same principles apply to flaxleaf fleabane. Crop competition can be an effective tool that reduces reliance on herbicides, as any fleabane plants that do establish in a competitive cereal crop will be small and produce relatively little seed.

Table 6. *Control of emerged flaxleaf fleabane in wheat. Trial was conducted at Warwick in 2010.**

Herbicide	% Weed kill	
	4 week old fleabane	8 week old fleabane
No herbicide	0	0
Ally 5 g/ha	40	12
Amicide 625 1.2 L/ha	69	57
Hotshot 750 mL/ha	83	62
Starane Advance 600 mL/ha	64	11
Tordon 242 1 L/ha	77	69
Tordon 75D 300 mL/ha	54	77
Ally 5 g/ha + MCPA LVE 750 mL/ha	48	40
Hotshot 750 mL/ha + MCPA LVE 750 mL/ha	79	19
Starane Advance 600 mL/ha + MCPA LVE 750 mL/ha	63	49
Tordon 242 1 L/ha + Ally 5 g/ha	58	76
Tordon 75D 300 mL/ha + Amicide 625 375 mL/ha	69	70

*Refer to herbicide labels for plant-backs periods to cotton.

Summer crops, such as sorghum, are generally less competitive than winter crops (due to the wide row spacing normally used), but allow the use of atrazine, which is effective for reducing flaxleaf fleabane emergence (Tables 3 and7). Atrazine applications made early in a fallow before planting sorghum can provide season-long control.

However, cotton can not follow close-on to an atrazine application. Atrazine plant-back periods to cotton range from 6 months for applications up to 1.26 kg active/ha, to 18 months for applications between 1.26 - 2.97 kg active/ha (the plant-back periods will be longer in dry conditions). In the experiments presented in Table 7, 4 L atrazine/ha (2 kg active/ha) was the more effective rate and this rate has a plant-back period to cotton of 18 months. It is therefore, very important to consider cropping rotations and the whole farming system when planning control of flaxleaf fleabane with herbicides such as atrazine, that have prolonged plant-back periods to cotton.

An understanding of the lifecycle of flaxleaf fleabane and how it fits into the farming system is illustrated in Tables 8 and 9. As control is more effective when plants are young, it is important to be aware of when flaxleaf fleabane is likely to emerge. Tactics can then be adapted to either reduce the numbers emerging, or control emerged plants. Stopping plants from maturing and setting seed is vital to preventing additions to the seed bank.

Table 7. *Control of flaxleaf fleabane in 3 sorghum experiments*.*

Herbicide treatment (product/ha)			% Weed kill		
Fallow	Pre-plant	Pre-emergent	2004	2005(1)	2005(2)
Atrazine 4L/ha			89	84	99
Atrazine 2L/ha			60	64	85
	Glyphosate CT 2L/ha + Surpass 3L/ha	Atrazine 4L/ha	99	95	100
	Glyphosate CT 2L/ha ⇨ Sprayseed 1.5L/ha	Atrazine 4L/ha	99	88	99
	Glyphosate CT 2L/ha + Surpass 3L/ha	Atrazine 2L/ha	98	100	97
	Glyphosate CT 2L/ha + Dicamba 1.0L/ha	Atrazine 2L/ha	99	95	100

**Refer to herbicide labels for plant-back periods to cotton.*

Glyphosate resistance

In a recent assessment of species that have a high risk of developing resistance to glyphosate, flaxleaf fleabane was found to be one of the highest risk species. Its capacity to produce large quantities of seed, often resulting in very dense populations, makes it an ideal candidate for glyphosate resistance, particularly if glyphosate is the predominate herbicide used to manage those dense populations.

Flaxleaf fleabane has always been perceived as being relatively tolerant of glyphosate and its prevalence has been attributed to reliance on glyphosate in no-till farming systems. Recent research, however, has shown that this is not the full story and that the level of control with glyphosate is linked with the weed control history.

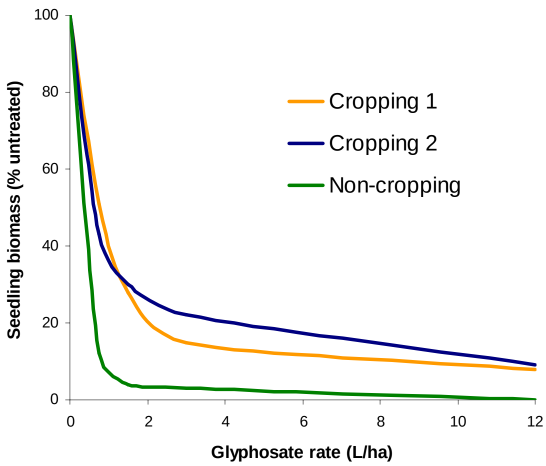

Figure 6. *Decreased response to glyphosate of flaxleaf fleabane populations from cropping backgrounds.*

A large number of samples of flaxleaf fleabane populations from Queensland and New South Wales were gathered in 2003 to test their sensitivity to glyphosate. These populations came from cultivated fields, roadsides and town water reservoirs, all with varied histories of exposure to herbicides. There was a clear difference in the sensitivity of flaxleaf fleabane population that had previous exposure to herbicides, compared to those that didn't (Figure 6). Some of these populations have since been confirmed as being resistant.A further experiment compared the effectiveness of the double-knock tactic on two populations with different herbicide histories. The population from the cropping background was found to be less sensitive to a mix of glyphosate + 2,4-D in addition to being less sensitive to glyphosate (Figure 7). However, using the double-knock tactic still proved to be effective on both populations. When the first application contained glyphosate and 2,4-D, total control was achieved. This further highlights the importance of employing the double-knock tactic in managing flaxleaf fleabane.

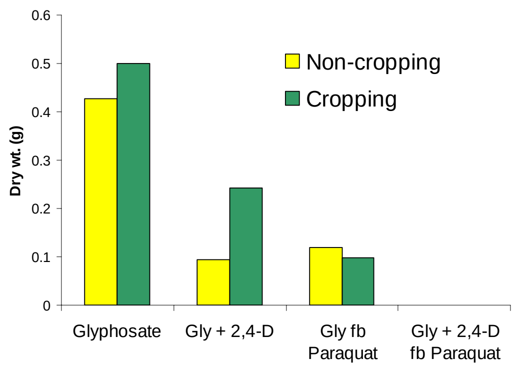

Figure 7. *Response of flaxleaf fleabane populations from non-cropping and cropping areas to glyphosate, 2,4-D and "double-knock".*

Table 7. *Fleabane lifecycle and integrated weed management options in back-to-back Roundup Ready Flex® cotton cropping systems*

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Fleabane Emergence	Likely		Less likely				Likely			Less likely		Likely			Less likely				Likely	
Fleabane Flowering / seeding																				
Crop	Roundup Ready Flex® cotton								Fallow				Roundup Ready Flex® cotton							
Double-knock for a clean start and to control survivors																				
Pre-emergent herbicides																				
At-planting residual																				
In-crop directed residual																				
Robust Roundup Ready® fb shielded paraquat / Spray.Seed																				
Inter-row cultivation																				
Hand chipping																				
Spot spraying – non-selective herbicides																				
Scouting (key times)																				
Farm hygiene (key times for equipment)	Planting equipment Cultivation equipment							Transport equipment		Planting equipment			Planting equipment Cultivation equipment							

Table 8. *Fleabane lifecycle and integrated weed management options in Roundup Ready Flex® cotton/rotation crop farming systems*

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Fleabane Emergence	Likely		Less likely				Likely		Less likely		Likely				Less likely				Likely			Less likely		
Fleabane Flowering / seeding																								
Crop	Roundup Ready Flex® cotton								Winter cereal						Fallow prior to cotton									
Double-knock for a clean start and to control survivors																								
Pre-emergent herbicides																								
At-planting residual																								
Post-emergent herbicides																								
In-crop directed residual																								
Robust Roundup Ready® fb shielded paraquat / Spray.Seed																								
Inter-row cultivation																								
Hand chipping																								
Spot spraying – non-selective herbicides																								
Scouting (key times)																								
Farm hygiene (key times for equipment)	Planting equipment Cultivation equipment						Transport equipment			Planting equipment								Cultivation equipment						

Farm hygiene

Controlling flaxleaf fleabane on non-crop areas, such as beside fields, roadsides, irrigation channels and fence lines, is very important as fleabane is easily spread by wind and water. The double-knock tactic can be used effectively in these areas, although it is still important to taget small weeds as larger plants are difficult to control and even the double-knock struggles to control these plants.

A number of residual herbicides have also been trialled for controlling fleabane in non-crop areas, however, diuron was the most consistent of these.

Roadsides, irrigation channels and fence lines can be potential sources of fleabane infestation and must be included in a property-wide management program.

Summary

The success of fleabane in the cotton system can be attributed to its ability to emerge in different seasons, relative tolerance to glyphosate and its prolific fecundity. A long term, whole farm, integrated approach is needed for its effective control. Key management tactics include:

- close monitoring of seedling emergence flushes,
- controlling weeds when young to maximise herbicide performance,
- controlling survivors to prevent seed production and reduce the soil seed bank
- using a combination of pre- and post-emergent herbicides, cultivation and hand hoeing
- using a double-knock tactic to gain effective control and prevent seed set,
- using crop competition to reduce the weed's competitive ability and improve its management in winter cereals,
- implementing an intense control program for 2-3 years to reduce the seed bank, and
- controlling fleabane on non-crop areas, such as roads, irrigation channels and fence lines, to prevent re-infestation into the crop.

An IWM plan needs to be implemented for the whole farm and crop rotation for effective management and prevention of resistance to herbicides.

MANAGING FEATHERTOP RHODES GRASS IN COTTON

Jeff Werth, Vikki Osten, Michael Widderick, Steve Walker
(Department of Agriculture, Fisheries and Forestry Queensland, Queensland Alliance for Agriculture and Food Innovation)

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Introduction

Feathertop Rhodes grass (*Chloris virgata*) is becoming increasingly prevalent in cropping systems in the northern region. This species is already a major problem in central Queensland. This is largely due to an apparent tolerance to glyphosate, combined with minimum and no-till, glyphosate based cropping systems.

In the past feathertop Rhodes grass was considered a very minor weed. As a result, this weed appears only on the labels of clethodim (Sequence®) and butroxydim (Factor®), both which are registered for use in cotton. Recently, a minor use permit for Verdict® pre-plant to mungbeans as part of a double knock with paraquat was released. This permit is current until 31st August 2016.

Feathertop Rhodes grass is a member of the genus *Chloris*. Other *Chloris* species that are found in cotton growing regions are *Chloris truncata* (Windmill grass) and perhaps the most well known *Chloris gayana* (Rhodes grass), a common pasture species. Windmill grass is also becoming a major weed problem in grains systems in southern NSW.

Feathertop Rhodes grass is a weed which was introduced from America and has become widely established in Queensland and northern NSW, especially on road sides.

The plant

Feathertop Rhodes grass is an annual grass capable of producing over six thousand seeds per plant. It generally emerges in the warmer months of spring, summer and autumn, although in central Queensland it is able to emerge nearly year round. Trials conducted in CQ at the end of summer showed emergences throughout summer, autumn and winter (Figure 1). Being an annual, the key to managing this weed lies in the seed and seed bank.

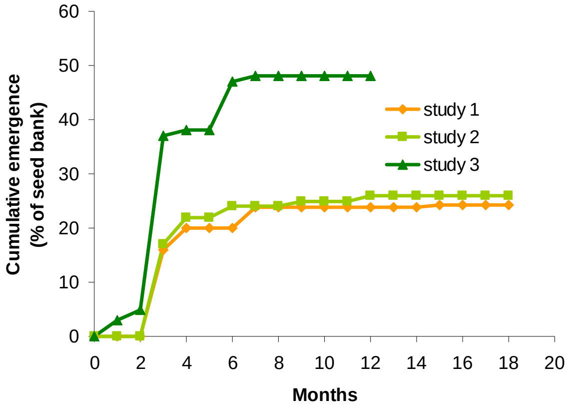

Figure 1. *Cumulative in-field emergence of feathertop Rhodes grass from seed buried in the top 2cm of soil in three separate studies. All studies started at the end of summer.*

Research has shown that seed appears to be relatively short lived regardless of burial depth in the soil. Studies in central Queensland showed that no recovered seed could be germinated after 12 months burial in the soil (Figure 2). This suggests that intensive control to stop seed set for a couple of years will have a major impact on reducing the seed bank. This is now being investigated under southern Queensland growing conditions.

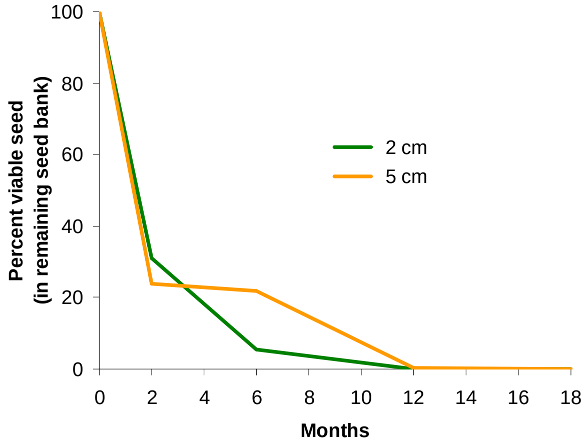

Figure 2. *Feathertop seed bank viability over time in central Queensland*

Feathertop seed responds quickly to small amounts of rainfall. An experiment conducted in controlled conditions examining the effect of rainfall amount on emergence showed that seeds germinated following 10mm of accumulated rain (Figure 3). Another experiment had feathertop emergences following as little as 5mm of rain. Some emergences occurred within two days of rainfall, which was considerably faster than other species in the experiment. The numbers emerging increased significantly with increasing rainfall with over 60-75% emergence following 30mm rain.

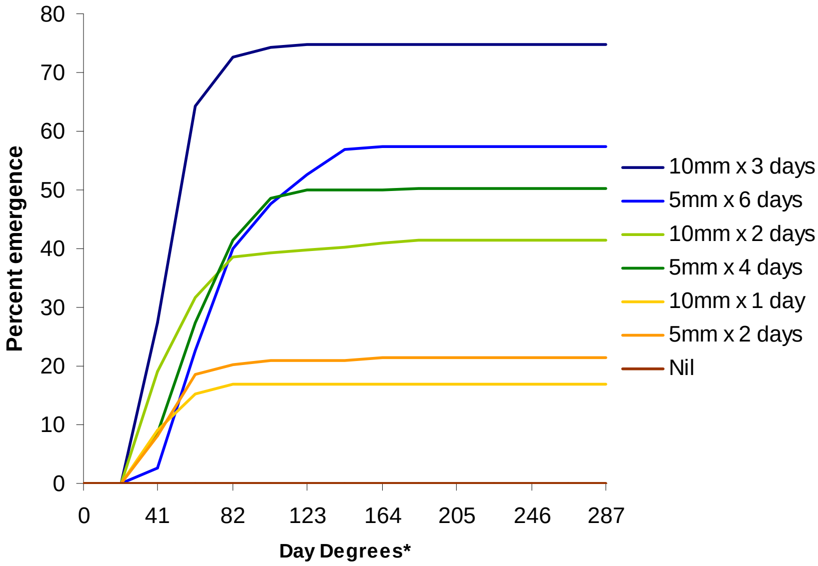

Figure 3. *Cumulative emergence of feathertop Rhodes grass in response to rainfall treatments. *Base temperatures for day degrees calculations were based on Chloris gayana (13°C).*

Strategies for managing feathertop Rhodes grass

Successful management of feathertop Rhodes grass requires a program centred on reducing replenishment of the seed bank.

A number of components will be central to any feathertop management program. These include:

- monitoring for seedling emergence,
- using a diversity of residual and post-emergent herbicides and cultivation, and
- preventing survivors from setting seed.

Peak flushes of feathertop Rhodes grass emerging in close proximity to the mother plant.

Monitoring seedling emergence

As with all species, feathertop is much easier to control when it is in the seedling stage. It is likely to emerge throughout the warmer months even with smaller rainfall events. Therefore control tactics are best aimed at reducing emergences and targeting seedlings.

Fallow paddock heavily infested with feathertop Rhodes grass. Chemical control at this growth stage can be ineffective. (Photo: R. Collins, DAFF)

Reducing emergences

Pre-emergent herbicides

Pre-emergent residual herbicides play an important role in reducing the numbers of seedlings emerging. This reduces the number exposed to post-emergent herbicides and therefore reduces the risk of resistance evolution.

Currently the only registered residual herbicide for use in cropping situation is isoxaflutole (Balance®) in fallow situations at 100 g/ha. However, when using residual herbicides for other species such as awnless barnyard grass recent trials indicate that effective levels of control can be achieved.

Data collected from a number of trials in central and southern Queensland is shown in Table 1. Feathertop can emerge late in winter crops, making it difficult to control in the following fallow after harvest. Research is investigating options for controlling these spring flushes using residual herbicides. A recent trial conducted by the Northern Grower Alliance (NGA) included a number of residual herbicides registered for use in wheat (Table 2). They conducted trials across four sites with a range of responses due to climatic variations. In a number of situations, effective control of feathertop was able to be achieved. A number of these herbicides can be used in cotton crops and rotations.

Table 1. *Residual control of feathertop Rhodes grass approximately one month after application (Source: DAFFQ 2010, NGA 2011, GSCQ 2009-10).*

Herbicide	Rates (ha)	Control (%)	
		Average	Range (n)
Flame	0.15-0.2L	80	5 – 100 (10)
Dual Gold	2L	89	75 – 98 (6)
Atrazine	1.25-2kg	65	20 – 100 (8)
Atrazine+ Dual Gold	3.2L	95	80 – 100 (10)

Table 2. *Residual control of feathertop Rhodes grass in wheat, approximately 3 months after application as incorporated by sowing or post-sowing pre-emergent (Source: NGA 2012)*

Herbicide (MOA)	Rate (mL or g/ha)	Control (%) at wheat harvest Site 1	Site 2	Site 3	Site 4
Incorporated by sowing					
Sakura (K)	118	100	99	46	57
Sakura + Glean (K+B)	118+20	100	100	86	53
Logran (B)	35	89	13	0	34
Boxer Gold (J+K)	2500	95	96	0	48
Avadex Xtra (J)	1600	100	62	0	0
Treflan (D)	2000	97	98	97	58
Stomp 440 (D)	2500	100	74	99	5
Post-plant pre-emergent					
Glean (B)	20	100	0	20	38
Balance (H)	100	100	100	8	63
Balance + Simazine 900 (H+C)	100+883	100	100	0	83
Simazine 900 (C)	2200	0	0	0	0
Terbyne (C)	1400	79	0	18	14
Balance + Terbyne (H+C)	100+1000	100	100	42	0

Tillage

Feathertop Rhodes grass seed is small and therefore unable to emerge successfully when buried. This makes tillage an important option for reducing seedling emergence. A recent trial by DAFFQ demonstrated the effect of tillage on feathertop emergence (Figure 4).

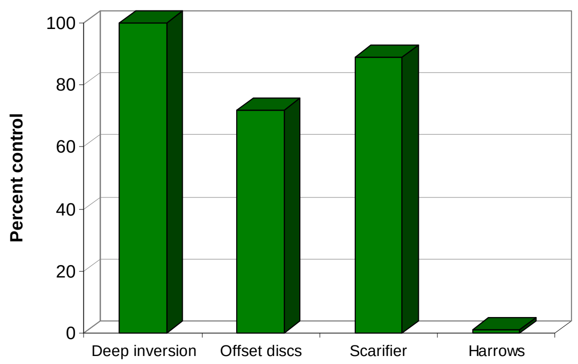

Figure 4. *Impact of different tillage types, some with residual herbicides included, on the control of feathertop Rhodes grass 9 months after application (and after > 200 mm total rain received during the period).*

Tillage operations that bury the seed prevented almost all emergences. Seed burial below 5 cm will place the seed too deep for germination. Lighter tillage operations such as harrows and Kelly chains will do little to minimise emergences, however they can be used to stimulate emergences to facilitate peak flushes, to which control tactics such as the double knock can be applied. This practice can be very effective at driving down the seed bank.

Post-emergent options

As mentioned earlier there are some group A herbicides that are registered for use in cotton. These are clethodim (Sequence®) and butroxydim (Factor®). Haloxyfop (Verdict®) is registered for use in cotton, but not specifically on feathertop Rhodes grass. Haloxyfop has recently been registered for pre-plant use in mungbeans in conjunction with a double knock with paraquat. Also there is a permit for using these products in fallow with a weed detector.

Tables 3 and 4 show results of post-emergent herbicides on feathertop control. As can be seen from Table 3, it is not controlled well by glyphosate alone.

It is also important to note the decline in control as feathertop age and size increase. For example, in Table 3, Verdict was able to provide consistent control of feathertop on seedlings, as plants reached mid-tillering and maturity, both the efficacy and consistency of control across sites declined dramatically. Control of mid-tillering plants was affected by rate and conditions at spraying. It is also important to note the heavy reliance on group A herbicides: this group of herbicides has a high risk for resistance.

Table 3. *Control of feathertop Rhodes grass when treated at seedling, mid-tillering and mature stages (Source: GSCQ 2011-12)*

Herbicide (MOA)	Control (%)						
	Seedling			*Mid-tillering*		*Mature*	
Rate (ha)	Site A	Site B	Site C	Site D	Site E	Site F	Site G
Roundup Powermax 1L (M)	48	28	30	69	9	0	6
Roundup Powermax 2L (M)	74	60	59	94	5	0	4
Roundup Powermax 4L (M)	86	88	96	99	13	5	6
Verdict 150mL (A)	91	92	98	44	36	48	23
Verdict 300mL (A)	100	99	100	44	60	49	45
Verdict 400mL (A)	100	99	100	70	68	96	78
DAT	*38*	*21*	*38*	*22*	*35*	*49*	*35*

Table 4. *Control of seedling and mature feathertop Rhodes grass with different Group A products at three field sites (Source: NGA 2010)*

Herbicide (MOA)	Seedling control (%)		Mature plant control (%)
Rate (ha)	Site A	Site B	Site C
Verdict 150mL + Uptake (A)	100	81	
Verdict 300mL+ Uptake (A)	100	99	
Verdict 500mL+ Uptake (A)			34
Glyphosate CT 2L + Liase / LI700 (M)	60	0	45
Glyphosate CT 4L + Liase / LI700 (M)	71	60	80

Double knock strategies

Using the double knock tactic is one way to minimise the risk of resistance development, and provide improved control of seedlings and older plants. Table 5 shows a trial conducted by NGA on the effect of applying paraquat in a double knock at different intervals to seedling feathertop. In these trials timing of the second knock largely didn't affect the level of control achieved. However, it is important to note the reduced control when glyphosate was applied as the first knock. The tolerance of feathertop to glyphosate was illustrated when a double knock was not applied; this indicates that when paraquat was applied it was providing most of the control. If this practice was to continue over several generations/seasons, the risk of paraquat resistance would become high.

When plants pass seedling stage, the double knock is the best herbicidal option for control. A glasshouse experiment on plants that were mid-late tillering (Table 6) showed that applications of Verdict followed by Sprayseed® provided good control of older feathertop plants The effect of timing slightly differed between the two experiments however the results suggest that a window of 1-4 days between applications is effective. Once again, glyphosate proved to be a poor partner for providing effective control.

Table 5. *Control of feathertop Rhodes grass with double-knock tactics (DK) when the second knock of Paraquat at 2L/ha is applied at different intervals at two field sites (Source: NGA 2012)*

First knock	Seedling control (%)				
			Site A		
Rate (ha)	-DK	+DK 3 days	+DK 7 days	+DK 16 days	+DK 19 days
Verdict 150mL	95	100	99	96	99
Glyphosate CT 4L	70	74	68	69	79
			Site B		
Rate (ha)	-DK	+DK 4 days	+DK 7 days	+DK 14 days	+DK 21 days
Verdict 150mL	93	100	100	100	100
Glyphosate CT 4L	31	26	76	100	52

Table 6. *Efficacy of the double knock later-tillering plants in pots, when the second knock of Sprayseed at 1.2L/ha followed glyphosate or Verdict (at sub-lethal rates) at seven intervals (Source: QDAFF 2011-2013)*

First knock	Weed biomass (g/pot)							
Rate (ha)	Interval between knocks (days)							
	-DK	1	2	4	7	10	14	21
				Pot experiment 1				
Glyphosate CT 400mL	6.8	8.9	6.3	2.7	0.3	4.9	4.5	7.7
Verdict 40mL	1.7	0	0	0	0	0	0	0.72
				Pot experiment 2				
Glyphosate CT 400mL	16.7	21.1	13.4	13.1	6.1	7.7	4.4	9.1
Verdict 40mL	4.3	0	0	0	1.4	2.2	1.7	2.8

Combining DK + residual

Adding a residual herbicide to paraquat when applying a double knock can be an effective way to get control of existing plants, and minimise further emergences. This is shown in Figure 5 where residual herbicides were added to paraquat. In this trial a combination of Dual Gold® had the greatest reduction in feathertop emergences. None of the residual herbicides appeared to be antagonistic when mixed with paraquat.

Double-knock (Group M herbicide followed 11 days later by Group L mixed with a Group B residual herbicide) in fallow on feathertop Rhodes grass (right) compared with untreated (left).

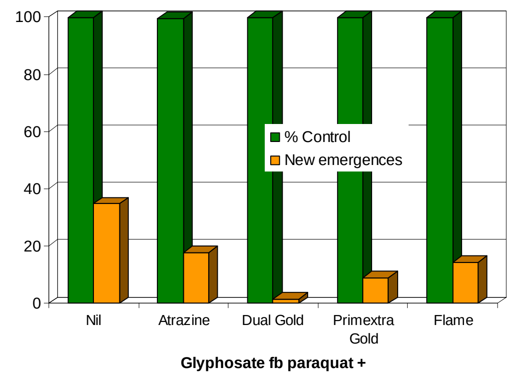

Figure 5. *Effect on initial control and reduction in emergences in the next flush (plants/m²) from adding a residual herbicide to paraquat (Source: QDAFF)*

Summary

Feathertop Rhodes grass is poorly controlled by glyphosate and as a result is increasing in prevalence in cotton growing regions.

It is a small-seeded annual species, so the key to management lies in managing the seed bank and preventing new seed from entering the soil.

This can best be achieved by:

- Utilising tillage and pre-emergent herbicides to reduce numbers of seedlings emerging
- Monitoring emergences and controlling seedlings when they are small
- Using robust herbicides and rates and the double knock tactic to control plants and prevent seed set

Feathertop Rhodes grass seeds have a relatively short life compared to other species, so intensive management for up to two years can have a major impact on driving down the seed bank.

ROTATION CROPS

Introduction

The use of rotation crops and fallows is an important part of the Integrated Weed Management strategy, as well as being beneficial for managing diseases, insects, and soil problems. Rotation crops and fallows give cotton growers the opportunity to use a different range of herbicides, and to use strategic cultivation to manage specific problems.

One of the difficulties with the use of alternative herbicides, however, is that most herbicides are not inactivated on contact with the soil. Consequently, they have residual properties and can be toxic to the following crops. This is equally true of many of the herbicides used in cotton, in fallows and in rotation crops.

One result of this problem in the cotton cropping system is that many of the herbicides that are effective in fallows and rotation crops can not be used in the cotton system because they are likely to be toxic to the following cotton crop. Weed control has been an issue in many of the rotation crops, and particularly in the broad-leaf rotation crops.

Contents:

I2. Herbicides for use with Pigeon Pea Trap Crops

Pigeon peas are useful as a trap crop and refuge for beneficial insects.

A range of herbicides is now available for use with pigeon peas, covered by product registration (refer to the product label) and a minor use permit from the Australian Pesticides & Veterinary Medicines Authority (refer to the APVMA web site at www.apvma.gov.au for details). The products covered by the permit may only be used on pigeon peas that are not used for human or livestock consumption. These crops can only be harvested for planting seed for future trap crops.

Weeds in pigeon peas can be best managed using a pre-planting application of prometryn or Sencor and either trifluralin or pendimethalin, and post-emergence applications of prometryn as a directed spray, or Sencor, or one of the selective grass herbicides listed.

I3. Managing Weeds in Vetch Rotation Crops

Vetch is being increasingly grown as an alternative rotation crop for cotton, capable of adding large amounts of nitrogen to the soil.

Weed management in vetch is problematic, with few registered herbicides for pre-planting applications, and no herbicides registered for controlling broad-leaf weeds in vetch, or for controlling vetch prior to planting cotton.

Many of the herbicide options discussed in this article are off-label. Growers wishing to make an off-label pesticide application must first obtain a minor-use permit from the APVMA for the proposed use.

14. Managing Lucerne Strips in Cotton

Lucerne strips are valuable for promoting beneficial insects in cotton and as trap crops.

Weeds can be controlled in established lucerne with diuron and prometryn and some of the grass herbicides. Bromoxynil and 2,4-DB can also be used to control small broad-leaf weeds in lucerne after cotton picking and before cotton planting.

Established lucerne can be killed with heavy cultivation or herbicides when the lucerne is actively growing. A tank mix of Grazon DS®+ Roundup CT® is registered for controlling established lucerne. However, picloram, one of the components of Grazon DS, has a long plant-back period to cotton and some other rotataion crops. There is also an APVMA permit to control lucerne with 2,4-D amine. Check the APVMA web site for the current permit status at: www.apvma.gov.au. None of the 2,4-D formulations can be safely used near cotton, so this herbicide option is limited to the period when no cotton is present.

HERBICIDES FOR PIGEON PEA TRAP CROPS

Graham Charles

(NSW Dept of Primary Industries)

Contents

Weeds can be a major problem in pigeon pea trap crops. This crop at Emerald was over-run by amaranthus and black pigweed.

Registration and permit information

The use of Sencor 480 SC® and some formulations of pendimethalin (a range of trade names) in pigeon peas is covered by product registration. A range of other products (as indicated below) may be used under permit from the Australian Pesticides & Veterinary Medicines Authority (APVMA). This permit (PER 7942) is in force till 30 Jun 07. Check the APVMA website for the current permit status at www.apvma.gov.au. This permit covers other registered products containing the same active ingredient as those named as their only active constituent and at the indicated concentrations and rates. Seed and residues from pigeon peas treated with these products may not be fed to livestock.

Herbicides fro use with pigeon pea trap crops grown in conjunction with Bollgard II cotton. Products are covered by registration or minor use permit.

	Post-emergence	
Pre-planting	Broadcast	Directed spray
pendimethalin (330 g/L) @ 2.5 to 3 L/ha	Falcon WG (250 g/kg) @ 180 g/ha	prometryn (500 g/L) @ up to 4.5 L/ha
pendimethalin (455 g/L) @ 1.8 to 2.2 L/ha	Fusilade WG (212 g/L) @ 1 L/ha	prometryn (900 g/kg) @ up to 2.5 kg/ha
trifluralin (400 g/L) @ up to 2.8 L/ha	quizalofop (99.5 g/L) @ 250-1000 mL/ha	
trifluralin (480 g/L) @ up to 2.3 L/ha	Select (240 g/L) @ 250-375 mL/ha	
prometryn (500 g/L) @ up to 4.5 L/ha	Sencor 480 (480 g/L) @ 750 mL/ha	
prometryn (900 g/kg) @ up to 2.5 kg/ha	Sertin Plus (120 g/L) @ 1.6 L/ha	
Sencor 480 (480 g/L) @ 750 mL/ha	Verdict (130 g/L) @ 0.6 L/ha	
	Verdict (520 g/L) @ 0.6 L/ha	

Background

Pigeon peas are being grown throughout the cotton industry as a trap crop and refuge for beneficial insects. These crops are grown as part of the insect management strategy, in association with Bollgard II® cotton and area wide management. However, poor weed management has been a major problem in many pigeon pea crops.

Basic agronomy work to develop pigeon peas as a commercial cash crop was undertaken in the 1980s. As part of this work, a range of herbicides was screened for use with pigeon peas (Tables 1 & 2). Herbicide phytotoxicity was rated 0 (no phytotoxicity) to 5 (dead plants).

Table 1. *Herbicides applied to pigeon pea pre-planting.*

Herbicide	Rate (kg or L)	Phytotoxicity*
Gesagard	3	0
Stomp	3	0
Teflan	1.4	0
Gesagard	4	0.5
Sencor 700	0.5	0.5
Scepter	1	0.5
Scepter	1.5	1
Dual	3	1
Simazine	2	1
Diuron 500	2	2
Atrazine	3	3
Simazine	3	3

**Herbicide phytotoxicity was rated 0 (no phytotoxicity) to 5 (dead plants).*

Another weedy pigeon pea crop infested with broad-leaf weeds including wild sunflower and sesbania.

Of the herbicides applied pre-planting, Gesagard, Stomp and Treflan all appeared to be relatively safe to use with pigeon peas. Varying degrees of phytotoxicity were observed with the remaining herbicides applied pre-planting and with all the herbicides applied post-emergence.

Table 2. *Herbicides applied broadcast, post-planting to pigeon peas.*

Herbicide	Rate (kg or L)	Phytotoxicity
Basagran	2	1
Sencor 700	0.35	1
Scepter	1	1
Gesagard	2	2
Scepter	1.5	3
Gesagard	4	3
Blazer	2	3
Diuron	2	3

Sencor 480 and pendimethalin are registered for use on pigeon peas and registration is included on some trifluralin labels but not on others.

With the introduction of Bollgard II cotton, trap crops and area wide management, pigeon peas have been widely planted throughout the cotton industry. With limited herbicide options available, these trap crops are often the weediest crops on a farm. Problem weeds range from bellvine and wild sunflower, to amaranthus and black pigweed. Broad-leaf weed control is a major issue for pigeon peas.

Pre-emergent herbicides

A range of pre-emergent herbicides was tested in the 1999/2000 season in trials at Narrabri, Theodore and Emerald. The experiments focused on the herbicides and herbicide combinations that are currently used in cotton. These herbicides have the advantage that they are readily available on cotton farms and have no plant-back problems to cotton. Crop safety (phytotoxicity) and the weed control (weed pressure index) attained with each treatment was recorded.

The weed pressure index was estimated by recording the presence of weeds in each plot and adding the numbers, after weighting the data for the bigger (more competitive) weeds. This index is expressed as small weed equivalents per m^2. The data were averaged over the 3 sites (Table 3).

Table 3. *Early- and mid-season weed control from the herbicides applied pre-planting and incorporated, or post-planting broadcast.*

Treatment	Weed index	
	Early-	Mid-
Untreated	76.6	28.0
Treflan 1.4 L/ha	13.2	5.1
Treflan 2.8 L/ha	11.0	5.5
Stomp 3 L/ha	51.2	18.1
Gesagard 2.25 L/ha	8.5	9.1
Gesagard 4.5 L/ha	3.8	6.2
Cotoran 2 L/ha	25.0	9.0
Cotoran 4 L/ha	5.1	3.3
Spinnaker 0.2 L/ha	21.9	11.2
Spinnaker 0.4 L/ha	15.6	3.8
Treflan 2.8 + Gesagard 4.5 L/ha	1.5	2.6
Treflan 2.8 + Cotoran 4 L/ha	0.9	1.4
Stomp 3 + Gesagard 4.5 L/ha	2.6	6.5
Stomp 3 + Cotoran 4 L/ha	5	2.4
Post-emergence treatments		
Basagran 1 L/ha		11.7
Basagran 2 L/ha		24.8
Sencor 0.7 L/ha		13.9
Sencor 1.4 L/ha		21.6
Spinnaker 0.2 L/ha		14.5
Spinnaker 0.4 L/ha		9.1

Three additional herbicides were applied broadcast, post-emergence at each site. Results from a second set of observations include the additional herbicides. None of the herbicides applied post-emergence gave as good weed control as the pre-planting combinations.

All treatments gave some weed control compared to the untreated plots, with the best control on the herbicide combinations that included Treflan. The poor result from Stomp was due to very poor weed control on only one of the three sites. Large numbers of common sowthistle and blackberry nightshade were present on this site, but were not controlled by Stomp. Good control was observed with Stomp on the other two sites where these two weeds were not so abundant.

Crop safety

Not all the herbicides used were safe on pigeon peas.

Phytotoxicity was observed on the diuron treatment on the first trial at Narrabri, as expected from the earlier data. No problems were apparent with the other herbicides.

However, 50 to 75 mm of rain occurred during crop emergence at Theodore and Emerald and a large proportion of the seedlings on the Cotoran treatments and combinations including Cotoran were killed (Table 4).

Table 4. *Phytotoxicity from the herbicides and combinations applied pre-emergence.*

Herbicide	Phytotoxicity rating
Untreated	0
Treflan 1.4 L/ha	0
Treflan 2.8 L/ha	0.13
Stomp 3 L/ha	0
Gesagard 2.25 L/ha	0
Gesagard 4.5 L/ha	0
Cotoran 2 L/ha	0.54
Cotoran 4 L/ha	1.21
Diuron 2 L/ha	1.11
Spinnaker 0.2 L/ha	0.28
Spinnaker 0.4 L/ha	0
Treflan 2.8 + Gesagard 4.5 L/ha	0.38
Treflan 2.8 + Cotoran 4 L/ha	2.63
Stomp 3 + Gesagard 4.5 L/ha	0.17
Stomp 3 + Cotoran 4 L/ha	1.33

Given the similar levels of weed control observed with both Gesagard and Cotoran and their combinations, Cotoran was dropped due to its risk of phytotoxicity, in favour of Gesagard which showed no phytotoxicty, even with rain during emergence.

Pigeon pea seedlings killed by Cotoran following rain during emergence at Theodore (above) and Emerald (below).

A small amount of stunting was observed with the high rate of Treflan, but the damage was minor and the plants soon grew out of this damage.

Post-emergence options

A further experiment examined the best options for post-emergence weed control, using some of the selective grass herbicides, and standard broad-leaf herbicides as directed sprays.

All herbicides were applied over-the-top of 70-cm high pigeon peas to test the level of phytotoxicity of these herbicides. This was done on the assumption that the herbicide that caused the least damage when applied over-the-top, would have the least potential to cause damage when applied as a directed spray.

Phytotoxicity was assessed 8, 28 and 48 days after treatment, by assessing the extent of damage to old growth (growth present at the time of spraying), the damage to new growth, and the effect on flowering.

Pigeon peas were completely tolerant of the selective grass herbicides used, which had no effect on growth or flowering.

All the broad-leaf herbicides damaged the pigeon peas, with diuron causing the most damage and Gesagard the least damage (Table 5).

Table 5. *Percentage leaf damage 48 days after herbicide application over-the-top of 70-cm high pigeon peas.*

Treatment	Bottom leaves (old growth)	Top leaves (new growth)
Untreated	0	0
Diuron 0.9 L/ha	55	5.5
Diuron 1.8 L/ha	82.8	7.4
Diuron 3.5 L/ha	87.5	20.1
Cotoran 1.4 L/ha	17.5	0
Cotoran 2.8 L/ha	29.9	2.8
Cotoran 5.6 L/ha	52.4	6.6
Cotogard 0.9 L/ha	7.3	0.2
Cotogard 1.8 L/ha	20.3	0.5
Cotogard 3.5 L/ha	42.5	2.3
Gesagard 1.12 L/ha	14.6	0
Gesagard 2.25 L/ha	20.3	1.5
Gesagard 4.5 L/ha	32.6	0.4

The herbicides had surprisingly little effect on flowering (Table 6), even though the over-the-top treatments caused a large amount of leaf damage to the pigeon peas. Even the highest rate of diuron, which caused an 88% loss of the sprayed leaves, resulted in only a 32% reduction in flowering. There was an 7% reduction in flowering from applying the heaviest rate of Gesagard over-the-top.

Figure 6. *Percentage flowers relative to untreated plots 48 days after spraying.*

Treatment	% Flowering
Diuron 0.9 L/ha	85
Diuron 1.8 L/ha	75
Diuron 3.5 L/ha	68
Cotoran 1.4 L/ha	100
Cotoran 2.8 L/ha	90
Cotoran 5.6 L/ha	83
Cotogard 0.9 L/ha	98
Cotogard 1.8 L/ha	98
Cotogard 3.5 L/ha	88
Gesagard 1.12 L/ha	100
Gesagard 2.25 L/ha	90
Gesagard 4.5 L/ha	93

Summary

Pigeon peas are useful as a trap crop and refuge for beneficial insects.

A range of herbicides are now available for use with pigeon peas, covered by product registration (refer to the product label) and a minor use permit from the Australian Pesticides & Veterinary Medicines Authority (refer to the APVMA web site for details). The products covered by the permit may only be used on pigeon peas that are not used for human or livestock consumption. These crops can only be harvested for planting seed for future trap crops.

Weeds in pigeon peas can be best managed using a pre-planting application of prometryn or Sencor and either trifluralin or pendimethalin, and post-emergence applications of prometryn as a directed spray, or Sencor, or one of the selective grass herbicides listed.

MANAGING WEEDS IN VETCH ROTATION CROPS

Graham Charles

(NSW Dept of Primary Industries)

Contents

Background

Vetch is being increasingly grown as an alternative rotation crop for cotton. It is a useful green manure crop, and is capable of adding large amounts of nitrogen to the soil.

Vetch crops can be sown in autumn into a fallow or crop stubble. They are commonly sown into cotton stubble soon after picking. Vetch grows over winter, and is normally removed in early spring, prior to cotton planting and before the vetch has started to set seed. Removing the crop prior to seed-set is important as vetch is hard-seeded and can produce large quantities of viable seed. If it is allowed to seed, vetch will be a nuisance weed in later cotton crops.

Weed management in vetch is problematic, with few herbicides registered for in-crop weed control. Management of broadleaf weeds is especially difficult in vetch. Broadleaf weeds can compete strongly with the vetch, reducing the value of the crop and potentially leading to increased weed problems in later years. Also, no herbicides are registered for controlling the vetch to allow replanting back to cotton where this option is desired.

It is a legal requirement that pesticide users follow the directions on the product label. Growers who wish to make an off-label pesticide application must first obtain a minor-use permit from the APVMA for the proposed use.

Many of the herbicide options discussed in this article are off-label and must be covered by a minor-use permit.

Vetch crops may be sown into cotton trash after picking. They can fix large amounts of nitrogen and may be plowed in as green manure, or killed by herbicides and left as a surface mulch.

Pre-planting herbicides

Vetch should be sown into a clean seedbed, with weeds controlled prior to planting with cultivation and/or herbicides. A wide range of products are registered for controlling weeds in fallows. Spray.Seed (various trade names) and Surpass + glyphosate (various trade names for both products) are registered for controlling weeds prior to planting vetch. There is a 7 - 10 day plant-back period constraint before planting vetch following a Surpass application.

Growers should be aware that vetch emergence and establishment may be adversely affected by residual herbicides previously applied to cotton when vetch is planted immediately following a cotton crop.

There are no pre-planting residual herbicides registered for use with vetch crops in NSW or Qld. Some formulations of trifluralin (sold under a range of trade names) are registered for pre-planting use in vetch crops in SA and WA, but not in NSW or Qld.

A range of residual pre-planting herbicides and herbicide combinations were screened in an experiment at the ACRI in 2005. Herbicides were applied and incorporated prior to planting the vetch and the crop was watered up.

No establishment problems were observed with any of the herbicides used, with satisfactory establishment levels on all treatments (Table 1). Some variability was apparent in the data related to background residual herbicides used on the preceeding cotton crop.

Table 1. *Establishment of vetch following applications of pre-planting residual herbicides.*

Herbicide	% establishment
Diuron 2kg/ha	95
Simazine 2 kg/ha	93
Crew* 2.4 L/ha + Diuron 2 kg/ha	90
Fluometuron 4 L/ha	88
Stomp 3 L/ha + Prometryn 2 kg/ha	85
Prometryn 2 kg/ha	85
Stomp 3 L/ha + Simazine 2 kg/ha	83
Stomp 3 L/ha + Fluometuron 4 L/ha	80
Crew 2.4 L/ha + Prometryn 2 kg/ha	80
Crew 2.4 L/ha + Simazine 2 kg/ha	80
Crew 2.4 L/ha	78
Crew 2.4 L/ha + Fluometuron 4 L/ha	78
Stomp 3 L/ha + Diuron 2kg/ha	78
Stomp 3 L/ha	73
Nil	90

**The active ingredient in Crew is trifluralin (330 g/L).*

Vetch growth was monitored following establishment. All treatments grew satisfactorily, but some stunting was observed on treatments containing simazine and fluometuron (Table 2), indicating that vetch had less tolerance to these herbicides.

These results indicate that pendimethalin, trifluralin, diuron and prometryn might all be satisfactorily used as pre-planting residual herbicides for vetch crops.

Table 2. *Vetch growth following applications of pre-planting residual herbicides. Growth was recorded relative to the nil treatment.*

Herbicide	Relative growth %
Prometryn 2 kg/ha	100
Crew 2.4 L/ha	100
Stomp 3 L/ha	100
Crew 2.4 L/ha + Diuron 2 kg/ha	100
Stomp 3 L/ha + Diuron 2kg/ha	100
Crew 2.4 L/ha + Prometryn 2 kg/ha	99
Diuron 2kg/ha	99
Simazine 2 kg/ha	99
Crew 2.4 L/ha + Fluometuron 4 L/ha	96
Stomp 3 L/ha + Simazine 2 kg/ha	96
Stomp 3 L/ha + Prometryn 2 kg/ha	95
Stomp 3 L/ha + Fluometuron 4 L/ha	95
Crew 2.4 L/ha + Simazine 2 kg/ha	86
Fluometuron 4 L/ha	81

Herbicide combinations for early removal of a vetch crop 7 weeks after planting.

Post-emergence weed control in vetch crops

A number of herbicides are registered for controlling grass weeds in vetch. These herbicides include Aramo, Correct, Fusilade Forte, FusionSuper, Targa and Verdict.

No herbicides are registered for broad-leaf weed control in vetch crops.

A range of herbicides were screened for broad-leaf weed control in vetch, not all of which could be safely used if a cotton crop was to be planted in the same season. Basagran and simazine had no negative affect on the vetch (Table 3), but simazine has a long soil half-life and a 9-month plant-back to cotton. Fluometuron, prometryn, atrazine and diuron all caused some initial leaf damage to the vetch, but caused no long-term damage. These products could be used with some caution, with lower rates used where possible. These products would ideally be applied as shielded or directed sprays in young vetch. Atrazine also has a long soil half-life and an 18-month plant-back to cotton at the rate used in this experiment. Spinniker, Sencor and Ally all caused unacceptable levels of damage and could not be safely used with vetch.

Table 3. *Herbicides applied broadcast, post-planting to vetch.*

Herbicide	Phytotoxicity*	
	3 weeks	6 weeks
Simazine 2 kg/ha	0	0
Basagran 2 L/ha	0	0
Fluometuron 4 L/ha	1.4	0.3
Prometryn 2 kg/ha	1.8	0.3
Atrazine 2 kg/ha	1.5	0.4
Diuron 2kg/ha	2.1	0.4
Spinniker 0.2 L/ha	1.4	1.1
Sencor 1.4 L/ha	3.9	3.6
Ally 10 g/ha	4.5	5.0
Nil	0	0

**Herbicide phytotoxicity was rated 0 (no phytotoxicity) to 5 (dead plants).*

Removing vetch crops with herbicides

Vetch crops are normally planted in the autumn/winter before a cotton crop and must be killed prior to cotton planting.

Slashing and incorporating the vetch crop is the best option for removal, as this method returns the maximum amount of available nitrogen to the following cotton crop, while minimising any potential problems with insects and diseases.

There are no herbicides registered for killing a vetch crop. 2,4-D (a range of trade names) is registered for controlling vetches in a range of crops, but the registrations only covers Vic. and SA, not NSW or Qld.

A range of herbicides and herbicide combinations with Roundup PowerMAX were screened for removing a young vetch crop in late winter (Tables 4 & 5), and an older crop at the flowering stage in spring (Table 6).

MCPA 500 at 4 L/ha and Starane at 1 and 2 L/ha gave the best control of young vetch, with better than 95% control observed (Table 4). There was some background vetch emergence on the site from an experiment run in the previous season and it is likely that some of the "surviving" shoots came from seedlings that emerged after the herbicide application.

Table 4. *Herbicides for early removal of a vetch crop in late winter (28 July), 7 weeks after planting.*

Herbicide	% Vetch kill	
	3 weeks	6 weeks
MCPA 500 4 L/ha	95	98
Starane 2 L/ha	97	97
Starane 1 L/ha	92	96
Roundup PowerMAX 4 L/ha	84	89
MCPA 500 2 L/ha	86	87
Buctril MA 4 L/ha	90	86
Roundup PowerMAX 2 L/ha	77	81
Surpass 2 L/ha	86	80
Buctril MA 2 L/ha	94	66
Buctril 4 L/ha	87	56
Spray.Seed 3.6 L/ha	88	45
Surpass 1 L/ha	72	22
Spray.Seed 2.4 L/ha	82	17
Buctril 2 L/ha	72	14
Nil	0	0

Roundup PowerMAX at 4 L/ha gave a reasonable result, also controlling all other weeds present on the plots. A range of combinations using lower rates of Roundup PowerMAX in combination with lower rates of some of the other herbicides was also screened (Table 5).

Table 5. *Herbicide combinations for early removal of a vetch crop in late winter (28 July), 7 weeks after planting.*

Herbicides	% Vetch kill	
	3 weeks	6 weeks
Roundup PowerMAX 1 L/ha + Envoke 10 g/ha	81	96
Roundup PowerMAX 2 L/ha + Envoke 10 g/ha	89	96
Roundup PowerMAX 2 L/ha + Starane 1 L/ha	99	94
Roundup PowerMAX 2 L/ha + Surpass 2 L/ha	97	90
Roundup PowerMAX 2 L/ha + Buctril MA 2 L/ha	98	89
Roundup PowerMAX 1 L/ha + Starane 0.5 L/ha	87	84
Roundup PowerMAX 1 L/ha + Surpass 1 L/ha	86	80
Roundup PowerMAX 2 L/ha + Buctril 2 L/ha	91	79
Roundup PowerMAX 1 L/ha + Buctril MA 1 L/ha	87	61
Roundup PowerMAX 2 L/ha + Hammer 750 mL/ha	80	60
Roundup PowerMAX 2 L/ha + Pledge 30 g/ha	93	56
Roundup PowerMAX 1 L/ha + Buctril 1 L/ha	87	51
Roundup PowerMAX 1 L/ha + Pledge 30 g/ha	80	25
Nil	0	0

The Roundup PowerMAX + Envoke and Roundup PowerMAX + Starane at 1 L/ha combinations both gave good results, although the result for the Starane combination was no improvement over Starane alone at 1 L/ha (Table 4). Envoke was not tested by itself in this experiment.

Cotton was planted into all treatments in early October and no phytotoxicity was observed with any of the treatments. However, the Envoke label specifies a 9-month plant-back period to cotton and so Envoke can not be used to remove vetch prior to a cotton crop.

A later application was made to much larger vetch on 30 Sept., 16 weeks after planting (Table 6).

Envoke at 20 g/ha, Starane and MCPA 500 all gave very good control of large vetch plants. The combination of Roundup PowerMAX + Envoke at 10 g/ha also gave good control and controlled all other weeds present on the plots. The combination gave much better control than Envoke alone at 10 g/ha. However, Envoke has a 9-month plant-back period to cotton and so can't be used to remove vetch immediately prior to a cotton crop. Starane has a much shorter plant-back to cotton of 14 to 28 days (depending on the application rate). The plant-back to MCPA should be similar, at around 14 days, although the plant-back period to cotton is not specified on the product label.

Table 6. *Herbicides for late removal of a vetch crop in spring (30 September), 16 weeks after planting. The crop had begun to naturally senesce, resulting in some plant death on all treatments.*

Herbicide	% Vetch kill
	4 weeks
Envoke 20 g/ha	100
Starane 2 L/ha	100
MCPA 500 4 L/ha	100
Starane 1 L/ha	100
Roundup PowerMAX 2 L/ha + Envoke 10 g/ha	100
Roundup PowerMAX 2 L/ha + MCPA 500 4 L/ha	95
Envoke 10 g/ha	80
Staple 120 g/ha	58
Staple 60 g/ha	38
Nil	43

Both Roundup and Envoke may be valuable for controlling volunteer vetch plants in a cotton crop, should these become a problem.

The Roundup PowerMAX + MCPA 500 at 4 L/ha combination also gave a good result and controlled all other weeds, but gave a slightly inferior result to MCPA 500 at 4 L/ha alone. Growers electing to use this combination would have to weigh up the advantage of an increased weed control spectrum with the disadvantage of possibly poorer control of vetch. The results with the Roundup PowerMAX + Envoke combinations in Table 5 suggest that a lower rate of Roundup PowerMAX may have given as good or better control of vetch without compromising the control of other weeds.

Herbicides for late removal of a vetch crop in late September, 16 weeks after planting, when vetch was at the flowering stage.

Summary

Vetch is being increasingly grown as an alternative rotation crop for cotton, capable of adding large amounts of nitrogen to the soil.

Weed management in vetch is problematic, with few registered herbicides for pre-planting applications, and no herbicides registered for controlling broad-leaf weeds in vetch, or for controlling vetch prior to planting cotton.

Many of the herbicide options discussed in this article are off-label. Growers wishing to make an off-label pesticide application must first obtain a minor-use permit from the APVMA for the proposed use.

Vetch should be sown into a clean seedbed, with weeds controlled prior to planting with cultivation and/or herbicides. A wide range of products are registered for controlling weeds in fallows. Spray.Seed and Surpass + glyphosate are registered for controlling weeds prior to planting vetch. There is a 7 - 10 day plant back period restraint following a Surpass application.

A range of herbicides were screened for use with vetch crops. Pendimethalin, trifluralin, diuron and prometryn applied as pre-planting residual herbicides caused no establishment or growth problems.

A range of herbicides are registered for controlling grass weeds in vetch. These herbicides include Correct, FusionSuper, Targa and Verdict.

For post-emergence broad-leaf weed control in vetch, Basagran and simazine had excellent crop safety), but simazine has a 9-month plant-back to cotton. Fluometuron, prometryn and diuron all caused some initial leaf damage to the vetch, but caused no long-term damage. These products could be used with some caution, with lower rates used where possible. They would ideally be applied as shielded or directed sprays in young vetch crops.

A range of herbicides were screened for removing vetch crops. MCPA 500 at 4 L/ha and Starane at 1 and 2 L/ha gave the best control of young vetch.

Envoke at 20 g/ha, Starane and MCPA 500 all gave good control of large vetch plants. However, Envoke has a 9-month plant-back period to cotton. Starane has a much shorter plant-back of 14 to 28 days and MCPA around 14 days.

Both Roundup and Envoke may be valuable for controlling volunteer vetch plants in a cotton crop, should these become a problem.

MANAGING LUCERNE STRIPS IN COTTON

Graham Charles and Robert Mensah
(NSW Dept of Primary Industries)

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Background

Lucerne strips are valuable for promoting beneficial insects in cotton and as trap crops. They provide a refuge for beneficial insects and spiders which can then be encouraged to move into cotton with the strategic use of Envirofeast® sprays. Used this way, lucerne strips can be an effective management tool, providing beneficial insects that help with the early-season control of *Helicoverpa* spp. in conventional cotton varieties.

Lucerne strips can also be used as an effective trap crop for green mirids and aphids, as these insects prefers lucerne over cotton.

Well managed lucerne can be a useful for managing insects in cotton, and can be a valuable tool for managing weed problems such as nutgrass.

Alternatively, lucerne can be planted in a field adjacent to a cotton field or on a centrally located block on the farm, and still effectively serve as a trap for mirids and aphids as well as enhancing the build up of beneficial insects.

Establishing lucerne strips

Lucerne can be planted as strips within a cotton field. Strips of 8, 12 or 16 rows of lucerne should be planted every 300 rows of cotton. This equates to about 2.0-2.5% of the field area. Alternatively, lucerne can be grown on the borders of a field, using an area equivalent to 5% of the field, or can be planted in a field adjacent to cotton.

A range of lucerne varieties is available. Varieties with good resistance to lucerne aphids, phytophthora root rot and colletotrichum crown rot should be selected. Lucerne should ideally be sown from April to June, and no later than August. August planted lucerne may need an additional irrigation in November of the establishment year. A strong and dense plant stand is needed, so good seed bed preparation is important as lucerne has a very small seed. Seeding rates of 10 to 15 kg/ha (irrigated) or 5 kg/ha (dryland) are required. Irrigated lucerne should be sown on beds (not 1 m hills), using two beds of 4 rows in an 8 row strip, or two beds of 6 rows in a 12 row strip.

Weed control is important in establishing lucerne, as lucerne has a small, relatively slow growing seedling. A range of herbicides is available for use in lucerne but not all can be safely used in cotton. Of the commonly used herbicides of cotton production, trifluralin can be applied pre-planting with lucerne, and some of the grass herbicides such as Sertin Plus® and Fusion Super® are registered for post-emergence grass control.

Prometryn can be applied early post-emergence for broad-leaf weed control in pastures including lucerne (applied after lucerne reaches 5 true leaves). All of the other products registered for broad-leaf weed control in lucerne are likely to damage cotton if drift occurs. Bromoxynil and 2,4-DB for example, could be used over winter but would not be safe to apply to a lucerne strip within a cotton crop.

Refer to the NSW Department of Primary Industries publication “Weed control in lucerne and pastures” for more information on registered products. Always follow the directions on the product label.

Lucerne seedlings are susceptible to damage from some insect pests. Blue oat mite, redlegged earth mite, lucerne flea and cutworms can all cause severe damage to seedling and young lucerne stands. Mite damaged seedlings progressively show yellowing and then whitening of the cotyledons and/or leaves. Lucerne flea make small membranous ‘windows’ in the leaves, with ultimately only the skeletons of the leaves remaining. Badly infested strips look whitish.

In severe cases, pests may need to be controlled with pesticides during the first few weeks after seedling emergence. However, the use of pesticides beyond this point would be counter productive, removing the beneficial insects the lucerne has been planted to promote.

Managing lucerne strips

Lucerne needs to be managed to maintain new growth and attractiveness to green mirids and aphids throughout the season. The aphid species that infest lucerne will not infest cotton, but are a food source for predators that can move into the cotton. Half of each lucerne strip should be cut (slashed or mown) every 4 weeks and before the lucerne begins to flower. Cutting should commence in November, and continue throughout the cotton season.

Lucerne needs to be watered to maintain fresh growth and has a similar water requirement to cotton. Irrigation can most easily be timed to coincide with cotton irrigation.

Lucerne should not be allowed to set seed or hay off, as it is much less attractive to insects once this occurs. Volunteer lucerne plants can also be a serious nuisance in following crops. This problem can be avoided by timely slashing, preventing lucerne setting seed.

Apart from being a refuge for beneficial insects and a trap crop for green mirids, lucerne can also be an important contributor to the nitrogen budget, fixing up to 200 kg N per year.

However, poorly managed lucerne strips can be a source of green mirids to cotton and a source of weed seeds.

Weeds can be controlled in established lucerne more than 1 year old (in cotton) with the residual herbicides diuron and prometryn (prometryn is registered for controlling weeds in pastures including lucerne), and grass weeds can be controlled with post-emergence grass herbicides such as Verdict and Sertin. Bromoxynil and 2,4-DB can also be used to control small broad-leaf weeds in lucerne after cotton picking and before cotton planting.

Removing lucerne strips

Established lucerne strips can be difficult to remove, with scattered plants potentially remaining as weeds in following cotton crops. Volunteer lucerne seedlings can also cause problems if lucerne has been allowed to seed, as none of the residual herbicides which kill lucerne seedlings are safe in cotton.

Established lucerne can be killed either with cultivation or with herbicides. When the soil is dry, heavy cultivation such as a crawler with a cutter bar across the rippers has been shown to be 100% effective in removing established lucerne plants. However, this approach is expensive and slow and the success of this technique requires dry soil and dry weather after treatment.

Herbicides are only effective for controlling lucerne when it is actively growing. Grazon DS® is registered for controlling established lucerne at 300-500 mL/ha + Roundup CT® at 1.2 L/ha. However, picloram, one of the components of Grazon DS, has a long plant-back period to cotton and some other rotataion crops, and so can’t be used to remove lucerne prior to the planting of these crops. There is also a permit from the Australian Pesticides & Veterinary Medicines Authority (APVMA) to control established lucerne with 2,4-D Amine at 3 L/ha (500 g/L) or 2.4 L/ha (625 g/L) or 2,4-D ipa (Surpass®) plus glyphosate at 5 L/ha + 1 L/ha (450 g/L). Check the APVMA web site for the current permit status at: www.apvma.gov.au.

However, none of these formulations of 2,4-D can be safely used near cotton, so these herbicide options are limited to the period after cotton harvest, when no cotton is present. Any 2,4-D application must also be made well before cotton planting as a 14 day plant-back period for cotton planting after herbicide application applies. This 14 day period only commences following rainfall of at least 15 mm. Thorough decontamination of spraying equipment is essential after 2,4-D applications. For optimal control of lucerne, plants should be actively growing and at least 5 cm tall, and preferably 10 to 15 cm tall at the time of herbicide application. Cultivation is likely to give better control than herbicides when moisture is limiting.

Summary

Lucerne strips are valuable for promoting beneficial insects in cotton and as trap crops for green mirids. Lucerne strips can also be an effective tool, providing beneficial insects that help with the early-season control of *Helicoverpa* spp.

Lucerne can be planted as strips within a cotton field or grown on the borders of a field or in a field adjacent to cotton. A range of varieties is available, best sown from April to June. A strong and dense plant stand is needed, so good seed bed preparation is important.

Weed control is important in establishing lucerne, as lucerne has a small, relatively slow growing seedling. A range of herbicides is available for use in lucerne but some can not be safely used in cotton. Of the herbicides commonly used in cotton production, trifluralin can be applied pre-planting with lucerne, and some of the grass herbicides such as Sertin Plus® and Fusion Super® are registered for post-emergence grass control. Prometryn can be applied early post-emergence for broad-leaf weed control.

Lucerne needs to be managed to maintain new growth and attractiveness to beneficials. Half of each lucerne strip should be cut every 4 weeks before the lucerne begins to flower.

Weeds can be controlled in established lucerne with the residual herbicides diuron and prometryn, and grass weeds can be controlled with post-emergence grass herbicides.

Established lucerne strips can be difficult to remove, with scattered plants potentially remaining as weeds in following cotton crops. Volunteer lucerne seedlings can also cause problems as none of the residual herbicides which kill lucerne seedlings are safe to use in cotton.

Established lucerne can be killed with heavy cultivation or herbicides. Herbicides are only effective for controlling lucerne when it is actively growing. A tank mix of Grazon DS®+ Roundup CT® is registered for controlling established lucerne. However, picloram, one of the components of Grazon DS, has a long plant-back period to cotton and some other rotataion crops. There is also a permit from the APVMA to control established lucerne with 2,4-D amine. Check the APVMA web site for the current permit status at: www.apvma.gov.au.

However, none of the 2,4-D formulations can be safely used near cotton, so these herbicide options are limited to the period when no cotton is present.

APPENDICES

Included are the following appendices

REGIONAL WEEDS OF COTTON

Ian Taylor, Leah MacKinnon and Benita Inchbold
(NSW Agriculture, University of New England & NSW Agriculture)

The following lists contain weeds that have been identified by growers and consultants during recent interviews as being problematic in their particular region. Information in the lists has been supplemented with weed survey data that researchers have compiled over recent years in each of the valleys. The lists are arranged by valley so that consultants/agronomists and growers may be aware of the weeds that have been observed in their particular region. Consultants and agronomists are encouraged to use the regional lists in combination with the weed identification guide so that they are more familiar with the weeds they are likely to encounter in their region. New incursions such as David's spurge have been included in the lists to assist agronomists with recognition of these species and to enhance early detection so that management strategies can be put in place prior to the development of a wide scale problem. While all effort has been made to make the lists as comprehensive as possible it is acknowledged that some species are likely to have been missed. The weeds are sorted by preferred common names as listed in *Plants of Importance to Australia: A Checklist* (Shepherd *et al*. 2001) published by R.G and F.J Richardson. Each of the lists has been divided into major and minor weed species determined by frequency of observation and number of farms that have the weed as a problem. The scientific name is provided for reference, as are comments that either consultants or growers have made. These comments are the personal opinion of some of those interviewed and may not necessarily reflect the views of everyone. They are included to give an indication as to whether the weed problem is increasing or whether the weed species is apparent in a particular situation.

Additional and supplementary information is most welcome and may be directed to the primary author of this J2 section.

Macquarie Valley

Common name	Scientific name	Comments
Major Weeds		
Anoda weed	*Anoda cristata*	
Australian bindweed	*Convolvulus erubescens*	
Awnless barnyard grass	*Echinochloa colona*	
Barnyard grass	*Echinochloa crus-galli*	
Bathurst burr	*Xanthium spinosum*	
Blackberry nightshade	*Solanum nigrum*	along channels
Bladder ketmia (broad-leaf)	*Hibiscus trionum* var. *vesicarius*	late season
Bladder ketmia (narrow-leaf)	*Hibiscus trionum* var. *trionum*	
Blue heliotrope	*Heliotropium amplexicaule*	
Caltrop	*Tribulus terrestris*	
Common sowthistle	*Sonchus oleraceus*	late season
Common thornapple	*Datura stramonium*	
Cotton	*Gossypium hirsutum*	more of a concern now with Roundup Ready
Couch grass	*Cynodon dactylon*	
Cowvine	*Ipomoea lonchophylla*	starting to increase
Dirty Dora	*Cyperus difformis*	
Downs nutgrass	*Cyperus bifax*	
Dwarf amaranth	*Amaranthus macrocarpus*	
Fierce thornapple	*Datura ferox*	
Flaxleaf fleabane	*Conyza bonariensis*	
Grey raspwort	*Haloragis glauca*	
Mexican poppy	*Argemone ochroleuca*	
Mintweed	*Salvia reflexa*	
Noogoora burr	*Xanthium occidentale*	
Nutgrass	*Cyperus rotundus*	
Pigweed	*Portulaca oleracea*	
Polymeria take-all	*Polymeria longifolia*	
Red shank	*Amaranthus cruentus*	
Rough poppy	*Papaver hybridum*	
Sesbania pea	*Sesbania cannabina*	
Spineless caltrop	*Tribulus micrococcus*	
Umbrella sedge	*Cyperus involucratus*	
Wild gooseberry	*Physalis minima*	
Wild melon	*Citrullus lanatus*	
Minor Weeds		
Annual ground cherry	*Physalis ixocarpa*	
Annual polymeria	*Polymeria pusilla*	
Bellvine	*Ipomoea plebeia*	
Caustic weed	*Chamaesyce drummondii*	
Giant pigweed	*Trianthema portulacastrum*	
Liverseed grass	*Urochloa panicoides*	
Perennial ground cherry	*Physalis virginiana*	
Prickly paddy melon	*Cucumis myriocarpus*	
Rhynchosia	*Rhynchosia minima*	
Rough raspwort	*Haloragis aspera*	
West Indian gherkin	*Cucumis anguria*	

Upper Namoi Valley

Common name	Scientific name	Comments
Major Weeds		
Australian bindweed	*Convolvulus erubescens*	late season
Awnless barnyard grass	*Echinochloa colona*	
Barnyard grass	*Echinochloa crus-galli*	
Bathurst burr	*Xanthium spinosum*	
Bellvine	*Ipomoea plebeia*	
Blackberry nightshade	*Solanum nigrum*	
Bladder ketmia (broad-leaf)	*Hibiscus trionum* var. *vesicarius*	
Bladder ketmia (narrow-leaf)	*Hibiscus trionum* var. *trionum*	
Caltrop	*Tribulus terrestris*	found on lighter country
Common sowthistle	*Sonchus oleraceus*	BAD in FALLOW following cereal, some control due to insect host
Common thornapple	*Datura stramonium*	
Cotton	*Gossypium hirsutum*	
Cowvine	*Ipomoea lonchophylla*	
Field bindweed	*Convolvulus arvensis*	
Fierce thornapple	*Datura ferox*	problem if it seeds
Flaxleaf fleabane	*Conyza bonariensis*	in minimum tillage areas, difficult to control
Grey raspwort	*Haloragis glauca*	
Liverseed grass	*Urochloa panicoides*	
Noogoora burr	*Xanthium occidentale*	a real problem if it seeds
Nutgrass	*Cyperus rotundus*	
Rhynchosia	*Rhynchosia minima*	on some channels, known as native glycene
Rough raspwort	*Haloragis aspera*	
Spineless caltrop	*Tribulus micrococcus*	black soil
Wild gooseberry	*Physalis minima*	
Minor Weeds		
Annual ground cherry	*Physalis ixocarpa*	
Annual polymeria	*Polymeria pusilla*	
Anoda weed	*Anoda cristata*	isolated
Caustic weed	*Chamaesyce drummondii*	
Cobbler's peg	*Bidens pilosa*	spreading, increasing in non-cultivated areas, control difficult
Couch grass	*Cynodon dactylon*	small areas, but a concern
David's spurge	*Euphorbia davidii*	
Downs nutgrass	*Cyperus bifax*	
Dwarf amaranth	*Amaranthus macrocarpus*	
Giant pigweed	*Trianthema portulacastrum*	
Johnson grass	*Sorghum halepense*	
Mintweed	*Salvia reflexa*	transported via Pigeon pea seed
Perennial ground cherry	*Physalis virginiana*	
Pigweed	*Portulaca oleracea*	
Polymeria take-all	*Polymeria longifolia*	
Prickly paddy melon	*Cucumis myriocarpus*	
Sesbania pea	*Sesbania cannabina*	
Small flowered mallow	*Malva parviflora*	
West Indian gherkin	*Cucumis anguria*	
Wild melon	*Citrullus lanatus*	

Lower Namoi Valley

Common name	Scientific name	Comments
Major Weeds		
Anoda weed	*Anoda cristata*	
Bladder ketmia (narrow-eaf)	*Hibiscus trionum var. trionum*	
Nutgrass	*Cyperus rotundus*	
Minor Weeds		
Awnless barnyard grass	*Echinochloa colona*	
Barnyard grass	*Echinochloa crus-galli*	
Bathurst burr	*Xanthium spinosum*	
Common sowthistle	*Sonchus oleraceus*	
Common thornapple	*Datura stramonium*	
Cowvine	*Ipomoea lonchophylla*	
Downs nutgrass	*Cyperus bifax*	
Fierce thornapple	*Datura ferox*	
Mintweed	*Salvia reflexa*	
Noogoora burr	*Xanthium occidentale*	
Pigweed	*Portulaca oleracea*	
Polymeria take-all	*Polymeria longifolia*	

Gwydir Valley

Common name	Scientific name	Comments
Major Weeds		
Annual ground cherry	*Physalis ixocarpa*	becoming an issue
Annual polymeria	*Polymeria pusilla*	
Anoda weed	*Anoda cristata*	increasing
Australian bindweed	*Convolvulus erubescens*	increasing
Awnless barnyard grass	*Echinochloa colona*	
Barnyard grass	*Echinochloa crus-galli*	
Barnyard grass	*Echinochloa* species	increasing
Bathurst burr	*Xanthium spinosum*	
Bellvine	*Ipomoea plebeia*	
Black bindweed	*Fallopia convolvulus*	
Blackberry nightshade	*Solanum nigrum*	increasing
Bladder ketmia (broad-leaf)	*Hibiscus trionum* var. *vesicarius*	
Bladder ketmia (narrow-leaf)	*Hibiscus trionum* var. *trionum*	increasing, late season control
Caltrop	*Tribulus terrestris*	
Cobbler's peg	*Bidens pilosa*	increasing
Common sowthistle	*Sonchus oleraceus*	
Common thornapple	*Datura stramonium*	
Cotton	*Gossypium hirsutum*	more of a concern with Roundup Ready
Cowvine	*Ipomoea lonchophylla*	late season control, consistently germinating from cotton planting to end of April
Downs nutgrass	*Cyperus bifax*	increasing
Dwarf amaranth	*Amaranthus macrocarpus*	problem on channels
Fierce thornapple	*Datura ferox*	
Grey raspwort	*Haloragis glauca*	
Liverseed grass	*Urochloa panicoides*	
Mintweed	*Salvia reflexa*	increasing
Noogoora burr	*Xanthium occidentale*	
Nutgrass	*Cyperus rotundus*	
Pigweed	*Portulaca oleracea*	problem on channels
Polymeria take-all	*Polymeria longifolia*	increasing
Rhynchosia	*Rhynchosia minima*	increasing
Sesbania pea	*Sesbania cannabina*	increasing
Spineless caltrop	*Tribulus micrococcus*	
Variegated thistle	*Silybum marianum*	
Wild gooseberry	*Physalis minima*	
Minor Weeds		
Caustic weed	*Chamaesyce drummondii*	
Couch grass	*Cynodon dactylon*	
David's spurge	*Euphorbia davidii*	
Flaxleaf fleabane	*Conyza bonariensis*	
Giant pigweed	*Trianthema portulacastrum*	problem on channels
Perennial ground cherry	*Physalis virginiana*	
Prickly paddy melon	*Cucumis myriocarpus*	
Rough raspwort	*Haloragis aspera*	
West Indian gherkin	*Cucumis anguria*	
Wild melon	*Citrullus lanatus*	

Macintyre Valley

Common name	Scientific name	Comments
Major Weeds		
Annual ground cherry	*Physalis ixocarpa*	
Annual polymeria	*Polymeria pusilla*	
Anoda weed	*Anoda cristata*	
Awnless barnyard grass	*Echinochloa colona*	
Barnyard grass	*Echinochloa crus-galli*	
Bathurst burr	*Xanthium spinosum*	
Bellvine	*Ipomoea plebeia*	
Blackberry nightshade	*Solanum nigrum*	increasing
Bladder ketmia (broad-leaf)	*Hibiscus trionum* var. *vesicarius*	increasing
Bladder ketmia (narrow-leaf)	*Hibiscus trionum* var. *trionum*	
Caltrop	*Tribulus terrestris*	light soils
Caustic weed	*Chamaesyce drummondii*	increasing
Common sowthistle	*Sonchus oleraceus*	early season
Common thornapple	*Datura stramonium*	increasing, light soils
Cotton	*Gossypium hirsutum*	increasing, head ditches
Couch grass	*Cynodon dactylon*	
Cowvine	*Ipomoea lonchophylla*	
Devil's claw	*Martynia annua*	
Downs nutgrass	*Cyperus bifax*	
Dwarf amaranth	*Amaranthus macrocarpus*	
Fierce thornapple	*Datura ferox*	light soils
Flannel weed	*Sida cordifolia*	
Giant pigweed	*Trianthema portulacastrum*	increasing, high Mg soils
Liverseed grass	*Urochloa panicoides*	light soils
Mintweed	*Salvia reflexa*	light soils
Noogoora burr	*Xanthium occidentale*	
Nutgrass	*Cyperus rotundus*	
Pigweed	*Portulaca oleracea*	high Mg soils
Plains spurge	*Euphorbia planiticola*	
Polymeria take-all	*Polymeria longifolia*	
Sesbania pea	*Sesbania cannabina*	
Spineless caltrop	*Tribulus micrococcus*	light soils
Wild gooseberry	*Physalis minima*	increasing
Wild melon	*Citrullus lanatus*	dryland cotton
Minor Weeds		
Australian bindweed	*Convolvulus erubescens*	
Flaxleaf fleabane	*Conyza bonariensis*	especially dryland & drains; head-ditches
Grey raspwort	*Haloragis glauca*	
Perennial ground cherry	*Physalis virginiana*	
Prickly paddy melon	*Cucumis myriocarpus*	dryland cotton
Rhynchosia	*Rhynchosia minima*	
Rough raspwort	*Haloragis aspera*	
Velvetleaf	*Abutilon theophrasti*	
West Indian gherkin	*Cucumis anguria*	

St. George

Common name	Scientific name	Comments
Major Weeds		
Annual ground cherry	*Physalis ixocarpa*	
Annual polymeria	*Polymeria pusilla*	
Anoda weed	*Anoda cristata*	
Awnless barnyard grass	*Echinochloa colona*	
Barnyard grass	*Echinochloa crus-galli*	
Bathurst burr	*Xanthium spinosum*	
Bellvine	*Ipomoea plebeia*	increasing
Bladder ketmia (broad-leaf)	*Hibiscus trionum* var. *vesicarius*	
Bladder ketmia (narrow-leaf)	*Hibiscus trionum* var. *trionum*	
Caltrop	*Tribulus terrestris*	
Common sowthistle	*Sonchus oleraceus*	
Common thornapple	*Datura stramonium*	
Cotton	*Gossypium hirsutum*	
Cowpea	*Vigna unguiculata*	increasing
Cowvine	*Ipomoea lonchophylla*	
Downs nutgrass	*Cyperus bifax*	
Dwarf amaranth	*Amaranthus macrocarpus*	
Fierce thornapple	*Datura ferox*	
Giant pigweed	*Trianthema portulacastrum*	
Grey raspwort	*Haloragis glauca*	
Mintweed	*Salvia reflexa*	
Noogoora burr	*Xanthium occidentale*	
Nutgrass	*Cyperus rotundus*	
Pigweed	*Portulaca oleracea*	
Polymeria take-all	*Polymeria longifolia*	
Prickly paddy melon	*Cucumis myriocarpus*	
Rhynchosia	*Rhynchosia minima*	
Rough raspwort	*Haloragis aspera*	
Sesbania pea	*Sesbania cannabina*	
Spineless caltrop	*Tribulus micrococcus*	
Variegated thistle	*Silybum marianum*	
Wild gooseberry	*Physalis minima*	
Wild melon	*Citrullus lanatus*	
Minor Weeds		
Australian bindweed	*Convolvulus erubescens*	
Blackberry nightshade	*Solanum nigrum*	
Caustic weed	*Chamaesyce drummondii*	
Couch grass	*Cynodon dactylon*	
Liverseed grass	*Urochloa panicoides*	
Perennial ground cherry	*Physalis virginiana*	
West Indian gherkin	*Cucumis anguria*	

Dawson/Callide Valleys

Common name	Scientific name	Comments
Major Weeds		
Annual ground cherry	*Physalis ixocarpa*	
Barnyard grass	*Echinochloa crus-galli*	
Bathurst burr	*Xanthium spinosum*	
Bellvine	*Ipomoea plebeia*	increasing
Bladder ketmia (broad-leaf)	*Hibiscus trionum* var. *vesicarius*	
Bladder ketmia (narrow-leaf)	*Hibiscus trionum* var. *trionum*	
Columbus grass	*Sorghum almum*	
Common thornapple	*Datura stramonium*	
Couch grass	*Cynodon dactylon*	lighter soils
Cowvine	*Ipomoea lonchophylla*	
Downs nutgrass	*Cyperus bifax*	
Feathertop Rhodes grass	*Chloris virgata*	
Flannel weed	*Sida cordifolia*	
Giant pigweed	*Trianthema portulacastrum*	
Johnson grass	*Sorghum halepense*	
Mintweed	*Salvia reflexa*	
Mossman river grass	*Cenchrus echinatus*	
Noogoora burr	*Xanthium occidentale*	
Nutgrass	*Cyperus rotundus*	
Phasey bean	*Macroptilium lathyroides*	
Pigweed	*Portulaca oleracea*	
Sesbania pea	*Sesbania cannabina*	
Spineless caltrop	*Tribulus micrococcus*	
Starburr	*Acanthospermum hispidum*	
Tossa jute	*Corchorus olitorius*	
Wild gooseberry	*Physalis minima*	
Minor Weeds		
Anoda weed	*Urochloa panicoides*	
Annual polymeria	*Polymeria pusilla*	
Anoda weed	*Anoda cristata*	
Australian bindweed	*Convolvulus erubescens*	
Awnless barnyard grass	*Echinochloa colona*	
Blackberry nightshade	*Solanum nigrum*	
Caltrop	*Tribulus terrestris*	
Caustic weed	*Chamaesyce drummondii*	
Common sowthistle	*Sonchus oleraceus*	
Cotton	*Gossypium hirsutum*	
Dwarf amaranth	*Amaranthus macrocarpus*	
Fierce thornapple	*Datura ferox*	
Grey raspwort	*Haloragis glauca*	
Perennial ground cherry	*Physalis virginiana*	
Polymeria take-all	*Polymeria longifolia*	
Prickly paddy melon	*Cucumis myriocarpus*	
Rhynchosia	*Rhynchosia minima*	
Rough raspwort	*Haloragis aspera*	
West Indian gherkin	*Cucumis anguria*	
Wild melon	*Citrullus lanatus*	
Yellow nutgrass	*Cyperus esculentus*	

Emerald /Central Queensland

Common name	Scientific name	Comments
Major Weeds		
Bellvine	*Ipomoea plebeia*	
Bladder ketmia (broad-leaf)	*Hibiscus trionum* var. *vesicarius*	
Boggabri weed	*Amaranthus mitchelli*	
Columbus grass	*Sorghum almum*	fields & drains, spreads in irrigation water
Common sowthistle	*Sonchus oleraceus*	in winter crops
Cowvine	*Ipomoea lonchophylla*	
Crownbeard	*Verbesina encelioides*	
Giant pigweed	*Trianthema portulacastrum*	problem on head ditches
Johnson grass	*Sorghum halepense*	
Native jute	*Corchorus trilocularis*	
Native rosella	*Abelmoschus ficulneus*	
Nutgrass	*Cyperus rotundus*	
Parthenium weed	*Parthenium hysterophorus*	
Polymeria take-all	*Polymeria longifolia*	
Rhynchosia	*Rhynchosia minima*	
Sesbania pea	*Sesbania cannabina*	
Summer grass	*Digitaria ciliaris*	
Minor Weeds		
Annual ground cherry	*Physalis ixocarpa*	
Annual polymeria	*Polymeria pusilla*	
Anoda weed	*Anoda cristata*	
Australian bindweed	*Convolvulus erubescens*	
Awnless barnyard grass	*Echinochloa colona*	
Barnyard grass	*Echinochloa crus-galli*	
Bathurst burr	*Xanthium spinosum*	in gravel soils
Blackberry nightshade	*Solanum nigrum*	
Bladder ketmia (narrow-leaf)	*Hibiscus trionum* var. *trionum*	
Button grass	*Dactyloctenium radulans*	mainly tail-drains and head-ditches
Caltrop	*Tribulus terrestris*	mostly on head-ditches
Caustic weed	*Chamaesyce drummondii*	
Common thornapple	*Datura stramonium*	
Cotton	*Gossypium hirsutum*	
Couch grass	*Cynodon dactylon*	
Downs nutgrass	*Cyperus bifax*	
Dwarf amaranth	*Amaranthus macrocarpus*	
Fierce thornapple	*Datura ferox*	
Grey raspwort	*Haloragis glauca*	
Liverseed grass	*Urochloa panicoides*	
Mintweed	*Salvia reflexa*	
Noogoora burr	*Xanthium occidentale*	
Perennial ground cherry	*Physalis virginiana*	
Pigweed	*Portulaca oleracea*	
Prickly paddy melon	*Cucumis myriocarpus*	
Rough raspwort	*Haloragis aspera*	problem in dryland not irrigation in CQ
Spineless caltrop	*Tribulus micrococcus*	
West Indian gherkin	*Cucumis anguria*	
Wild gooseberry	*Physalis minima*	
Wild melon	*Citrullus lanatus*	

WEED SPECIES LISTS

Stephen Johnson and Susan Hazlewood
(University of New England)

The following lists of over 200 plant species can be found in cotton fields and in the areas that surround them. As such, not all the species outlined are of economic importance to cotton crops. Volunteer crop species such as volunteer sorghum and chickpea have been included, but one of the largest 'weed' species of cultivated cotton, volunteer cotton (*Gossypium hirsutum* and less commonly *Gossypium barbadense* i.e. Pima cotton) has not.

The plant species have been sorted by scientific name, for example *Cyperus rotundus* (Table 1) and by common name, for example nutgrass (Table 2). Both tables also contain either the common or scientific names respectively as a cross-reference. The family name and whether the species is a monocot (for example a grass, sedge, lily or other species) or a broad-leaf have been recorded in both tables.

The format of scientific names follows the Flora of NSW series while the common names are those outlined by Shepherd *et al.* (2001) *Plants of Importance to Australia. A checklist*. Refer to the further reading section for information on these two references.

We welcome your suggestions on other species that need to be added to the list. Please contact the primary author of this J3 section to register these suggestions. These registrations will be added when the list is updated in the future.

Table 1. Plant species that may be weeds in cotton fields and in surrounding areas. These species are sorted by scientific name.

Scientific name	Common Name	Family	Broad leaf/ Monocot
Abelmoschus ficulneus	Native rosella	Malvaceae	Broad leaf
Abutilon malvifolium	Bastard marshmallow	Malvaceae	Broad leaf
Abutilon theophrasti	Swamp Chinese lantern/Velvetleaf	Malvaceae	Broad leaf
Abutilon tubulosum	Abutilon	Malvaceae	Broad leaf
Aeschynomene indica	Budda pea	Fabaceae	Broad leaf
Alternanthera denticulata	Lesser joyweed	Amaranthaceae	Broad leaf
Alternanthera nodiflora	Common joyweed	Amaranthaceae	Broad leaf
Alternanthera pungens	Khaki weed	Amaranthaceae	Broad leaf
Amaranthus hybridus	Slim amaranth/Redshank	Amaranthaceae	Broad leaf
Amaranthus interruptus	Native amaranth	Amaranthaceae	Broad leaf
Amaranthus macrocarpus var. *macrocarpus*	Dwarf amaranth	Amaranthaceae	Broad leaf
Amaranthus macrocarpus var. *pallidus*	Dwarf amaranth	Amaranthaceae	Broad leaf
Amaranthus mitchellii	Boggabri weed	Amaranthaceae	Broad leaf
Amaranthus powellii	Powell's amaranth	Amaranthaceae	Broad leaf
Amaranthus retroflexus	Redroot amaranth	Amaranthaceae	Broad leaf
Amaranthus viridis	Green amaranth	Amaranthaceae	Broad leaf
Ammi majus	Bishop's weed/Queen Anne's lace	Apiaceae	Broad leaf
Anoda cristata	Anoda weed	Malvaceae	Broad leaf
Arctotheca calendula	Capeweed	Asteraceae	Broad leaf
Argemone ochroleuca subsp. *ochroleuca*	Mexcian poppy	Papaveraceae	Broad leaf
Asphodelus fistulosus	Onion weed	Liliaceae	Monocot
Avena fatua	Wild oat/Black oat	Poaceae	Monocot
Avena sterilis subsp. *ludoviciana*	Ludo wild oat	Poaceae	Monocot
Bidens pilosa	Cobbler's pegs/Sticky beak	Asteraceae	Broad leaf
Bidens subalternans	Greater beggar's ticks	Asteraceae	Broad leaf
Boerhavia dominii	Tarvine	Nyctaginaceae	Broad leaf
Brachiaria eruciformis	Sweet summer grass	Poaceae	Monocot
Brassica tournefortii	Mediterranean turnip/Wild turnip	Brassicaceae	Broad leaf
Brassica x napus var. *napus*	Rape/Volunteer canola	Brassicaceae	Broad leaf
Bromus catharticus	Prairie grass	Poaceae	Monocot
Bulbine bulbosa	Bulbine lily	Asphodelaceae	Monocot
Carduus nutans subsp. *nutans*	Nodding thistle	Asteraceae	Broad leaf
Carthamus lanatus	Saffron thistle	Asteraceae	Broad leaf
Cenchrus incertus	Spiny burrgrass	Poaceae	Monocot
Centaurea solstitialis	St. Barnaby's thistle	Asteraceae	Broad leaf
Chamaesyce drummondii	Caustic weed	Euphorbiaceae	Broad leaf
Chenopodium album	Fathen	Chenopodiaceae	Broad leaf
Chloris virgata	Feathertop Rhodes grass	Poaceae	Monocot
Cicer arietinum	Chickpea volunteer	Fabaceae	Broad leaf
Cichorium intybus	Chicory	Asteraceae	Broad leaf
Ciclospermum leptophyllum	Slender celery	Apiaceae	Broad leaf
Cirsium vulgare	Spear thistle	Asteraceae	Broad leaf
Citrullus lanatus var. *lanatus*	Wild melon/Paddy melon	Cucurbitaceae	Broad leaf
Cleome viscosa	Tickweed	Capparaceae	Broad leaf
Commelina benghalensis	Hairy wandering Jew	Commelinaceae	Monocot
Commelina cyanea	Scurvy weed/Wandering Jew	Commelinaceae	Monocot
Convolvulus arvensis	Field bindweed	Convolvulaceae	Broad leaf
Convolvulus erubescens	Australian bindweed	Convolvulaceae	Broad leaf
Conyza bonariensis	Flax-leaf fleabane	Asteraceae	Broad leaf
Conyza canadensis var. *canadensis*	Canadian fleabane	Asteraceae	Broad leaf
Corchorus olitorius	Tossa jute/Jute	Tiliaceae	Broad leaf
Corchorus trilocularis	Native jute	Tiliaceae	Broad leaf
Coriandrum sativum	Coriander volunteer	Apiaceae	Broad leaf
Coronopus didymus	Lesser swinecress	Brassicaceae	Broad leaf
Crotalaria dissitiflora subsp. *dissitiflora*	Grey rattlepod	Fabaceae	Broad leaf
Crotalaria goreensis	Gambia pea	Fabaceae	Broad leaf
Cucumis anguria var. *anguria*	West Indian gherkin/Burr gherkin	Cucurbitaceae	Broad leaf
Cucumis myriocarpus	Prickly paddy melon	Cucurbitaceae	Broad leaf
Cullen tenax	Emu foot/Verbine	Fabaceae	Broad leaf
Cuscuta campestris	Golden dodder	Convolvulaceae	Broad leaf
Cynodon dactylon	Couch	Poaceae	Monocot
Cyperus alterniflorus	Tall sedge	Cyperaceae	Monocot
Cyperus bifax	Downs nutgrass	Cyperaceae	Monocot
Cyperus concinnus	Trim sedge	Cyperaceae	Monocot
Cyperus difformis	Dirty Dora	Cyperaceae	Monocot
Cyperus eragrostis	Umbrella sedge	Cyperaceae	Monocot
Cyperus iria	Rice flatsedge	Cyperaceae	Monocot

Scientific name	Common Name	Family	Broad leaf/ Monocot
Cyperus rotundus	Nutgrass	Cyperaceae	Monocot
Cyperus victoriensis	Yelka	Cyperaceae	Monocot
Dactyloctenium radulans	Button grass	Poaceae	Monocot
Datura ferox	Fierce thornapple	Solanaceae	Broad leaf
Datura inoxia	Downy thornapple	Solanaceae	Broad leaf
Datura stramonium	Common thornapple	Solanaceae	Broad leaf
Daucus glochidiatus	Australian carrot	Apiaceae	Broad leaf
Digitaria ciliaris	Summer grass	Poaceae	Monocot
Dinebra retroflexa	Dinebra grass	Poaceae	Monocot
Echinochloa colona	Awnless barnyard grass	Poaceae	Monocot
Echinochloa crus-galli	Barnyard grass	Poaceae	Monocot
Echium plantagineum	Paterson's curse	Boraginaceae	Broad leaf
Echium vulgare	Viper's bugloss	Boraginaceae	Broad leaf
Eleusine indica	Crowsfoot grass	Poaceae	Monocot
Emex australis	Spiny emex/Three-cornered Jack	Polygonaceae	Broad leaf
Eragrostis cilianensis	Stink grass	Poaceae	Monocot
Euphorbia davidii	David's spurge	Euphorbiaceae	Broad leaf
Euphorbia helioscopia	Sun spurge	Euphorbiaceae	Broad leaf
Euphorbia peplus	Petty spurge	Euphorbiaceae	Broad leaf
Euphorbia planiticola	Plains spurge	Euphorbiaceae	Broad leaf
Fallopia convolvulus	Black bindweed	Polygonaceae	Broad leaf
Flaveria australasica	Speedy weed	Asteraceae	Broad leaf
Fumaria officinalis	Common fumitory	Fumariaceae	Broad leaf
Fumaria parviflora	Small-flowered fumitory	Fumariaceae	Broad leaf
Glycine max	Soybean volunteer	Fabaceae	Broad leaf
Gnaphalium pensylvanicum	Cudweed	Asteraceae	Broad leaf
Haloragis aspera	Rough raspwort/Haloragis take-all	Haloragaceae	Broad leaf
Haloragis glauca	Grey raspwort/Raspweed	Haloragaceae	Broad leaf
Helianthus annuus	Sunflower volunteer	Asteraceae	Broad leaf
Heliotropium amplexicaule	Blue heliotrope	Boraginaceae	Broad leaf
Heliotropium europaeum	Common heliotrope	Boraginaceae	Broad leaf
Hibiscus trionum var. *trionum*	Bladder ketmia narrow-leaf	Malvaceae	Broad leaf
Hibiscus trionum var. *vesicarius*	Bladder ketmia wide-leaf (red flowered)	Malvaceae	Broad leaf
Hibiscus trionum var. *vesicarius*	Bladder ketmia wide-leaf (yellow flowered)	Malvaceae	Broad leaf
Hypericum perforatum	St. John's wort	Clusiaceae	Broad leaf
Ibicella lutea	Yellow-flowered devils claw	Martyniaceae	Broad leaf
Ipomoea lonchophylla	Cowvine/Peachvine	Convolvulaceae	Broad leaf
Ipomoea panduranta	Wild potato vine	Convolvulaceae	Broad leaf
Ipomoea plebeia	Bellvine	Convolvulaceae	Broad leaf
Ipomoea purpurea	Common morning glory	Convolvulaceae	Broad leaf
Lablab purpureus	Lablab bean volunteer	Fabaceae	Broad leaf
Lactuca serriola	Prickly lettuce	Asteraceae	Broad leaf
Lamium amplexicaule	Deadnettle	Lamiaceae	Broad leaf
Lavatera plebeia	Australian hollyhock	Malvaceae	Broad leaf
Lepidium africanum	Common peppercress	Brassicaceae	Broad leaf
Leptochloa digitata	Umbrella canegrass	Poaceae	Monocot
Leptochloa fusca	Brown beetle grass	Poaceae	Monocot
Linum usitatissimum	Linseed volunteer	Linaceae	Broad leaf
Macroptilium lathyroides	Phasey bean	Fabaceae	Broad leaf
Malva parviflora	Small-flowered mallow/Marshmallow	Malvaceae	Broad leaf
Malvastrum americanum	Spiked malvastrum	Malvaceae	Broad leaf
Martynia annua	Devil's claw	Martyniaceae	Broad leaf
Medicago polymorpha	Burr medic	Fabaceae	Broad leaf
Melinis repens	Red Natal grass	Poaceae	Monocot
Mimosa pudica	Common sensitive plant	Mimosaceae	Broad leaf
Neonotonia wightii	Glycine/Tinaroo glycine	Fabaceae	Broad leaf
Oenothera affinis	Long-flowered evening primrose	Onagraceae	Broad leaf
Oenothera indecora subsp. *bonariensis*	Short-flowered evening primrose	Onagraceae	Broad leaf
Oxalis chnoodes	Oxalis	Oxalidaceae	Broad leaf
Oxalis perennans	Native oxalis	Oxalidaceae	Broad leaf
Oxalis pes-caprae	Soursob	Oxalidaceae	Broad leaf
Panicum decompositum	Native millet	Poaceae	Monocot
Panicum maximum	Guinea grass	Poaceae	Monocot
Parthenium hysterophorus	Parthenium weed	Asteraceae	Broad leaf
Persicaria maculosa	Redshank	Polygonaceae	Broad leaf
Persicaria prostrata	Creeping knotweed	Polygonaceae	Broad leaf
Phalaris paradoxa	Paradoxa grass	Poaceae	Monocot
Phyla nodiflora	Lippia	Verbenaceae	Broad leaf
Phyllanthus virgatus	Phyllanthus	Euphorbiaceae	Broad leaf

Scientific name	Common Name	Family	Broad leaf/ Monocot
Physalis ixocarpa	Ground cherry/Chinese lantern	Solanaceae	Broad leaf
Physalis minima	Wild gooseberry/Chinese lantern	Solanaceae	Broad leaf
Physalis virginiana	Perennial ground cherry/Chinese lantern	Solanaceae	Broad leaf
Poa annua	Annual poa/Winter grass	Poaceae	Monocot
Polygonum aviculare	Wireweed/Knotweed	Polygonaceae	Broad leaf
Polymeria longifolia	Polymeria/Polymeria take-all	Convolvulaceae	Broad leaf
Polymeria pusilla	Polymeria/Annual polymeria	Convolvulaceae	Broad leaf
Portulaca oleracea	Pigweed/Red pigweed	Portulacaceae	Broad leaf
Pratia darlingensis	Darling pratia/Matted pratia	Campanulaceae	Broad leaf
Proboscidea louisianica	Purple-flowered devils claw	Martyniaceae	Broad leaf
Raphanus raphanistrum	Wild radish	Brassicaceae	Broad leaf
Rapistrum rugosum	Turnip weed	Brassicaceae	Broad leaf
Rhynchosia minima	Rhynchosia/Ryncho	Fabaceae	Broad leaf
Ricinus communis	Castor oil plant	Euphorbiaceae	Broad leaf
Rumex crispus	Curled dock	Polygonaceae	Broad leaf
Salsola kali	Soft roly-poly	Chenopodiaceae	Broad leaf
Salvia reflexa	Mintweed	Lamiaceae	Broad leaf
Senecio daltonii	Dalton weed/Dalton's groundsel	Asteraceae	Broad leaf
Senecio lautus subsp. *dissectifolius*	Variable groundsel	Asteraceae	Broad leaf
Senna occidentalis	Coffee senna	Caesalpiniaceae	Broad leaf
Sesbania cannabina	Sesbania pea	Fabaceae	Broad leaf
Sida acuta	Spiny-head sida	Malvaceae	Broad leaf
Sida cordifolia	Flannel weed	Malvaceae	Broad leaf
Sida fibulifera	Pin sida	Malvaceae	Broad leaf
Sida rhombifolia	Paddy's lucerne	Malvaceae	Broad leaf
Sida spinosa	Spiny sida	Malvaceae	Broad leaf
Silybum marianum	Variegated thistle	Asteraceae	Broad leaf
Sinapis arvensis	Charlock	Brassicaceae	Broad leaf
Sisymbrium irio	London rocket	Brassicaceae	Broad leaf
Sisymbrium officinale	Hedge mustard	Brassicaceae	Broad leaf
Sisymbrium orientale	Indian hedge mustard	Brassicaceae	Broad leaf
Sisymbrium thellungii	African turnip weed	Brassicaceae	Broad leaf
Solanum americanum	Glossy nightshade	Solanaceae	Broad leaf
Solanum elaeagnifolium	Silver-leaved nightshade	Solanaceae	Broad leaf
Solanum esuriale	Quena	Solanaceae	Broad leaf
Solanum nigrum	Blackberry nightshade	Solanaceae	Broad leaf
Sonchus asper subsp. *glaucescens*	Rough sowthistle/Prickly sowthistle	Asteraceae	Broad leaf
Sonchus oleraceus	Common sowthistle/Milk thistle	Asteraceae	Broad leaf
Sorghum bicolor	Sorghum volunteer	Poaceae	Monocot
Sorghum halepense	Johnson grass	Poaceae	Monocot
Sorghum x almum	Columbus grass	Poaceae	Monocot
Tetragonia tetragonioides	New Zealand spinach	Aizoaceae	Broad leaf
Teucrium integrifolium	Teucry weed/Peak Downs curse	Lamiaceae	Broad leaf
Trianthema portulacastrum	Giant pigweed/Black pigweed	Aizoaceae	Broad leaf
Tribulus micrococcus	Spineless caltrop/Yellow vine	Zygophyllaceae	Broad leaf
Tribulus terrestris	Caltrop	Zygophyllaceae	Broad leaf
Typha domingensis	Narrow-leaf cumbungi	Typhaceae	Monocot
Typha orientalis	Broad-leaf cumbungi	Typhaceae	Monocot
Urochloa panicoides	Liverseed grass	Poaceae	Monocot
Urochloa praetervisa	Large armgrass/Velvet-leaved summer grass	Poaceae	Monocot
Urochloa subquadripara	Green summer grass	Poaceae	Monocot
Urtica incisa	Scrub nettle/Stinging nettle	Urticaceae	Broad leaf
Verbena bonariensis	Purpletop	Verbenaceae	Broad leaf
Verbena rigida	Veined verbena	Verbenaceae	Broad leaf
Verbesina encelioides subsp. *encelioides*	Crownbeard	Asteraceae	Broad leaf
Vicia faba	Broad bean/Faba bean volunteer	Fabaceae	Broad leaf
Vicia monantha	Spurred vetch	Fabaceae	Broad leaf
Vigna lanceolata var. *filiformis*	Maloga bean	Fabaceae	Broad leaf
Vigna lanceolata var. *lanceolata*	Maloga bean	Fabaceae	Broad leaf
Vigna lanceolata var. *latifolia*	Maloga bean	Fabaceae	Broad leaf
Vigna luteola	Dalrymple vigna	Fabaceae	Broad leaf
Vigna radiata var. *setulosa*	Mung bean volunteer	Fabaceae	Broad leaf
Wahlenbergia stricta	Tall bluebell	Campanulaceae	Broad leaf
Xanthium italicum	Italian cockleburr/Hunter burr	Asteraceae	Broad leaf
Xanthium occidentale	Noogoora burr	Asteraceae	Broad leaf
Xanthium orientale	Californian burr	Asteraceae	Broad leaf
Xanthium spinosum	Bathurst burr	Asteraceae	Broad leaf
Zea mays	Maize volunteer	Poaceae	Monocot

Table 2. *Plant species that may be weeds in cotton fields and in surrounding areas. These species are sorted by common name.*

Common Name	Scientific name	Family	Broad leaf/ Monocot
Abutilon	*Abutilon tubulosum*	Malvaceae	Broad leaf
African turnip weed	*Sisymbrium thellungii*	Brassicaceae	Broad leaf
Annual poa/Winter grass	*Poa annua*	Poaceae	Monocot
Anoda weed	*Anoda cristata*	Malvaceae	Broad leaf
Australian bindweed	*Convolvulus erubescens*	Convolvulaceae	Broad leaf
Australian carrot	*Daucus glochidiatus*	Apiaceae	Broad leaf
Australian hollyhock	*Lavatera plebeia*	Malvaceae	Broad leaf
Awnless barnyard grass	*Echinochloa colona*	Poaceae	Monocot
Barnyard grass	*Echinochloa crus-galli*	Poaceae	Monocot
Bastard marshmallow	*Abutilon malvifolium*	Malvaceae	Broad leaf
Bathurst burr	*Xanthium spinosum*	Asteraceae	Broad leaf
Bellvine	*Ipomoea plebeia*	Convolvulaceae	Broad leaf
Bishop's weed/Queen Anne's lace	*Ammi majus*	Apiaceae	Broad leaf
Black bindweed	*Fallopia convolvulus*	Polygonaceae	Broad leaf
Blackberry nightshade	*Solanum nigrum*	Solanaceae	Broad leaf
Bladder ketmia narrow-leaf	*Hibiscus trionum* var. *trionum*	Malvaceae	Broad leaf
Bladder ketmia wide-leaf (red flowered)	*Hibiscus trionum* var. *vesicarius*	Malvaceae	Broad leaf
Bladder ketmia wide-leaf (yellow flowered)	*Hibiscus trionum* var. *vesicarius*	Malvaceae	Broad leaf
Blue heliotrope	*Heliotropium amplexicaule*	Boraginaceae	Broad leaf
Boggabri weed	*Amaranthus mitchellii*	Amaranthaceae	Broad leaf
Broad bean/Faba bean volunteer	*Vicia faba*	Fabaceae	Broad leaf
Broad-leaf cumbungi	*Typha orientalis*	Typhaceae	Monocot
Brown beetle grass	*Leptochloa fusca*	Poaceae	Monocot
Budda pea	*Aeschynomene indica*	Fabaceae	Broad leaf
Bulbine lily	*Bulbine bulbosa*	Asphodelaceae	Monocot
Burr medic	*Medicago polymorpha*	Fabaceae	Broad leaf
Button grass	*Dactyloctenium radulans*	Poaceae	Monocot
Californian burr	*Xanthium orientale*	Asteraceae	Broad leaf
Caltrop	*Tribulus terrestris*	Zygophyllaceae	Broad leaf
Canadian fleabane	*Conyza canadensis* var. *canadensis*	Asteraceae	Broad leaf
Capeweed	*Arctotheca calendula*	Asteraceae	Broad leaf
Castor oil plant	*Ricinus communis*	Euphorbiaceae	Broad leaf
Caustic weed	*Chamaesyce drummondii*	Euphorbiaceae	Broad leaf
Charlock	*Sinapis arvensis*	Brassicaceae	Broad leaf
Chickpea volunteer	*Cicer arietinum*	Fabaceae	Broad leaf
Chicory	*Cichorium intybus*	Asteraceae	Broad leaf
Cobbler's pegs/Sticky beak	*Bidens pilosa*	Asteraceae	Broad leaf
Coffee senna	*Senna occidentalis*	Caesalpiniaceae	Broad leaf
Columbus grass	*Sorghum x almum*	Poaceae	Monocot
Common fumitory	*Fumaria officinalis*	Fumariaceae	Broad leaf
Common heliotrope	*Heliotropium europaeum*	Boraginaceae	Broad leaf
Common joyweed	*Alternanthera nodiflora*	Amaranthaceae	Broad leaf
Common morning glory	*Ipomoea purpurea*	Convolvulaceae	Broad leaf
Common peppercress	*Lepidium africanum*	Brassicaceae	Broad leaf
Common sensitive plant	*Mimosa pudica*	Mimosaceae	Broad leaf
Common sowthistle/Milk thistle	*Sonchus oleraceus*	Asteraceae	Broad leaf
Common thornapple	*Datura stramonium*	Solanaceae	Broad leaf
Coriander volunteer	*Coriandrum sativum*	Apiaceae	Broad leaf
Couch	*Cynodon dactylon*	Poaceae	Monocot
Cowvine/Peachvine	*Ipomoea lonchophylla*	Convolvulaceae	Broad leaf
Creeping knotweed	*Persicaria prostrata*	Polygonaceae	Broad leaf
Crownbeard	*Verbesina encelioides* subsp. *encelioides*	Asteraceae	Broad leaf
Crowsfoot grass	*Eleusine indica*	Poaceae	Monocot
Cudweed	*Gnaphalium pensylvanicum*	Asteraceae	Broad leaf
Curled dock	*Rumex crispus*	Polygonaceae	Broad leaf
Dalrymple vigna	*Vigna luteola*	Fabaceae	Broad leaf
Dalton weed/Dalton's groundsel	*Senecio daltonii*	Asteraceae	Broad leaf
Darling pratia/Matted pratia	*Pratia darlingensis*	Campanulaceae	Broad leaf
David's spurge	*Euphorbia davidii*	Euphorbiaceae	Broad leaf
Deadnettle	*Lamium amplexicaule*	Lamiaceae	Broad leaf
Devil's claw	*Martynia annua*	Martyniaceae	Broad leaf
Dinebra grass	*Dinebra retroflexa*	Poaceae	Monocot
Dirty Dora	*Cyperus difformis*	Cyperaceae	Monocot
Downs nutgrass	*Cyperus bifax*	Cyperaceae	Monocot
Downy thornapple	*Datura inoxia*	Solanaceae	Broad leaf
Dwarf amaranth	*Amaranthus macrocarpus* var. *pallidus*	Amaranthaceae	Broad leaf
Dwarf amaranth	*Amaranthus macrocarpus* var. *macrocarpus*	Amaranthaceae	Broad leaf

Common Name	Scientific name	Family	Broad leaf/ Monocot
Emu foot/Verbine	*Cullen tenax*	Fabaceae	Broad leaf
Fathen	*Chenopodium album*	Chenopodiaceae	Broad leaf
Feathertop Rhodes grass	*Chloris virgata*	Poaceae	Monocot
Field bindweed	*Convolvulus arvensis*	Convolvulaceae	Broad leaf
Fierce thornapple	*Datura ferox*	Solanaceae	Broad leaf
Flannel weed	*Sida cordifolia*	Malvaceae	Broad leaf
Flax-leaf fleabane	*Conyza bonariensis*	Asteraceae	Broad leaf
Gambia pea	*Crotalaria goreensis*	Fabaceae	Broad leaf
Giant pigweed/Black pigweed	*Trianthema portulacastrum*	Aizoaceae	Broad leaf
Glossy nightshade	*Solanum americanum*	Solanaceae	Broad leaf
Glycine/Tinaroo glycine	*Neonotonia wightii*	Fabaceae	Broad leaf
Golden dodder	*Cuscuta campestris*	Convolvulaceae	Broad leaf
Greater beggar's ticks	*Bidens subalternans*	Asteraceae	Broad leaf
Green amaranth	*Amaranthus viridis*	Amaranthaceae	Broad leaf
Green summer grass	*Urochloa subquadripara*	Poaceae	Monocot
Grey raspwort/Raspweed	*Haloragis glauca*	Haloragaceae	Broad leaf
Grey rattlepod	*Crotalaria dissitiflora* subsp. *dissitiflora*	Fabaceae	Broad leaf
Ground cherry/Chinese lantern	*Physalis ixocarpa*	Solanaceae	Broad leaf
Guinea grass	*Panicum maximum*	Poaceae	Monocot
Hairy wandering Jew	*Commelina benghalensis*	Commelinaceae	Monocot
Hedge mustard	*Sisymbrium officinale*	Brassicaceae	Broad leaf
Indian hedge mustard	*Sisymbrium orientale*	Brassicaceae	Broad leaf
Italian cockleburr/Hunter burr	*Xanthium italicum*	Asteraceae	Broad leaf
Johnson grass	*Sorghum halepense*	Poaceae	Monocot
Khaki weed	*Alternanthera pungens*	Amaranthaceae	Broad leaf
Lablab bean volunteer	*Lablab purpureus*	Fabaceae	Broad leaf
Large armgrass/Velvet-leaved summer grass	*Urochloa praetervisa*	Poaceae	Monocot
Lesser joyweed	*Alternanthera denticulata*	Amaranthaceae	Broad leaf
Lesser swinecress	*Coronopus didymus*	Brassicaceae	Broad leaf
Linseed volunteer	*Linum usitatissimum*	Linaceae	Broad leaf
Lippia	*Phyla nodiflora*	Verbenaceae	Broad leaf
Liverseed grass	*Urochloa panicoides*	Poaceae	Monocot
London rocket	*Sisymbrium irio*	Brassicaceae	Broad leaf
Long-flowered evening primrose	*Oenothera affinis*	Onagraceae	Broad leaf
Ludo wild oat	*Avena sterilis* subsp. *ludoviciana*	Poaceae	Monocot
Maize volunteer	*Zea mays*	Poaceae	Monocot
Maloga bean	*Vigna lanceolata* var. *filiformis*	Fabaceae	Broad leaf
Maloga bean	*Vigna lanceolata* var. *lanceolata*	Fabaceae	Broad leaf
Maloga bean	*Vigna lanceolata* var. *latifolia*	Fabaceae	Broad leaf
Mediterranean turnip/Wild turnip	*Brassica tournefortii*	Brassicaceae	Broad leaf
Mexcian poppy	*Argemone ochroleuca* subsp. *ochroleuca*	Papaveraceae	Broad leaf
Mintweed	*Salvia reflexa*	Lamiaceae	Broad leaf
Mung bean volunteer	*Vigna radiata* var. *setulosa*	Fabaceae	Broad leaf
Narrow-leaf cumbungi	*Typha domingensis*	Typhaceae	Monocot
Native amaranth	*Amaranthus interruptus*	Amaranthaceae	Broad leaf
Native jute	*Corchorus trilocularis*	Tiliaceae	Broad leaf
Native millet	*Panicum decompositum*	Poaceae	Monocot
Native oxalis	*Oxalis perennans*	Oxalidaceae	Broad leaf
Native rosella	*Abelmoschus ficulneus*	Malvaceae	Broad leaf
New Zealand spinach	*Tetragonia tetragonioides*	Aizoaceae	Broad leaf
Nodding thistle	*Carduus nutans* subsp. *nutans*	Asteraceae	Broad leaf
Noogoora burr	*Xanthium occidentale*	Asteraceae	Broad leaf
Nutgrass	*Cyperus rotundus*	Cyperaceae	Monocot
Onion weed	*Asphodelus fistulosus*	Liliaceae	Monocot
Oxalis	*Oxalis chnoodes*	Oxalidaceae	Broad leaf
Paddy's lucerne	*Sida rhombifolia*	Malvaceae	Broad leaf
Paradoxa grass	*Phalaris paradoxa*	Poaceae	Monocot
Parthenium weed	*Parthenium hysterophorus*	Asteraceae	Broad leaf
Paterson's curse	*Echium plantagineum*	Boraginaceae	Broad leaf
Perennial ground cherry/Chinese lantern	*Physalis virginiana*	Solanaceae	Broad leaf
Petty spurge	*Euphorbia peplus*	Euphorbiaceae	Broad leaf
Phasey bean	*Macroptilium lathyroides*	Fabaceae	Broad leaf
Phyllanthus	*Phyllanthus virgatus*	Euphorbiaceae	Broad leaf
Pigweed/Red pigweed	*Portulaca oleracea*	Portulacaceae	Broad leaf
Pin sida	*Sida fibulifera*	Malvaceae	Broad leaf
Plains spurge	*Euphorbia planiticola*	Euphorbiaceae	Broad leaf
Polymeria/Annual polymeria	*Polymeria pusilla*	Convolvulaceae	Broad leaf
Polymeria/Polymeria take-all	*Polymeria longifolia*	Convolvulaceae	Broad leaf

Common Name	Scientific name	Family	Broad leaf/ Monocot
Powell's amaranth	*Amaranthus powellii*	Amaranthaceae	Broad leaf
Prairie grass	*Bromus catharticus*	Poaceae	Monocot
Prickly lettuce	*Lactuca serriola*	Asteraceae	Broad leaf
Prickly paddy melon	*Cucumis myriocarpus*	Cucurbitaceae	Broad leaf
Purple-flowered devils claw	*Proboscidea louisianica*	Martyniaceae	Broad leaf
Purpletop	*Verbena bonariensis*	Verbenaceae	Broad leaf
Quena	*Solanum esuriale*	Solanaceae	Broad leaf
Rape/Volunteer canola	*Brassica x napus* var. *napus*	Brassicaceae	Broad leaf
Red Natal grass	*Melinis repens*	Poaceae	Monocot
Redroot amaranth	*Amaranthus retroflexus*	Amaranthaceae	Broad leaf
Redshank	*Persicaria maculosa*	Polygonaceae	Broad leaf
Rhynchosia/Ryncho	*Rhynchosia minima*	Fabaceae	Broad leaf
Rice flatsedge	*Cyperus iria*	Cyperaceae	Monocot
Rough raspwort/Haloragis take-all	*Haloragis aspera*	Haloragaceae	Broad leaf
Rough sowthistle/Prickly sowthistle	*Sonchus asper* subsp. *glaucescens*	Asteraceae	Broad leaf
Saffron thistle	*Carthamus lanatus*	Asteraceae	Broad leaf
Scrub nettle/Stinging nettle	*Urtica incisa*	Urticaceae	Broad leaf
Scurvy weed/Wandering Jew	*Commelina cyanea*	Commelinaceae	Monocot
Sesbania pea	*Sesbania cannabina*	Fabaceae	Broad leaf
Silver-leaved nightshade	*Solanum elaeagnifolium*	Solanaceae	Broad leaf
Slender celery	*Ciclospermum leptophyllum*	Apiaceae	Broad leaf
Slim amaranth/Redshank	*Amaranthus hybridus*	Amaranthaceae	Broad leaf
Small-flowered evening primrose	*Oenothera indecora* subsp. *bonariensis*	Onagraceae	Broad leaf
Small-flowered fumitory	*Fumaria parviflora*	Fumariaceae	Broad leaf
Small-flowered mallow/Marshmallow	*Malva parviflora*	Malvaceae	Broad leaf
Soft roly-poly	*Salsola kali*	Chenopodiaceae	Broad leaf
Sorghum volunteer	*Sorghum bicolor*	Poaceae	Monocot
Soursob	*Oxalis pes-caprae*	Oxalidaceae	Broad leaf
Soybean volunteer	*Glycine max*	Fabaceae	Broad leaf
Spear thistle	*Cirsium vulgare*	Asteraceae	Broad leaf
Speedy weed	*Flaveria australasica*	Asteraceae	Broad leaf
Spiked malvastrum	*Malvastrum americanum*	Malvaceae	Broad leaf
Spineless caltrop/Yellow vine	*Tribulus micrococcus*	Zygophyllaceae	Broad leaf
Spiny burrgrass	*Cenchrus incertus*	Poaceae	Monocot
Spiny emex/Three-cornered Jack	*Emex australis*	Polygonaceae	Broad leaf
Spiny sida	*Sida spinosa*	Malvaceae	Broad leaf
Spiny-head sida	*Sida acuta*	Malvaceae	Broad leaf
Spurred vetch	*Vicia monantha*	Fabaceae	Broad leaf
St. Barnaby's thistle	*Centaurea solstitialis*	Asteraceae	Broad leaf
St. John's wort	*Hypericum perforatum*	Clusiaceae	Broad leaf
Stink grass	*Eragrostis cilianensis*	Poaceae	Monocot
Summer grass	*Digitaria ciliaris*	Poaceae	Monocot
Sunflower volunteer	*Helianthus annuus*	Asteraceae	Broad leaf
Sun spurge	*Euphorbia helioscopia*	Euphorbiaceae	Broad leaf
Swamp Chinese lantern/Velvetleaf	*Abutilon theophrasti*	Malvaceae	Broad leaf
Sweet summer grass	*Brachiaria eruciformis*	Poaceae	Monocot
Tall bluebell	*Wahlenbergia stricta*	Campanulaceae	Broad leaf
Tall sedge	*Cyperus alterniflorus*	Cyperaceae	Monocot
Tarvine	*Boerhavia dominii*	Nyctaginaceae	Broad leaf
Teucry weed/Peak Downs curse	*Teucrium integrifolium*	Lamiaceae	Broad leaf
Tickweed	*Cleome viscosa*	Capparaceae	Broad leaf
Tossa jute/Jute	*Corchorus olitorius*	Tiliaceae	Broad leaf
Trim sedge	*Cyperus concinnus*	Cyperaceae	Monocot
Turnip weed	*Rapistrum rugosum*	Brassicaceae	Broad leaf
Umbrella canegrass	*Leptochloa digitata*	Poaceae	Monocot
Umbrella sedge	*Cyperus eragrostis*	Cyperaceae	Monocot
Variable groundsel	*Senecio lautus* subsp. *dissectifolius*	Asteraceae	Broad leaf
Variegated thistle	*Silybum marianum*	Asteraceae	Broad leaf
Veined verbena	*Verbena rigida*	Verbenaceae	Broad leaf
Viper's bugloss	*Echium vulgare*	Boraginaceae	Broad leaf
West Indian gherkin/Burr gherkin	*Cucumis anguria* var. *anguria*	Cucurbitaceae	Broad leaf
Wild gooseberry/Chinese lantern	*Physalis minima*	Solanaceae	Broad leaf
Wild melon/Paddy melon	*Citrullus lanatus* var. *lanatus*	Cucurbitaceae	Broad leaf
Wild oat/Black oat	*Avena fatua*	Poaceae	Monocot
Wild potato vine	*Ipomoea panduranta*	Convolvulaceae	Broad leaf
Wild radish	*Raphanus raphanistrum*	Brassicaceae	Broad leaf
Wireweed/Knotweed	*Polygonum aviculare*	Polygonaceae	Broad leaf
Yelka	*Cyperus victoriensis*	Cyperaceae	Monocot
Yellow-Flowered devils claw	*Ibicella lutea*	Martyniaceae	Broad leaf

FURTHER READING

Compiled by: **Stephen Johnson**
(University of New England)

The following lists contain a number of references that may assist the reader in various aspects of weed identification, biology and general management. Many of the references are available at large libraries or can be purchased from various publishers. The following sections are covered in the reference list: -

General plant identification,

Botanical identification/Taxonomy,

General biology and management,

Scientific journal publications and

Other useful references.

General plant identification

- Auld, B. A. and Medd, R. W. (1987). *Weeds. An Illustrated Botanical Guide to the Weeds of Australia*. Inkata Press, Melbourne. pp. 255.
- Cunningham, G. M., Mulham, W. E., Milthorpe, P. L. and Leigh, J. H. (1981). *Plants of Western New South Wales*. Inkata Press, Melbourne. pp. 776.
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- Wilson, B. J., Hawton, D. and Duff, A. A. (1995). *Crop Weeds of Northern Australia*. Queensland Department of Primary Industries, Brisbane. pp. 160.
- Wood, P., Cahill, M., Marlow, G. and Douglas, N. (compilers) (2000). *Weeds: The Ute Guide, Northern Grain Belt Edition*. Queensland Department of Primary Industries, Brisbane. pp. 190. (This guide is based on *Crop Weeds of Northern Australia*).

Botanical identification/Taxonomy

This is a list of books commonly used by botanists to identify and classify plants. Only those related to New South Wales and Queensland have been included.

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General biology and management

This list contains theses and books with sections on weeds that occur in Australian cotton farming systems.

- Groves, R. H., Shepherd, R. C. H. and Richardson, R. G. (editors) (1995). *The Biology of Australian Weeds*, *Volume 1*. Richardson, Melbourne. pp. 314.
- Johnson, S. B. (2000). Biology and management of the 'take-all' weed, *Polymeria longifolia* (Peaks Downs curse), in cotton. Doctor of Philosophy thesis. University of New England, Armidale. pp. 291. (Available through the University of New England or by contacting the author).
- Kleinschmidt, H. E. and Johnson, R. W. (1977). *Weeds of Queensland*. Australian Government Publishing Service, Brisbane. pp. 469.
- McWhorter, C. G. and Abernathy, J. R. (1992). *Weeds of Cotton: Characterization and Control*. The Cotton Foundation Reference Book Series, Number 2. The Cotton Foundation. Memphis, Tennessee, USA. pp. 631.
- Osten, V. A. (1996). *Haloragis aspera* Lindley (raspweed). Master of Agricultural Science thesis. The University of Queensland. pp. 177. (Available through the University of Queensland or by contacting the author).
- Panetta, F. D., Groves, R. H. and Shepherd, R. C. H. (editors.) (1998). *The Biology of Australian Weeds*, *Volume 2*. Richardson, Melbourne. pp. 327.
- Parsons, W. T. and Cuthbertson, E. G. (2001). *Noxious Weeds of Australia, 2nd edition.* CSIRO Publishing, Collingwood, Melbourne. pp. 698.

Scientific journal publications

This list covers weed research performed in cotton farming systems in Australia. The journals can be accessed at a university library or by contacting the author. A search of other scientific journals like *Plant Protection Quarterly*, *Weed Research*, *Weed Science* and *Weed Technology* may yield other overseas information.

- Charles, G. W. (1991). A grower survey of weeds and herbicide use in the New South Wales cotton industry. *Australian Journal of Experimental Agriculture*, **31**, 387-392.
- Charles, G. W. (1995). Nutgrass (*Cyperus rotundus* L.) control in cotton (*Gossypium hirsutum* L.). *Australian Journal of Experimental Agriculture*, **35**, 633-639.
- Charles, G. W. (1997). Herbicide strategies for reducing nutgrass (*Cyperus rotundus* L.) density in cotton (*Gossypium hirsutum* L.). *Australian Journal of Experimental Agriculture*, **37**, 231-241.
- Charles, G. W., Murison, R. D. and Harden, S. (1998). Competition of noogoora burr (*Xanthium occidentale*) and fierce thornapple (*Datura ferox*) with cotton (*Gossypium hirsutum*). *Weed Science*, **46**, 442-446.

Other useful references

This list contains a number of general references, many of which have been published since 1995 in the *Australian Cottongrower* or in *Cotton Conference Proceedings*.

- Baskaran, S. and Kennedy, I. (1999). Minimizing the environmental impact of cotton herbicides. *The Australian Cottongrower*, **20**, no. 1, 54-58.
- Charles, G. W. (1996). Sustainable weed management on permanent beds. *Proceedings of the 8th Australian Cotton Conference*, Broadbeach, Queensland. pp. 507-512.
- Charles, G. W. (1996). Understanding the weed seed menace. *The Australian Cottongrower*, **17**, no. 6, 26-28.
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- Charles, G. W. (1998). The economics of chipping large weeds. *The Australian Cottongrower*, **19**, no. 2, 42-44.
- Charles, G. W. (1998). Sorting out cotton weed control options. *The Australian Cottongrower*, **19**, no. 4, 13-17.
- Charles, G. W. (1998). Weed management in farming systems. *Proceedings of the 1998 Cropping Systems Forum*. Eds. I. Rochester and H. Dugdale. Co-operative Research Centre for Sustainable Cotton Production, Narrabri.
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- Charles, G. (2002). Using precision spraying technology for weed management. *The Australian Cottongrower*, **23**, no. 1, 50-52.
- Charles, G. W., Constable, G. A. and Kennedy, I. R. (1995). Current and future weed control practices in cotton: the potential use of transgenic herbicide resistance. In *Herbicide-Resistant Crops and Pastures in Australian Farming Systems*. Editors. G. D. McLean and G. Evans. Bureau of Resource Sciences, Canberra. pp. 89-100.
- Charles, G., Hickman, M., Llewellyn, D. and Constable, G. (1998). 2,4-D tolerant cotton in the field. *The Australian Cottongrower*, **19**, no. 5, 44-46.
- Charles, G. W., Hickman, M., Llewellyn, D. and Constable, G. (1998). Field evaluation of transgenic 2,4-D tolerant cotton. *Proceedings of the 9th Australian Cotton Conference*, Broadbeach, Queensland. pp. 193-201.
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- Hawkey, D. J. (1995). *Effects of irrigation water on weed seed populations in cotton fields in the Macquarie Valley*. Bachelor of Rural Science Honours Thesis, University of New England. Armidale, NSW.
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ABBREVIATIONS

ACRI	Australian Cotton Research Institute
ai	active ingredient
ae	acid equivalent
cm	centimetre(s)
CRDC	Cotton Research and Development Corporation
DAT	days after treatment
DF	dry flowables
EC	emulsifiable concentrates
g	grams(s)
g/kg	grams per kilogram
g/L	grams per litre
ha	hectare(s)
hr	hour(s)
IWM	Integrated Weed Management
kg	kilogram(s)
kg/ha	kilogram(s) per hectare
L/ha	litre(s) per hectare
m	metre(s)
m^2	square metre
mg	milligram(s)
mL	millilitre(s)
ml/ha	millilitres per hectare
mm	millimetre(s)
NRA	National Registration Authority
p.	page
post-em	post-emergence
pp.	pages
pre-em	pre-emergence
SC	suspension concentrate
SP	soluble powder
sp.	species (singlular)
spp.	species (plural)
sub. sp.	sub species
var.	variety
WDG	water-dispersible granule
WP	wettable powder

GLOSSARY

Compiled by: **Leah MacKinnon**
(University of New England)

absorption
: the process by which a herbicide passes from one system into another, eg. from the soil solution into a plant root cell or from the leaf surface into the leaf cells.

active ingredient
: the biologically active part of the chemical present in a herbicide formulation primarily responsible for its phytotoxity and which is identified as the active ingredient on the product label.

adsorption
: the process by which a herbicide associates with a surface, e.g. a soil colloidal surface.

allelopathic
: the adverse effect on the growth of plants or microorganisms caused by the action of chemicals produced by other living or decaying plants.

annual
: a plant which completes its life cycle within one year after germination.

application window
: the specific crop or weed growth stage to which a herbicide can be applied.

awn
: a stiff, bristle-like projection on the seed head of some grasses.

axil
: the angle between a leaf or a branch and the stem axis from which it arises.

banded treatment
: applied to a linear restricted strip on or along crop rows, rather than continuous over the field.

biennial
: a plant which completes its life cycle within two years after germination.

biotypes
: a population within a species that has a distinct genetic variation. Biotypes often have physical lifecycle or herbicide susceptibility differences.

broad-leaf weed (see dicots).

common name (chemical)
: a generic name for a chemical compound.

common name (plant)
: a name that a weed is commonly know by. A weed may be known by several common names.

community
: the populations of species living in a common ecosystem.

competition
: the active acquisition of limited resources by an organism which results in a reduced supply, and consequently reduced growth, of the organisms in a common environment.

contact herbicide
: a herbicide that causes injury to only the plant tissue to which it is applied, or a herbicide that is not appreciably translocated within plants.

cotyledon
: the seed leaf, the primary leaf of the embryo and the first leaf observed above the soil surface.

defoliant
: a chemical that causes the leaves to abscise from a plant.

dicot
: abbreviated term for dicotyledon; preferred in scientific literature over broad-leaf to describe plants.

dicotyledon
: a member of the Dicotyledonae; one of two classes of angiosperms usually characterised by the following: two seed leaves (cotyledons), leaves with net venation, and root systems with tap roots.

directed application
: precise application to a specific area or plant organ, such as, to a row or bed, or to the leaves or stems of plants.

directed sprays
: see directed application.

dispersible granule
a dry granular formulation that will separate or disperse to form a suspension when added to water.

dormancy
temporary suppression of growth which may be of advantage in surviving ultimately unfavourable conditions.

ecology
the science concerning the relationship between organisms and environment.

economic threshold
a level of expenditure above which it is no longer financially beneficial to continue an activity.

ecosystem
a biotic system maintained by the balance of organic life with its environment.

efficacy
the degree of which a herbicide controls a weed.

emergence
the event in seedling establishment when a shoot becomes visible by pushing through the soil surface.

emulsifiable concentrates (EC)
where the active ingredient is dissolved in an organic solvent to which an emulsifier has been added to make the solution mix readily with water.

fallow, fallows, fallow land
(i) the period of time between crops, or,
(ii) area of land set aside from a cropping regime - can be summer, winter or longer.

Family
of taxonomy, a category level below an 'order' but above a 'genus'. One uniting genera assessed as having been derived from a common ancestral stock, or from a single genus, when no other genera are believed related.

field capacity
the percentage (expressed on the basis of weight or volume) of water remaining in a soil.

flowable
a two-phase formulation containing solid herbicide suspended in liquid, and that forms a suspension when added to water.

flushing
light irrigation - particularly used soon after planting pre-irrigated cotton if the surface soil dries too rapidly for emerging cotton seedlings.

foliar activity
the term used to describe post-emergent herbicide effects on the leaves of plants.

formulation
(i) herbicide preparation supplied by a manufacturer for practical use;
(ii) the process, carried out by manufacturers.

fourth true-leaf
the first four leaves after the cotyledons, prior to the unfurling of the fifth leaf - last possible cotton growth stage for the safe over-the-top application of glyphosate in Roundup Ready cotton.

germination
the initiation of growth in seeds.

Group A herbicide
these post-emergence grass herbicides act through inhibiting acetyl-coA caboxylase, leading to membrane disruption in the plant.

Group B herbicide
these herbicides inhibit acetolactate synthase.

Group C herbicide
these herbicides inhibit photosynthesis at photosystem II.

Group D herbicide
these herbicides inhibit tubulin formation, effectively inhibiting plant growth.

Group E herbicide
these herbicides inhibit mitosis.

Group F herbicide
these herbicides inhibit carotenoid biosynthesis.

Group G herbicide
these herbicides inhibit protoporphyrinogen oxidase.

Group H herbicide
these herbicides inhibit protein systhesis.

Group I herbicide
these herbicides disrupt cell growth.

Group J herbicide
these herbicides inhibit fat synthesis.

Group K herbicide
these herbicides have multiple modes of action inhibiting growth and root elongation.

Group L herbicide
these herbicides inhibit photoshythesis at photosystem I.

Group M herbicide
these herbicides inhibit EPSP synthase.

Group N herbicide
these herbicides inhibit glutamine synthetase.

half-life
the time taken for a herbicide to be degraded by 50%.

herbicide
a chemical substance or cultured biological organism designed to interfere with specific chemical processes in plants.

herbicide drift
the drift of a herbicide off-target, or from where it was applied.

herbicide registration
before herbicides can be sold, supplied, distributed or used in Australia, they must be registered by the National Registration Authority (NRA). The registration process is governed by Commonwealth legislation and undertaken according to accepted scientific principles and through rigorous independent analysis by several government agencies and the NRA.

in-crop
refers to (i) period of time from crop emergence to crop defoliation, or (ii) within a crop area.

inflorescence
the part of a floral shoot where the flowers are segregated as more or less distinct units.

Integrated Weed Management
a set of management tools or options that, when used in conjunction with each other, result in a sustainable system of whole-farm management of weeds.

inter-row cultivation
the act of cultivation between the plant lines.

label
the directions for using a herbicide approved as a result of the registration process.

lateral (root system)
the secondary roots attached to the tap root generally in a horizontal plane.

lateral movement
movement of a herbicide through soil, generally in a horizontal plane, from the original site of application.

lay-by
the last application and incorporation of herbicides prior to canopy closure.

leaching
the movement of a substance downward or out of the soil as the result of water movement.

lifecycle
the timing of various stages in the life of a plant e.g. emergence, flowering, seed set.

ligule
a projection at the junction of the leaf blade and leaf sheath in grasses.

lobe
a rounded projection generally of a leaf, hence lobed.

microbial activity
the action of soil microbes in degrading herbicides.

mode of action
method or process by which a herbicide can have an impact upon a plant, or a plant process or pathway.

monocot
abbreviated term for monocotyledon.

monocotyledon
a member of Monocotyledonae; one of two classes of angiosperms, usually characterised by the following: one seed leaf (cotyledon), leaves with parallel venation, root systems arising adventitiously and usually diffuse (fibrous).

node
: a joint of a stem from which leaves and branches arise.

non-selective herbicide
: a herbicide that is generally toxic to all plants treated.

noxious weed
: a plant regulated or identified by law, as being undesirable, troublesome, and difficult to control. Precise definition varies according to legal interpretations.

overtop application

over-the-top application
: a broadcast or banded application applied over the canopy of crops.

pathogen
: an organism that causes a disease in another organism.

perennial
: living more than two years, usually flowering each year.

persistent herbicide
: a herbicide that, when applied at the recommended rate, will have an impact upon susceptible crops planted in normal rotation after harvesting the treated crop, or that interferes with regrowth of native vegetation in non-crop sites for an extended period of time.

pH
: the negative logarithm of the hydrogen-ion concentration of a soil. The degree of acidity (or alkalinity) of a soil as determined by means of a glass, quinhydrone, or other suitable electrode or indicator, at a specified moisture content or soil-water ratio, and expressed in terms of the pH scale.

phloem
: the living tissue in plants that functions primarily to transport metabolic compounds from the site of synthesis or storage to the site of utilization.

phytotoxic
: injurious or lethal to plants.

plant-back periods
: recommended periods of time, after the use of herbicides, that will avoid damage to crops.

population
: in ecology, a group of individuals of any one species.

post-emergence (POST)
: applied after the emergence of the specified crop.

post-emergent
: period of time after the emergence of crop seedlings.

pre-emergence (PRE)
: applied to the soil before emergence of the specified crop.

pre-emergent
: period of time before the emergence of crop seedlings.

pre-irrigation
: refers to irrigating before planting a crop.

pre-plant application
: applied before planting a crop, either as a foliar application to control existing vegetation or as a soil application.

preplant incorporated (PPI)
: applied and blended into the soil before seeding.

ratoon cotton
: cotton regrown from left-over root stock from a pervious season.

re-cropping interval
: period of time between crops (particularly related to time after residual herbicide use).

residual herbicides & residuals
: herbicides that have a time-span of impact (i.e. injure or kill germinating weed seedlings) on plant growth well after the application of the herbicide. Different herbicides have different time-spans of impact, (different residual effects), can remain in the soil profile for long periods of time, and can be moved around in the soil by irrigation, rainfall events or groundwater movement. (see 'persistent herbicide' Glossary above).

resistant populations
: whereby the repeated use of one herbicide, or other herbicides with the same mode of action, has removed susceptible plants but has allowed the survivors to grow and multiply, producing a resistant population of plants.

rhizome
: an underground stem, usually horizontal, producing leafy shoots and roots.

root pruning
: the reduction of the root mass that can occur by either mechanical (cultivation) or chemical means.

seed bank
: the number of seeds, accumulated over time, present in the soil.

selective herbicide
: a chemical that is more toxic to some plant species than to others.

shielded sprays
: herbicides applied to the interow areas, beneath a protective shield.

soil moisture
: the amount of water in the soil (wet weight minus dry weight).

soil organic matter
: the organic fraction of the soil: includes plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population.

soluble concentrate
: a liquid formulation that forms a solution when added to water.

soluble granule
: a dry granular formulation that forms a solution when added to water.

soluble powder
: a dry formulation that forms a solution when added to water .

species composition
: the number of species within a community of plants.

species shift
: the selection and increase of naturally tolerant weed species.

spot spraying
: targeting of individual weeds with herbicides.

spray drift
: movement of airborne spray from the intended areas of application. see 'herbicide drift' Glossary above.

suppression
: a degree of reduction of plant growth, but not death.

surfactant
: a material that improves the emulsifying, dispersing, spreading, wetting or other properties of a liquid by modifying its surface characteristics.

susceptibility
: the sensitivity to, or, degree to which, a plant is injured by a herbicide treatment.

suspension concentrates (SC)
: suspension concentrates are also referred to as flowable concentrates. They are formulated by dispersing small particles in a liquid, usually water. Dispersing and suspending agents are added during formulation to keep these particles suspended in solution.

synergism
: an interaction of two or more factors such that the effect, when combined, is greater than the predicted effect, based on the response to each factor applied separately.

synergist
: for herbicides - a non-herbicidal compound used to increase the phytotoxicity of a herbicide by a physiological mechanism.

systemic
: the property of pesticides that penetrate and disperse throughout a plant.

tap root
: the primary descending root.

target site
: the particular plant process to which a treatment is directed.

target species
: the plant species selected for treatment.

thresholds
: a defined level beyond which action should occur.

tolerance
: ability to continue normal growth or function when exposed to a potentially harmful agent.

toxicity
: the quality, or potential, of a substance to cause injury, illness, or other undesirable effects.

trade name
: a trademark or other designation by which a commercial product is identified.

transgenic varieties
: varieties of cotton that have been genetically modified, in this case, herbicide tolerant varieties of cotton that have been genetically modified to enhance their tolerance of specific herbicides - e.g. Roundup Ready cotton.

translocated herbicide
: a herbicide that is moved within the plant. Translocated herbicides may be either phloem mobile or xylem mobile.

translocation
: the process whereby a chemical is absorbed into the plant, via the leaves or roots, and is then moved to other parts of the plant.

vegetative reproduction
: the reproduction of a plant via stems, leaves and rhizomes.

viability (seed)
: the potential of a seed to be able to germinate.

volunteer cotton
: are plants that have germinated, emerged and established unintentionally.

watering-up
: refers to irrigating after planting - a method used to establish a cotton crop.

weed escapes
: weeds that have survived a weed management method.

weed spectrum
: the different species of weeds present within a community or given area.

wettable powder (WP)
: a finely divided dry formulation that can be readily suspended in water.

wetting agent
: (i) a substance that serves to reduce the interfacial tensions and causes spray solutions or suspensions to make better contact with treated surfaces (see surfactant);
(ii) a substance in a wettable powder formulation that causes it to wet readily when added to water.

xylem
: the non-living tissue in plants that functions primarily to conduct water and mineral nutrients from roots to the shoot.

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