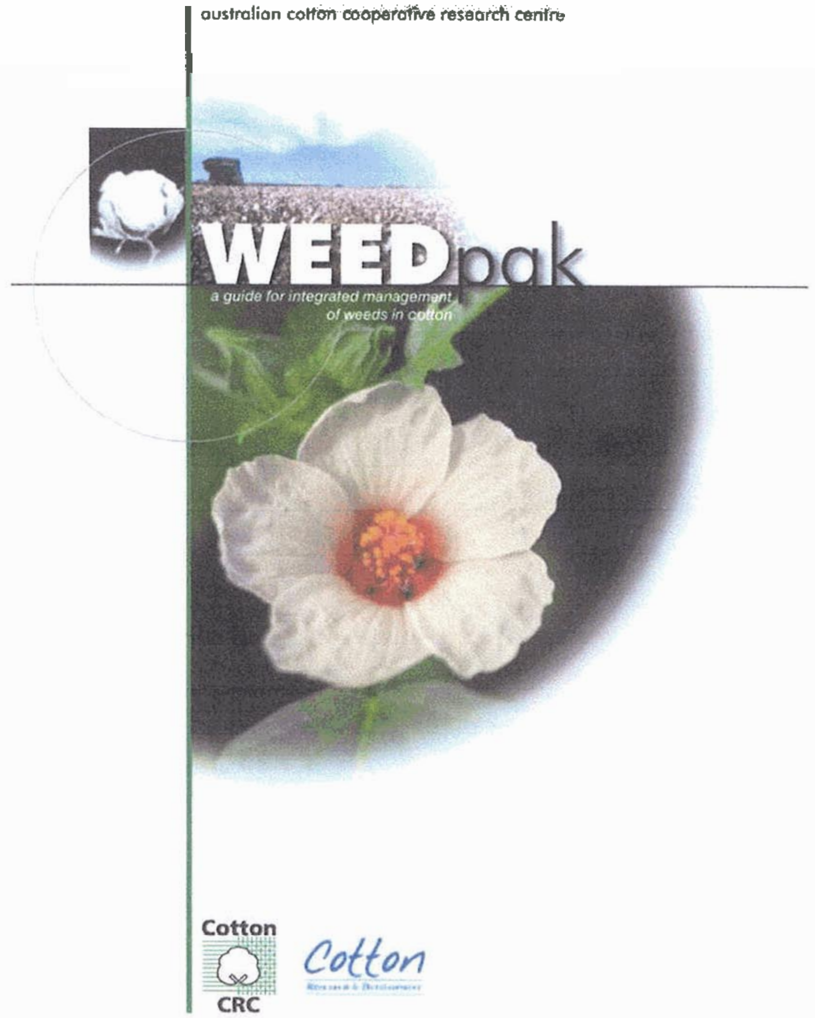
**COTTON RESEARCH & DEVELOPMENT CORPORATION**

# FINAL REPORT

# WEED MANAGEMENT PACKAGES FOR COTTON

# DAN 156C




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

**Graham Charles, ACRI Narrabri (02 6799 1524)**

**ISBN 0 7347 1428 9**

**July 1 2001 to June 30 2002**

NSW Agriculture

Cotton
Research & Development

January, August & Final Reports

# REPORTS

## *Part 1 - Summary Details*

*Please use your TAB key to complete part 1 & 2.*

**CRDC Project Number:** **156C**

| | | |
|---|---|---|
| **January Report:** | ☐ | Due 31-Jan-02 |
| **August Report:** | ☐ | Due 01-Aug-02 |
| **Final Report:** | ☒ | Due within 3 months of project completion |

**Project Title:** Weed Management Packages for Cotton

**Project Commencement Date:** July 01 **Project Completion Date:** June 02

**Research Program:** Diseases Weeds

## *Part 2 – Contact Details*


**Administrator:** Mr. Graham Denny, Manager External Funding
**Organisation:** NSW Agriculture
**Postal Address:** locked Bag 21, Orange 2800
**Ph:** 02 6391 3219 **Fx:** 02 6391 3327 **E-mail:** graham.denny@agric.nsw.gov.au

**Principal Researcher:** Mr. Graham Charles, Research Agronomist (Weeds)
**Organisation:** NSW Agriculture
**Postal Address:** Australian Cotton Research Institute, Narrabri 2390
**Ph:** 02 6799 1524 **Fx:** 02 6799 1503 **E-mail:** graham.charles@agric.nsw.gov.au

**Supervisor:** Mr. Dallas Gibb, Program Leader (Cotton)
**Organisation:** NSW Agriculture
**Postal Address:** Australian Cotton Research Institute, Narrabri 2390
**Ph:** 02 6799 1500 **Fx:** 02 6799 1503 **E-mail:** dallas.gibb@agric.nsw.gov.au

**Researcher 2** (Name & position of additional researcher or supervisor).
**Organisation:**
**Postal Address:**
**Ph:** **Fx:** **E-mail:**


**Signature of Research Provider Representative:** [signature]

## *Part 3 – Final Report Format*

### 1. Outline the background to the project.

Since 1988, CRDC has funded a series of projects focussing on the management of problem weeds (nutgrass, polymeria takeall, cowvine, budda pea, lippia and others) and weed management systems for the cotton industry. The research included work on transgenic, herbicide tolerant cotton (Roundup Ready, Oxygene, Liberty Link and 2,4-D tolerant cotton), noogoora and thornapple competition, herbicides for use with pigeon peas, and monitoring weed management systems.

Nevertheless, weeds continne to cause significant problems for the cotton industry, and the cost of weed control increases year by year. Four of the key weed problems in cotton are nutgrass, cowvine, bellvine, and polymeria takeall. While considerable research has been undertaken on nutgrass, there are still considerable gaps in the knowledge of this weed and its management. Even less is known of the management options for cowvine, bellvine and polymeria takeall in irrigated cotton.

Problems with weed control are being exacerbated by changes in the farming system, with trends towards reduced cultivation, reduced chipping and stubble retention. These changes are placing increasing pressure on the use of herbicides, and as a consequence, a group of problem weeds that are largely tolerant of the commonly used herbicides has been selected out. The increase in residual herbicide use also has flow-on environmental impacts both on and off the farm.

In order to address this situation, ACGRA has requested that the weeds team put all available information together into a WEEDpak format during the next year. Much of the data collected in DAN 124C and previous projects will form an important part of WEEDpak. This will provide a valuable resource to cotton growers and will also allow future research and extension priorities to be more readily identified.

### 2. List the project objectives and the extent to which these have been achieved.

### Objectives:

1. To continue research on the management of cowvine, bellvine and polymeria take-all.
2. To develop integrated management guidelines for the major problem weeds of cotton. These guidelines will draw together all available information so it can be complied into a grower based information package (WEEDpak). This package will include grower case studies of successful and unsuccessful management approaches.
3. To continue monitoring weed density and diversity on the CRC farming systems experiment at Warra and on farmers' fields throughout the industry.
4. To explore and identify the strengths and gaps in current knowledge of weed management in cotton and to clearly identify grower priorities for future research.

### Achievements:

All objectives have been achieved. The results of the work were written up as a major component of WEEDpak. Extracts of WEEDpak are included as an Appendix.

1. Field experiments on cowvine management were undertaken at Bloomvale (Moree) and Clyde (Dirranbandi). Results were mixed. The best treatment, an application of Zoliar at 2 kg/ha, gave a 75% reduction in cowvine numbers (averaged over the season), but this result is still inadequate, leaving 3 plants/$m^2$. Long-term monitoring of the cowvine seedbank experiment continued at Beechworth (Merah North), showing a 50% reduction in the seedbank over 3 seasons under grower management. More detailed examination of the viability of the seed in the seedbank will commence this season.

   Polymeria take-all and lippia field experiments continue, although the results have been adversely impacted by the current dry conditions, as these experiments are situated on rain-fed sites.

   Nutgrass management in Roundup Ready® cotton is being assessed at Auscott (Narrabri). Visual observations indicate improved control with Roundup in Roundup Ready® cotton compared to MSMA in conventional cotton. Soil samples and visual assessment over the next 2 seasons should confirm this result.

Detailed glasshouse studies of cowvine, bellvine, polymeria take-all and nutgrass management continued. Experiments focus on questions that are not adequately answered in the weed management guides in WEEDpak, such as the minimum interval for cultivation following a glyphosate application to nutgrass. This information will be released in a supplement to WEEDpak when the results become available.

2. WEEDpak has been a major collaborative undertaking. It was officially launched at the Australian Cotton Conference and will be released in early October 2002. My direct input into WEEDpak include the sections:

- Weed identification and information guide, with identification of 38 weeds (Stephen Johnson compiled the information component
- Integrated weed management (IWM) in Australian cotton production (with Grant Roberts)
- Managing weeds in cotton
- Managing herbicide resistance in cotton
- Managing Roundup Ready® cotton (with Ian Taylor)
- Research results with Roundup Ready® cotton
- Managing weeds on roads, channels and water storages (with others)
- Managing cowvine in cotton
- Managing nutgrass in cotton
- Managing polymeria (take-all) in cotton (with Stephen Johnson)
- Herbicides for pigeon pea trap crops

These sections are included as an Appendix to this document.

Editing, formatting, reviewing and developing WEEDpak has also required a very large investment of time.

3. Weed pressure continues to be monitored on the CRC cropping rotation experiment at Prospect (Warra) and growers' fields. Nutgrass and cowvine continue to be major problems for growers. Bladder ketmia, pigweed and dwarf amaranth are also becoming more problematic for growers who are relying more heavily on glyphosate.

4. Compilation of the WEEDpak components has given a clear understanding of the strengths and gaps in the weed management system. A number of gaps in the current research have been identified. These gaps are the future focus of the research effort.

## 5. How has your research addressed the Corporations three outputs: Sustainability, profitability and international competitiveness, and/or people and community?

The research directly addresses the issues of sustainability and profitability.

Objective 1 assesses a range of weed management options to determine the optimum (most profitable) systems using old and newer technologies including transgenic cotton, stubble retention and permanent beds.

Objectives 2, 3 & 4 examine issues of sustainability, developing management packages for problem weeds which threaten sustainability, and assessing the sustainability of current production and farming systems. The production of WEEDpak represents a major step forward in getting this information out to the cotton industry and the community. The WEEDpak material will be made available on the internet later this year, making the information readily available.

## 6. Detail the methodology and justify the methodology used.

Experiments were undertaken in the field and glasshouse using standard techniques, with full replication of treatments. Most experiments used 4 replicates. Three replicates were used on a few field experiments (such as the polymeria take-all management experiment) where resources were limited, generally because of the limited size of the weed patches available. Most field experiments were conducted using fully randomised complete block designs with plots of 20 m by 4 m. Glasshouse experiments were either factorials or complete block designs. Data were analysed in Genstat using REML and regression using the Poisson model. These methods give the most reliable results, ensuring a high probability of accuracy with an efficient use of resources.

Soil cores were used to monitor the nutgrass and cowvine seedbanks. The sample depth was determined from a prior understanding of the distribution of seeds down the soil profile. Ten replicate 75 mm cores of 300 mm length were taken per plot. This sample size was small and resulted in a high degree of variability in the results, but was limited by the amount of work required to process the samples (around 3 weeks full-time for 1 person per sampling date) and the practical need to limit the amount of soil taken from each plot over a number of years (approximately 1000 kg of soil was taken from the field at each sampling date).

The weed surveys were undertaken using predetermined transects across fields and plots. Weed density was measured on 10 strips of 1 m by 50 m along the cotton, with 2 replicates in growers fields row. Five strips were observed on each treatment of the Warra CRC sit, which had 3 replicates). Observations were taken in approximately the same position each season using measurements and GPS coordinates. Every weed present in each strip was recorded, except where weeds in a single species were present at greater than 1 per $m^2$. The density of these species was recorded after 50 weeds had been observed. This survey method was adapted from the method used by Felton and is practical and efficient in the cotton system where most weeds are present at relatively low densities (frequently fewer than 1 weed per 10 $m^2$).

Experiments were generally a combination of field work and glasshouse work. Field experiments give the best understanding of how treatments work in the real world, under typical field conditions, but can be strongly influenced by factors such as soil moisture and temperature. Actual weed density and age can be difficult to determine in the field. Glasshouse experiments allow detailed examination of treatments excluding external factors, but do not always give a good indication of likely results in the field.

Experiments undertaken included:

- Weed incidence was monitor on the Warra cropping rotation experiment
- Weed incidence was monitored on fields on 6 cooperating farms using permanent bed
- Weed incidence was monitored on the permanent bed experiment at ACRI, incorporating stubble retention, Roundup Ready, bromoxynil and Basta tolerant material
- Cowvine management experiments were conducted at Moree and Dirranbandi
- 2 glasshouse experiments looking at the depth of emergence and residual herbicides on peachvine
- 4 glasshouse experiments looking at the depth of emergence and herbicides for bellvine control
- Nutgrass management in Roundup Ready® cotton and rotation crops was assessed at Auscott (Narrabri)
- 2 glasshouse experiments examining the efficacy of herbicides on the nutgrass species *Cyperus rotundus*, *C. bifax* and *C. victoriensis*
- 2 glasshouse experiments examining the minimum interval between glyphosate to nutgrass and cultivation
- Polymeria take-all management was assessed in a field experiment on Twynam Central (Colly)
- 2 glasshouse experiments looked at additives and surfactants to improve glyphosate efficacy for polymeria control
- 2 field experiments compared herbicides for lipia control

## 7. Detail results including the statistical analysis of results.

Detailed results from this and earlier work has been compiled into management guidelines and other components included in WEEDpak and are presented in the attached Appendix. All results were statistically analysed, as indicated in Section 6. Only statistically significant results are included in these guidelines.

## 8. Discuss the results, and include an analysis of research outcomes compared with objectives.

1. Comprehensive management guides for nutgrass, cowvine and polymeria take-all are included in WEEDpak. These documents have provided a vehicle to incorporate all the available information in a structured way. These documents also highlight the gaps in the current knowledge. Obvious gaps are:

   - The field results for cowvine (peachvine) management were poor. Trials this season focus on split applications to ensure that herbicide rates are maintained season-long. Additional work on some currently unregistered herbicides and alternative herbicides that may be used in rotation crops is needed. A better understanding of the seedbank and the longevity and fate cowvine seeds is also needed. Work on this is being initiated this season.

- Work to understand the minimum period for cultivation following a glyphosate application to nutgrass is under way. Two new promising herbicides are also now available (experimentally) and will need to be examined both in the glasshouse (work under way) and field on the range of nutgrass species. Work to date has concentrated on 3 nutgrass species. Additional work on some of the other species such as dirty dora may be needed. Some nutgrass species that occur in Qld., such as yellow nutsedge (the most important nutgrass species in the US) have not been included in the nutgrass management guide. Feedback from WEEDpak should clarify this need to include other species.

- Work to understand the effect of humidity, temperature and soil moisture on glyphosate efficacy on nutgrass and cowvine will be initiated as soon as the controlled climate cabinets recently ordered become available. These cabinets will also be used to examine some of the other interactions of climate and herbicide efficacy with these and other weeds.

- The effects of heavy cultivation and 2,4-D on polymeria take-all control are not well covered in WEEDpak. Glasshouse and some field work on 2,4-D efficacy have been initiated.

- Additional information on photoperiod effects, emergence temperatures and responses to soil moisture will be assessed for these and other weeds.

2. WEEDpak has been a milestone in the weeds work, incorporating results from years of research into a single entity. WEEDpak is available to the cotton industry in an attractive A4 folder, allowing sections to be upgraded over time. It is our intention to upgrade WEEDpak as necessary, with the first upgrade planned for next winter. These upgrades will be simplified by the style used in WEEDpak, allowing pages to be easily added or replaced. The first upgrade of WEEDpak will include more weed identification and information sets, information on herbicides in rivers etc, and management packages for additional weeds including caustic weed and mint weed.

WEEDpak is a visually attractive, comprehensive, full-colour document that presents a mass of information in an informative, but very readable format. WEEDpak will also be available on the CRC web site, making it easily and freely available to the general public.

WEEDpak has focused around the need for cotton growers to continue to use an integrated approach to weed management. It is important that growers understand the need for this approach, and understand the consequences of relying too heavily on a single tool for weed management. The concept of IWM is not new but the adoption of IWM is something that has been appreciated by too few industries. Most industries are working on the principle of using the most cost-effective tools until they fail, in the hope that a new and better tool will come along and replace them. This approach may be cost-effective in the short-term, but may be expensive in the long-term, as new management tools may not become immediately available and may be very expensive. IWM relies on the principle of reducing the weed seedbank over time, reducing the long-term cost of and need for weed control.

WEEDpak sets a new standard in information delivery to the cotton industry. With the support of CRDC, the result more-than meets the expectation.

3. Weed monitoring on growers' fields and the cropping systems experiment has continued to provide useful information on the level of weed pressure present and the changes in the weed spectrum over time. These changes have been slow to emerge, but are occurring. The slow response to changing weed management systems is due (at least in part) to the low density of many of these weeds in the first instance, the large size of the seedbank of many of these weeds, the use of regular cropping rotations and fallows, and the continuing use of a range of weed management tools. Changes in the weed spectrum will occur more rapidly if growers primarily use only 1 or 2 weed management tools. Growers in the US who have developed a Roundup only system have seen large changes in their weed spectrum within 2 to 3 seasons. These changes (to Roundup tolerant weeds) mean that the system has failed after only 2 to 3 seasons.

The outcomes from this project clearly meet or exceed the project's objectives.

## 9. Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. Where possible include a statement of the

**costs and potential benefits to the Australian cotton industry and future research needs.**

WEEDpak will have a clear impact on the cotton industry, promoting the use of integrated weed management (IWM), accurate weed identification, and the targeted management of specific problem weeds.

The adoption of IWM will have a long term benefit to the industry, reducing in-field weed pressure and weed management costs, and increasing yields. More accurate weed identification and targeted management plans for specific problem weeds will reduce the incidence of spray failure due to incorrect weed identification or incorrect product choice.

Weed management costs around $250/ha, or $125 million industry wide annually. A saving of even 5% of this cost amounts to a saving of $6.25 million annually. On top of this, weeds also reduce cotton yields. Improvements in weed control will improve cotton yields, giving much greater returns. An improvement in cotton yields of 5% will give a return of around $80 million. Research results have shown that improvements in weed management can improve yields by over 1 bale/ha, potentially improving yields by far more than $80 million.

**10. Describe the project technology (eg. commercially significant developments, patents applied for or granted licenses etc).**

Nil

**11. Provide a technical summary of any other information developed as part of the research project. Include discoveries in methodology, equipment design, etc.**

NA

**12. Detail a plan for the activities or other steps that may be taken;**

**(a) to further develop or to exploit the project technology.**

**(b) for the future presentation and dissemination of the project outcomes.**

Support and extension of WEEDpak has been identified as an important priority of the current project. This support commenced at the Australian cotton conference, where WEEDpak was show cased, and will continue as opportunity arises throughout the year. WEEDpak will be delivered to cotton growers on request, will be provided to the cotton extension team, and will be distributed at field days, industry meetings, etc. The cotton industry extension staff and consultants will be important to getting WEEDpak out into the industry.

Getting WEEDpak up and running on the CRC web will be the next hurdle. The web-site will allow community-wide access to the material, and will allow the material to be continually improved and updated. It will also allow much better cross-linking of information.

It is essential that WEEDpak is continually upgraded on a yearly or bi-yearly basis, as new and additional material becomes available. The weed identification and information guide especially needs more input to expand the range of weeds and to ensure that ecology and management information is available for all the weeds presented. Thirty eight weeds are currently in the guide. This will need to be expanded to several hundred weeds over the next few years.

Work on the management of specific problem weeds continues as a focus of this project. The current new project focuses on the management of bellvine, dwarf amaranth, pigweed and David's spurge, in addition to some continuing work on nutgrass and cowvine.

Basic information such as depth of emergence and minimum temperature for emergence needs to be generated for the major weeds of cotton, but is not currently available. This data could be generated relatively easily for a wide range of weed species and would be a valuable addition to weed information currently available in WEEDpak.

**13. List the publications arising from the research project.**

Charles G. & Johnson S. (2002) Weed identification and information guide. In "WEEDpak – a guide for integrated management of weeds in cotton", CSIRO, Canberra.

Roberts G. & Charles G. (2002) Integrated weed management (IWM) in Australian cotton production. In "WEEDpak – a guide for integrated management of weeds in cotton", CSIRO, Canberra.

Charles G. (2002) Managing weeds in cotton. In "WEEDpak – a guide for integrated management of weeds in cotton", CSIRO, Canberra.

Taylor I. & Charles G. (2002). Managing Roundup Ready cotton. In "WEEDpak – a guide for integrated management of weeds in cotton", CSIRO, Canberra.

Charles G. (2002) Research results with Roundup Ready cotton. In "WEEDpak – a guide for integrated management of weeds in cotton", CSIRO, Canberra.

Charles G., Sullivan A., Christiansen I., & Roberts G. (2002) Managing weeds on roads, channels and water storages. In "WEEDpak – a guide for integrated management of weeds in cotton", CSIRO, Canberra.

Charles G. (2002). Managing cowvine in cotton. In "WEEDpak – a guide for integrated management of weeds in cotton", CSIRO, Canberra.

Charles G. (2002). Managing nutgrass in cotton. In "WEEDpak – a guide for integrated management of weeds in cotton", CSIRO, Canberra.

Charles G. (2002). Managing polymeria (take-all) cotton. In "WEEDpak – a guide for integrated management of weeds in cotton", CSIRO, Canberra.

Charles G. (2002) Herbicides for pigeon pea trap crops. In "WEEDpak – a guide for integrated management of weeds in cotton", CSIRO, Canberra.

Charles G. W. (2001). Sustainable Weed Management for Cotton. Final Report on Project DAN 124C, 1998 - 2001 for the Cotton Research and Development Corporation. pp. 22

Charles G. W. (2001). Weed management. *In* Australian Dryland Cotton Production Guide. Narrabri, NSW: CRDC.

Johnson S. B., Charles G. W., Christiansen I. H., Hazlewood S. M., Kerlin S. E., Kelly D. G., Roberts G. N., Spora A. C., Taylor I. N. and Watson J. (2002). Getting the message out. WEEDpak - A developing weed identification and management guide for the Australian Cotton Industry. Australian Weeds Conference, Perth.

Johnson S. B., Sindel B. M. and Charles G. W. (2002). The problem of Malvaceae weeds in cotton farming systems. Australian Weeds Conference, Perth.

Taylor I. and Charles G. (2002). Integrated weed management for Australian cotton production systems. Proceedings of the Eleventh Australian Cotton Conference, Brisbane, Qld, pp. 133-145.

Taylor I., Charles G. and Inchbold B. (2002). Improved weed management in irrigated cotton production systems; reducing dependence on residual pre-plant and pre-emergent herbicides. Proceedings of the Eleventh Australian Cotton Conference, Brisbane, Qld, pp. 149-162.

Johnson S. B., Taylor J. N., Sindel B. M., Charles G. W. and MacKinnon L. (2002). The distribution, spread and management of bladder ketmia, anoda weed and velvetleaf in Australian cotton farming systems. Proceedings of the Eleventh Australian Cotton Conference, Brisbane, Qld, pp. 169-176.

Charles, G. (2002). Using precision spraying technology for weed management in the Australian Cotton Industry. *The Australian Cottongrower* **22, (1):** 50-52.

Charles, G. (2001). David's Spurge: a new weed in cotton. *The Australian Cottongrower* **21, (5):** 10-12.

Charles, G. (2001). Herbicide options for weed control in pigeon pea trap crops. *The Australian Cottongrower* **21, (6):** 50-53.

**Information dissemination:**

**During the life of the project, information was presented at the following meetings and workshops:**

Charles G. & Roberts G. (2002). Components of integrated weed management (IWM) for Australian cotton production. *In* Lower Namoi Valley Cotton Field Day. pp 2.

Charles G. (2002) Lippia workshop. Proceedings of the lippia –research priorities workshop, Narrabri, pp. 1.

Charles, G. (2001). Sustainable weed management systems for cotton. *In* Proceedings of the Cotton Consultants Conference, Dalby, Qld. pp 7.

Charles, G. (2001). Herbicide options for weed control in pigeon pea trap crops. *In* Upper Namoi Valley Cotton Trials, pp 4.

Charles, G. (2001). Herbicide options for weed control in pigeon pea trap crops. *In* Central Queensland Cotton Trial and Yearbook, pp. 133-135.

Charles, G. (2001). Managing lippia. Proceedings of the lippia field day, Narrabri, pp. 3.

Review of Post-Doctoral research progress, ACRI, February 12 2002.

Integrated weed management presentation. Cotton industry development Officers, ACRI, February 12 2002.

Integrated weed management presentation. Lower Namoi Valley field day. ACRI, March 7 2002.

The past, present and future of weeds research. Plant Industries Board of Management, ACRI, April 18 2002.

Weeds research in cotton. CRDC review. Narrabri, June 11 2002.

Update on WEEDpak progress. CRDC review. Narrabri, June 11 2002.

Review of the Roundup Ready crop management plan. ACRI, June 12 2002.

Lippia management. Lippia field day. ACRI, June 25 2002.

Auscott weed management meeting, Burrendong, July 23-25 2001.

Weed seminar, UNE Certificate in cotton production, ACRI, August 14 2001.

Weeds seminar, Bourke district growers, August 15-16 2001.

Weeds seminar, Lower Namoi CCA meeting, Wee Waa, September 26 2001.

Lippia control seminar. Northern Councils Weeds Officers, Narrabri, November 21, 2001.

## 14. Are changes to the Intellectual Property register required?

No

## *Part 4 – Final Report Plain English Summary*

### Project 156C Weed Management Packages for Cotton

**Background**. Research into weed management in cotton was initiated in 1988. The weeds team and research information have grown since that time, to now be at the level where WEEDpak, a comprehensive guide to weed management in cotton, is a practical and achievable outcome. This project focussed on developing management packages for the problem weeds of cotton, nutgrass, polymeria-takeall and cowvine (peach vine), and incorporating this information into WEEDpak.

**WEEDpak**. A large proportion of the time and effort of this project went into the production of WEEDpak, both with direct input into the production of numerous WEEDpak chapters (included in the Appendix), and also into the formatting, editing, and development of WEEDpak. The result has been outstanding. WEEDpak is an attractive, easily read, comprehensive and integrated package that puts a mass of research data and grower information into a single entity.

WEEDpak will be available to cotton growers in early October 2002, and will become available to the industry and community later this year through the CRC web site. WEEDpak will also be upgraded over time, with a number of additional units planned for incorporation next year.

**Research**. Field experiments on cowvine management were undertaken at Bloomvale (Moree) and Clyde (Dirranbandi). Results were mixed. The best treatment, an application of Zoliar at 2 kg/ha, gave a 75% reduction in cowvine numbers (averaged over the season), but this result is still inadequate, leaving 3 plants/$m^2$. Long-term monitoring of the cowvine seedbank experiment continued at Beechworth (Merah North), showing a 50% reduction in the seedbank over 3 seasons under grower management. More detailed examination of the viability of the seeds remaining in the seedbank will commence this season.

Polymeria take-all and lippia field experiments continue, although the results have been adversely impacted by the current dry conditions, as these experiments are situated on rain-fed sites.

Nutgrass management in Roundup Ready® cotton is being assessed at Auscott (Narrabri). Visual observations indicate improved control with Roundup in Roundup Ready® cotton compared to MSMA in conventional cotton. Assessments over the next 2 seasons should confirm this result.

Detailed glasshouse studies of cowvine, bellvine, polymeria take-all and nutgrass management continue. Experiments focus on questions that are not adequately answered in the weed management guides in WEEDpak, such as the minimum interval for cultivation following a glyphosate application to nutgrass.

Weed pressure continues to be monitored on the CRC cropping rotation experiment at Prospect (Warra) and growers' fields at Dalby, Moree, Narrabri and Warren. Nutgrass and cowvine continue to be major problems for some growers. Bladder ketmia, pigweed and dwarf amaranth are also becoming more problematic for some growers who are relying more heavily on glyphosate.

**Future priorities**. Support and extension of WEEDpak has been identified as an important priority of the current project. This support commenced at the Australian cotton conference, where WEEDpak was show cased, and will continue as opportunity arises throughout the year. WEEDpak will be delivered to cotton growers on request, will be provided to the cotton extension team, and will be distributed at field days, industry meetings, etc. The cotton industry extension staff and consultants will be important to getting WEEDpak out into the industry.

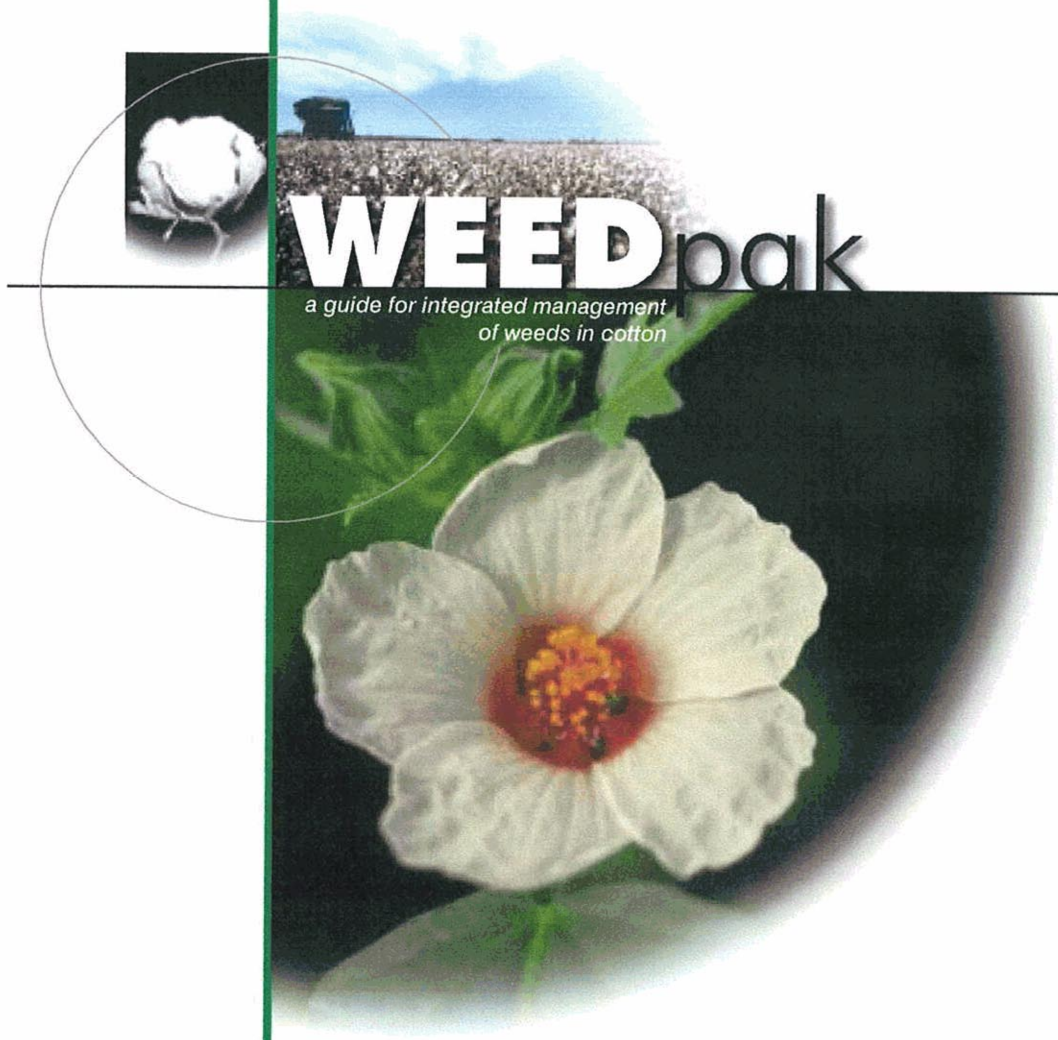
~~It is important~~ that WEEDpak is continually upgraded on a yearly or bi-yearly basis, as new and additional material becomes available. The weed identification and information guide especially needs more input to expand the range of weeds and to ensure that ecology and management information is available for all the weeds presented. Thirty eight weeds are currently in the guide. This will need to be expanded to several hundred weeds over the next few years.

Work on the management of specific problem weeds continues as a focus of this project. The current new project focuses on the management of bellvine, dwarf amaranth, pigweed and David's spurge, in addition to some continuing work on nutgrass and cowvine.

australian cotton cooperative research centre

# WEEDpak

a guide for integrated management of weeds in cotton



Cotton CRC

Cotton Research & Development

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

# 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.

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.

# INDEX OF WEED NAMES

Graham Charles
(NSW Agriculture)

Weeds in the Weed Identification and Information Guide have been listed in alphabetical order by their botanical name. Grasses and sedges are listed first, followed by the broad-leaf weeds, as shown below in the Index of Botanical Names.

To assist with finding a weed, these weeds are also listed by their preferred common name in the Quick Index. The preferred common names are generally those adopted by Shepherd *et. al.* (2001).

However, an alternative preferred common name has been adopted where a weed is widely known throughout the Australian cotton industry by a name other than the listed preferred common name. A complete listing of the weeds in the Weed Identification and Information Guide, listed by all their recognised common names follows in the Index of Common Names. The preferred common names are highlighted in bold in this index.

Unknown weeds may be identified from a collection of seedling and adult pictures, or by leafing through the collection. The seedling collection has been structured with seedlings with similar leaf shapes grouped together. The adult collection places weeds in the same order as they occur in the seedling collection.

## Index of Botanical Names

| Botanical name | Common name | May be confused with: |
|---|---|---|
| **Grasses and sedges** | | |
| *Cyperus rotundus* | Nutgrass | Downs nutgrass |
| *Echinochloa colona* | Awnless barnyard grass | Barnyard grass, Prickly barnyard grass, Hairy millet |
| *Leptochloa fusca* | Brown beetle grass | |
| *Urochloa panicoides* | Liverseed grass | |
| **Broad-leaf weeds** | | |
| *Abutilon theophrasti* | Velvetleaf | |
| *Amaranthus macrocarpus* var. *pallidus* | Dwarf amaranth | Boggabri weed |
| *Ammi majus* | Bishop's weed | |
| *Argemone ochroleuca* ssp. *ochroleuca* | Mexican poppy | |
| *Chamaesyce drummondii* | Caustic weed | Red caustic weed, Hairy caustic weed |
| *Cirsium vulgare* | Spear thistle | |
| *Citrullus lanatus* var. *lanatus* | Wild melon | Colocynth, Prickly paddy melon, Watermelon |
| *Convolvulus erubescens* | Australian bindweed | Field bindweed |
| *Crotalaria dissitiflora* | Grey rattlepod | |
| *Cullen cinereum* | Annual verbine | |
| *Datura ferox* | Fierce thornapple | Common thornapple, Downy thornapple, Hairy thornapple |
| *Euphorbia davidii* | David's spurge | |
| *Hibiscus trionum* var. *trionum* | Narrow-leaf bladder ketmia | Wide-leaf bladder ketmia |
| *Hibiscus trionum* var. *vesicarius* | Wide-leaf bladder ketmia | Narrow-leaf bladder ketmia |
| *Ipomoea lonchophylla* | Cowvine | Bellvine, Common morning glory, Silky cowvine |
| *Lamium amplexicaule* | Deadnettle | |
| *Medicago polymorpha* | Burr medic | |
| *Physalis minima* | Wild gooseberry | Annual ground cherry, Perennial ground cherry |
| *Polygonum aviculare* | Wireweed | |
| *Polymeria longifolia* | Polymeria | Annual polymeria |
| *Polymeria pusilla* | Annual polymeria | Polymeria |
| *Portulaca oleracea* | Pigweed | Hairy pigweed |
| *Rhynchosia minima* | Rhynchosia | |
| *Salsola kali* | Soft roly poly | |
| *Salvia reflexa* | Mintweed | |
| *Sesbania cannabina* | Sesbania pea | Budda pea, Red sesbania |
| *Sida fibulifera* | Pin sida | |
| *Sonchus oleraceus* | Common sowthistle | Rough sowthistle |
| *Trianthema portulacastrum* | Giant pigweed | |
| *Tribulus micrococcus* | Spineless caltrop | Caltrop |
| *Verbesina encelioides* | Wild sunflower | |
| *Xanthium italicum* | Italian cockleburr | Californian cockleburr, Noogoora burr |
| *Xanthium occidentale* | Noogoora burr | Italian cockleburr, Californian cockleburr |
| *Xanthium spinosum* | Bathurst burr | |

# Quick Index

| Common names | Botanical name | May be confused with: |
|---|---|---|
| **Grasses and sedges** | | |
| Awnless barnyard grass | *Echinochloa colona* [redacted] | Barnyard grass, Prickly barnyard grass, Hairy millet [redacted] |
| Brown beetle grass | *Leptochloa fusca* | |
| Liverseed grass | *Urochloa panicoides* [redacted] | [redacted] |
| Nutgrass | *Cyperus rotundus* | Downs nutgrass |
| **Broad-leaf weeds** | | |
| Annual polymeria | *Polymeria pusilla* | Polymeria |
| Annual verbine | *Cullen cinereum* [redacted] | |
| Australian bindweed | *Convolvulus erubescens* | Field bindweed |
| Bathurst burr | *Xanthium spinosum* [redacted] | |
| Bishop's weed | *Ammi majus* | |
| Bladder ketmia | *Hibiscus trionum* [redacted] | Narrow-leaf bladder ketmia, Wide-leaf bladder ketmia |
| Burr medic | *Medicago polymorpha* | |
| Caustic weed | *Chamaesyce drummondii* [redacted] | Red caustic weed, Hairy caustic weed [redacted] |
| Common sowthistle | *Sonchus oleraceus* | Rough sowthistle |
| Cowvine | *Ipomoea lonchophylla* | Bellvine, Common morning glory, Silky cowvine [redacted] |
| David's spurge | *Euphorbia davidii* [redacted] | |
| Deadnettle | *Lamium amplexicaule* | [redacted] |
| Dwarf amaranth | *Amaranthus macrocarpus* var. *pallidus* | Boggabri weed |
| Fierce thornapple | *Datura ferox* | Common thornapple, Downy thornapple, Hairy thornapple |
| Giant pigweed | *Trianthema portulacastrum* | |
| Grey rattlepod | *Crotalaria dissitiflora* | [redacted] |
| Italian cockleburr | *Xanthium italicum* | Californian cockleburr, Noogoora burr |
| Mexican poppy | *Argemone ochroleuca* ssp. *ochroleuca* | [redacted] |
| Mintweed | *Salvia reflexa* | |
| Narrow-leaf bladder ketmia | *Hibiscus trionum* var. *trionum* | Bladder ketmia [redacted] |
| Noogoora burr | *Xanthium occidentale* | Italian cockleburr, Californian cockleburr |
| Pigweed | *Portulaca oleracea* [redacted] | Hairy pigweed [redacted] |
| Pin sida | *Sida fibulifera* | |
| Polymeria | *Polymeria longifolia* [redacted] | Annual polymeria [redacted] |
| Rhynchosia | *Rhynchosia minima* | |
| Sesbania pea | *Sesbania cannabina* | Budda pea, Red sesbania [redacted] |
| Soft roly poly | *Salsola kali* | |
| Spear thistle | *Cirsium vulgare* | [redacted] |
| Spineless caltrop | *Tribulus micrococcus* | Caltrop |
| Velvetleaf | *Abutilon theophrasti* | [redacted] |
| Wide-leaf bladder ketmia | *Hibiscus trionum* var. *vesicarius* | Narrow-leaf bladder ketmia |
| Wild gooseberry | *Physalis minima* | Annual ground cherry, Perennial ground cherry [redacted] |
| Wild melon | *Citrullus lanatus* var. *lanatus* | Colocynth, Prickly paddy melon, Watermelon |
| Wild sunflower [redacted] | *Verbesina encelioides* | [redacted] |
| Wireweed | *Polygonum aviculare* | |

# Index of Common Names

| Common names | Preferred common name | Botanical name | May be confused with: |
|---|---|---|---|
| **Grasses and sedges** | | | |
| **Awnless barnyard grass** | | *Echinochloa colona* | Barnyard grass, Prickly barnyard grass, Hairy millet |
| **Brown beetle grass** | | *Leptochloa fusca* | |
| Jungle rice | Awnless barnyard grass | *Echinochloa colona* | |
| **Liverseed grass** | | *Urochloa panicoides* | |
| **Nutgrass** | | *Cyperus rotundus* | Downs nutgrass |
| Nutsedge | Nutgrass | *Cyperus rotundus* | |
| Pale beetle grass | Brown beetle grass | *Leptochloa fusca* | |
| Purple nutgrass | Nutgrass | *Cyperus rotundus* | |
| Purple nutsedge | Nutgrass | *Cyperus rotundus* | |
| River grass | Awnless barnyard grass | *Echinochloa colona* | |
| Silvertop | Brown beetle grass | *Leptochloa fusca* | |
| Small-flowered beetle grass | Brown beetle grass | *Leptochloa fusca* | |
| Swamp grass | Awnless barnyard grass | *Echinochloa colona* | |
| Urochloa grass | Liverseed grass | *Urochloa panicoides* | |
| Zebra grass | Awnless barnyard grass | *Echinochloa colona* | |
| **Broad-leaf weeds** | | | |
| Afghan melon | Wild melon | *Citrullus lanatus* var. *lanatus* | |
| American dogweed | Wild sunflower | *Verbesina encelioides* | |
| American jute | Velvetleaf | *Abutilon theophrasti* | |
| **Annual polymeria** [redacted] | [redacted] | *Polymeria pusilla* | Polymeria |
| **Annual verbine** | | *Cullen cinereum* | |

| Common names | Preferred common name | Botanical name | May be confused with: |
|---|---|---|---|
| **Australian bindweed** | | *Convolvulus erubescens* | Field bindweed |
| Bastard melon | Wild melon | *Citrullus lanatus* var. *lanatus* | |
| **Bathurst burr** | | *Xanthium spinosum* | |
| **Bishop's weed** | | *Ammi majus* | |
| Bitter apple | Wild melon | *Citrullus lanatus* var. *lanatus* | |
| Bitter melon | Wild melon | *Citrullus lanatus* var. *lanatus* | |
| Black pigweed | Giant pigweed | *Trianthema portulacastrum* | |
| Black thistle | Spear thistle | *Cirsium vulgare* | |
| Bladder ketmia | | *Hibiscus trionum* | Narrow-leaf bladder ketmia, Wide-leaf bladder ketmia |
| Blushing bindweed | Australian bindweed | *Convolvulus erubescens* | |
| Boar thistle | Spear thistle | *Cirsium vulgare* | |
| Bull thistle | Spear thistle | *Cirsium vulgare* | |
| Bullwort | Bishop's weed | *Ammi majus* | |
| **Burr medic** | | *Medicago polymorpha* | |
| Burr trefoil | Burr medic | *Medicago polymorpha* | |
| Burrweed | | *Xanthium* sp. | Bathurst burr, Noogoora burr |
| Butter daisy | Wild sunflower | *Verbesina encelioides* | |
| Caustic creeper | Caustic weed | *Chamaesyce drummondii* | |
| **Caustic weed** | | *Chamaesyce drummondii* | Red caustic weed, Hairy caustic weed |
| Camel melon | Wild melon | *Citrullus lanatus* var. *lanatus* | |
| Chinese hemp | Velvetleaf | *Abutilon theophrasti* | |
| Chinese jute | Velvetleaf | *Abutilon theophrasti* | |
| Chinese lantern | Wild gooseberry | *Physalis minima* | |
| Clotburr | Noogoora burr | *Xanthium occidentale* | |
| Clumped bindweed | Polymeria | *Polymeria longifolia* | |
| **Cockleburr** | | *Xanthium* sp. | Californian cockleburr, Italian cockleburr, Noogoora burr |
| Common cocklebur | Bathurst burr | *Xanthium spinosum* | |
| Common cowvine | Cowvine | *Ipomoea lonchophylla* | |
| Common pigweed | Pigweed | *Portulaca oleracea* | |
| Common purslane | Pigweed | *Portulaca oleracea* | |
| **Common sowthistle** | | *Sonchus oleraceus* | Rough sowthistle |
| **Cowvine** | | *Ipomoea lonchophylla* | Bellvine, Common morning glory, Silky cowvine |
| Creeping spurge | Caustic weed | *Chamaesyce drummondii* | |
| Crownbeard | Wild sunflower | *Verbesina encelioides* | |
| Crotalaria take-all | Grey rattlepod | *Crotalaria dissitiflora* | |
| **David's spurge** | | *Euphorbia davidii* | |
| **Deadnettle** | | *Lamium amplexicaule* | |
| Desert amaranth | Dwarf amaranth | *Amaranthus macrocarpus* var. *pallidus* | |
| Devil's fig | Mexican poppy | *Argemone ochroleuca* ssp. *ochroleuca* | |
| Dwarf amaranth | | *Amaranthus macrocarpus* var. *pallidus* | Boggabri weed |
| Erect bindweed | Polymeria | *Polymeria longifolia* | |
| European cockleburr | Noogoora burr | *Xanthium occidentale* | |
| False castor oil | Fierce thornapple | *Datura ferox* | |
| Flat Spurge | Caustic weed | *Chamaesyce drummondii* | |
| **Fierce thornapple** | | *Datura ferox* | Common thornapple, Downy thornapple, Hairy thornapple |
| Fuller's thistle | Spear thistle | *Cirsium vulgare* | |
| Gloden crownbeard | Wild sunflower | *Verbesina encelioides* | |
| Goldweed | Wild sunflower | *Verbesina encelioides* | |
| Golden thistle-of-Peru | Mexican poppy | *Argemone ochroleuca* ssp. *ochroleuca* | |
| **Giant pigweed** | | *Trianthema portulacastrum* | |
| Green thistle | Spear thistle | *Cirsium vulgare* | |
| Grey rattlepod | | *Crotalaria dissitiflora* | |
| Henbit | Deadnettle | *Lamium amplexicaule* | |
| Hoary scurfpea | Annual verbine | *Cullen cinereum* | |
| Hogweed | Wireweed | *Polygonum aviculare* | |
| Hunter burr | Italian cockleburr | *Xanthium italicum* | |
| Indian mallow | Velvetleaf | *Abutilon theophrasti* | |
| Ironweed | Wireweed | *Polygonum aviculare* | |
| Italian cockleburr | | *Xanthium italicum* | Californian cockleburr, Noogoora burr |
| Jam melon | Wild melon | *Citrullus lanatus* var. *lanatus* | |
| Knotweed | Wireweed | *Polygonum aviculare* | |
| Lace-leaf sage | Mintweed | *Salvia reflexa* | |
| Lanternflower | Velvetleaf | *Abutilon theophrasti* | |
| Large cockleburr | Noogoora burr | *Xanthium occidentale* | |
| Long-spined thornapple | Fierce thornapple | *Datura ferox* | |
| Long-spurred thornapple | Fierce thornapple | *Datura ferox* | |

| Common names | Preferred common name | Botanical name | May be confused with: |
|---|---|---|---|
| Mat spurge | Caustic weed | *Chamaesyce drummondii* | |
| Meadowsweet | Bishop's weed | *Ammi majus* | |
| **Mexican poppy** | | *Argemone ochroleuca* ssp. *ochroleuca* | |
| Mexican thistle | Mexican poppy | *Argemone ochroleuca* ssp. *ochroleuca* | |
| Mickey melon | Wild melon | *Citrullus lanatus* var. *lanatus* | |
| Milk thistle | Common sowthistle | *Sonchus oleraceus* | |
| Milkweed | Caustic weed | *Chamaesyce drummondii* | |
| Mintweed | | *Salvia reflexa* | |
| Narrow-leaf bladder ketmia | | *Hibiscus trionum* var. *trionum* | Bladder ketmia |
| Nardoo | Sesbania pea | *Sesbania cannabina* | |
| Narrow-leaf sage | Mintweed | *Salvia reflexa* | |
| Native rhynchosia | Rhynchosia | *Rhynchosia minima* | |
| Native rock trefoil | Rhynchosia | *Rhynchosia minima* | |
| Native trefoil | Burr medic | *Medicago polymorpha* | |
| Native yellow vine | Spineless caltrop | *Tribulus micrococcus* | |
| Neverdie | Pigweed | *Portulaca oleracea* | |
| Noogoora burr | | *Xanthium occidentale* | Italian cockleburr, Californian cockleburr |
| Paddy melon | Wild melon | *Citrullus lanatus* var. *lanatus* | |
| Peabush | Sesbania pea | *Sesbania cannabina* | |
| Peachvine | Cowvine | *Ipomoea lonchophylla* | |
| Peak Downs curse | Polymeria | *Polymeria longifolia* | |
| Perennial gooseberry | Wild gooseberry | *Physalis minima* | |
| Perennial pigweed | Pigweed | *Portulaca oleracea* | |
| Pie melon | Wild melon | *Citrullus lanatus* var. *lanatus* | |
| **Pigweed** | | *Portulaca oleracea* | Hairy pigweed |
| Pink bindweed | Australian bindweed | *Convolvulus erubescens* | |
| Pink weed | Deadnettle | *Lamium amplexicaule* | |
| Pin sida | | *Sida fibulifera* | |
| Plains rattlepod | Grey rattlepod | *Crotalaria dissitiflora* | |
| Polymeria | | *Polymeria longifolia* | Annual polymeria |
| Portulaca weed | Pigweed | *Portulaca oleracea* | |
| Prickly burrweed | Bathurst burr | *Xanthium spinosum* | |
| Prickly poppy | Mexican poppy | *Argemone ochroleuca* ssp *ochroleuca* | |
| Prostrate knotweed | Wireweed | *Polygonum aviculare* | |
| Purslane | Pigweed | *Portulaca oleracea* | |
| Queen Anne's lace | Bishop's weed | *Ammi majus* | |
| Red pigweed | Pigweed | *Portulaca oleracea* | |
| Rhynchosia | | *Rhynchosia minima* | |
| Rough cockleburr | Noogoora burr | *Xanthium occidentale* | |
| Rough medic | Burr medic | *Medicago polymorpha* | |
| Ryncho | Rhynchosia | *Rhynchosia minima* | |
| Scotch thistle | Spear thistle | *Cirsium vulgare* | |
| Sesbania pea | | *Sesbania cannabina* | Budda pea, Red sesbania |
| Sheep's burr | Noogoora burr | *Xanthium occidentale* | |
| Silver sida | Pin sida | *Sida fibulifera* | |
| Soft roly poly | | *Salsola kali* | |
| South African daisy | Wild sunflower | *Verbesina encelioides* | |
| Sowthistle | Common sowthistle | *Sonchus oleraceus* | |
| Spear thistle | | *Cirsium vulgare* | |
| Spineless caltrop | | *Tribulus micrococcus* | Caltrop |
| Spiny clotburr | Bathurst burr | *Xanthium spinosum* | |
| Spiny cockleburr | Bathurst burr | *Xanthium spinosum* | |
| Spurgewort | Caustic weed | *Chamaesyce drummondii* | |
| Stingless nettle | Deadnettle | *Lamium amplexicaule* | |
| Swamp Chinese lantern | Velvetleaf | *Abutilon theophrasti* | |
| Take-all | Polymeria | *Polymeria longifolia* | |
| Toothed medic | Burr medic | *Medicago polymorpha* | |
| Trefoil clover | Burr medic | *Medicago polymorpha* | |
| Thornapple | | *Datura* sp. | Common thornapple, Downy thornapple, Hairy thornapple |
| **Velvetleaf** | | *Abutilon theophrasti* | |
| Watermelon | Wild melon | *Citrullus lanatus* var. *lanatus* | |
| White thistle | Mexican poppy | *Argemone ochroleuca* ssp. *ochroleuca* | |
| **Wide-leaf bladder ketmia** | | *Hibiscus trionum* var. *vesicarius* | Narrow-leaf bladder ketmia |
| **Wild gooseberry** | | *Physalis minima* | Annual ground cherry, Perennial ground cherry |
| **Wild melon** | | *Citrullus lanatus* var. *lanatus* | Colocynth, Prickly paddy melon, Watermelon |
| Wild mint | Mintweed | *Salvia reflexa* | |
| **Wild sunflower** | | *Verbesina encelioides* | |
| **Wireweed** | | *Polygonum aviculare* | |
| Woodnep | Bishop's weed | *Ammi majus* | |
| Yellow peabush | Sesbania pea | *Sesbania cannabina* | |
| Yellow poppy | Mexican poppy | *Argemone ochroleuca* ssp. *ochroleuca* | |
| Yellow vine | Spineless caltrop | *Tribulus micrococcus* | |



Cotton CRC

## Comparison of Roundup Ready® systems

Roundup Ready cotton was grown from 1996/97 to 1999/00 in a weed management systems experiment at the Australian Cotton Research Institute, Narrabri. Small plots of Roundup Ready cotton were grown in the first season using early generation breeding material. Roundup Ready Siokra 189+ was used for the last two seasons of the experiment. Plots were 8 rows by 50 m in length.

The results from five Roundup Ready systems and two conventional systems are compared below. The cotton type and herbicides used in each system is shown in Table 1.

Results for systems using Roundup Ready cotton were very promising, but have also highlighted some of the potential difficulties with the Roundup Ready technology.

Roundup is very effective in controlling most small broadleaf and grass weeds present in young cotton. At a higher rate it is effective against more difficult to control weeds, such as large weeds and some perennial weeds. A Roundup application at the emergence to four leaf stage of crop growth can substitute for an earlier application of Roundup (pre-emergence for conventional cotton), or can substitute for some residual herbicides.

*Table 1. Cotton type and herbicides (L/ha) used in the weed management systems experiment. A total of three post-emergence Roundup applications occurred.*

| System | Cotton type | Pre-planting & at-planting | Post-emergence & layby |
|---|---|---|---|
| 1 - C | Conventional | Trifluralin 2.8 & Cotoran 4.0 | Gesagard 2.2 & Gesagard 2.3 |
| 1 - RR | Roundup Ready | Trifluralin 2.8 & Cotoran 4.0 | 3 applications Roundup CT 2.0 |
| 2 - C | Conventional | Trifluralin 2.8 + Diuron 1.9 | Gesagard 2.2 & Gesagard 2.3 |
| 2 - RR | Roundup Ready | Trifluralin 2.8 + Diuron 1.9 | 3 applications Roundup CT 2.0 |
| 3 - RR | Roundup Ready | Trifluralin 2.8 | 3 applications Roundup CT 2.0 |
| 4 - RR | Roundup Ready | | 3 applications Roundup CT 2.0 + 2 applications Staple 120 g |
| 5 - RR | Roundup Ready | | 3 applications Roundup CT 2.0 |

## Managing perennial weeds

Roundup Ready cotton has been a very useful tool for managing nutgrass (*Cyperus rotundus*). Nutgrass was present on the field before the experiment was commenced. Over the five seasons of the experiment, the nutgrass infestation on the conventional systems increased from 0.3 to 39% of the plot on system 1 - C and 14 to 80% on system 2 - C (Figure 1). In contrast, the nutgrass infestation was stable or decreased on the Roundup Ready systems over this period.

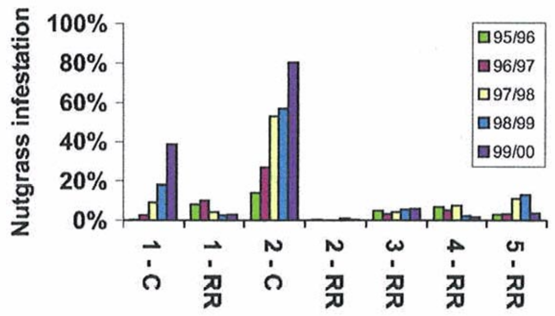



*Figure 1. Changes in nutgrass infestation on the different systems over five seasons of back-to-back cotton.*

The over-the-top Roundup application in spring was relatively ineffective in controlling nutgrass in some seasons, as the weed was often moisture and/or cold stressed at this time. The later applications were more effective. Nevertheless, nutgrass remained a problem in all treatments, as some unsprayed plants always remained in the crop plant-line. Also, some cultivation operations re-introduced tubers from neighboring uncontrolled plots.

The use of Roundup Ready cotton did not greatly improve nutgrass control compared to a conventional treatment where a shielded application of Roundup was used in-crop (these results are not shown). The use of Roundup Ready cotton did greatly improve crop safety from the Roundup application.

## Managing annual weeds

Management of annual weeds was also improved on the Roundup Ready systems compared to the conventional systems. Results of the weed pressure index and average yields from the 1998/99 and 1999/00 seasons are shown in Table 2.

*Table 2. Comparison of weed pressure and crop yields from conventional and Roundup Ready systems. Weed pressure was assessed mid-season.*

| System | Weed pressure index | Lint yield (bales/ha) |
|---|---|---|
| 1 - C | 30.7 | 4.7 |
| 1 - RR | 7.8 | 5.1 |
| 2 - C | 25.2 | 3.3 |
| 2 - RR | 8.0 | 4.7 |
| 3 - RR | 12.8 | 4.7 |
| 4 - RR | 9.5 | 5.1 |
| 5 - RR | 12.8 | 5.4 |

The highest cotton lint yield was recorded on the Roundup only system (system 5 - RR), which also had relatively low weed pressure.

Weed pressure was relatively low on the systems using Roundup Ready cotton and in-crop Roundup applications. Where direct comparisons of conventional and Roundup Ready systems are possible (systems 1 - C and 1 - RR, 2 - C and 2 - RR), the Roundup Ready systems had much lower weed pressure (better weed control) and better yields.

However, the relatively good weed control results were not achieved in all seasons. In December 1997, system 1 - C had a weed index of 18, but system 5 - RR (only using Roundup) had an index of 348!

In this season (1997/98), the cotton was planted into moisture on Sept. 30. Fifty two mm of rain over Oct. 6 & 7 brought the crop up, but also germinated a large number of weeds, predominantly barnyard grass. It was decided not to spray these weeds immediately, but to wait for further germinations and spray the crop closer to four true leaves. This decision appeared to be sound, as early season weed pressure does not reduce crop yields.

The crop and weeds ran out of moisture in November. The treatments were sprayed with Roundup over-the-top at the four-leaf stage on Nov. 6, but the weeds were stressed and control was poor. Consequently, the field was irrigated on Nov. 19. A large number of new weeds emerged following this irrigation. The in-furrow weeds were subsequently controlled with a directed Roundup application, but weeds in the plant-line were not controlled, resulting in a "hedge-hog" line of weeds which remained for the rest of the season. Control of these established barnyard grass plants with a grass herbicide was attempted, but control failed as the weeds were too advanced. The yield on this plot was still quite good, but significant lint contamination occurred.

*Small barnyard grass and Italian cockleburr[1] plants were easily controlled by a Roundup application over-the-top of young cotton (left of centre). No residual herbicides had been applied to either treatment.*

*1 Italian cockleburr is very similar to Noogoora burr and often confused with Noogoora burr. They are most easily distinguished by the shape of the claws at the end of the burrs. Initial observations indicate that much of the burr in the NSW cotton area is Italian cockleburr, not Noogoora burr.*

## Timing of the over-the-top Roundup application

The timing of the over-the-top Roundup application can be the key to successfully managing a Roundup Ready crop. The temptation is to wait as long as possible to allow as many weeds as possible to emerge before spraying, but this strategy puts a lot of pressure on a small application window. Bad weather (rain or wind), wet fields, dry fields (moisture stress), breakdowns, or the inability to cover sufficient ground in a limited time, can make it impossible to apply Roundup at the desired stage. If this happens and residual herbicides have not been applied, weeds can become unmanageable.

Problems were encountered with Roundup application timing in both the 1997/98 and 1998/99 seasons. Similar problems could be expected on large properties where Roundup has to be applied to multiple fields.

Cotton was planted on Sept. 30 in the 1997/98 season, but was slow to emerge with minimum temperatures below 12°C on 15 of the following 23 days. The cotton was due to be sprayed in mid-November. Rain on Nov. 11, 12, 15, 16, 18, 25, 26 and 30 made this task very difficult to accomplish.

In the 1998/99 season, the field was wet and planting was delayed. Cotton was planted on Oct. 21 and again should have been sprayed in mid-November. Rain on Nov. 12, 13, 14, 18, 23, 26 and 28 again made the task difficult to accomplish.

Similar problems occurred on a commercial field, where the planned over-the-top Roundup application was not applied due to unfavorable weather conditions.

*Small Italian cocklebur plants were easily controlled by a Roundup application over-the-top of young cotton (left of centre). No residual herbicides had been applied to either treatment.*

## Applying Roundup over-the-top to older cotton

The obvious solution to missing the Roundup Ready over-the-top application window is to apply Roundup as soon as possible after the missed target date. This strategy is contrary to the label and is likely to result in reduced crop yields.

The emergence to four true leaves application safety window for over-the-top Roundup applications was established from research data and grower experience. It reflects a very real application restriction. Applications outside of this window can result in yield penalties.

This yield reduction is clearly seen in the results provided by Grant Roberts (Cotton CRC and CSIRO), shown in Table 3. In this experiment, an over-the-top Roundup application at crop six-leaf stage resulted in a 20% yield reduction (Treatment 3), compared to two later, directed applications (Treatment 2). Three over-the-top applications resulted in a 67% yield reduction (Treatment 5).

*Table 3. Yield reduction from Roundup applied to Roundup Ready cotton at the wrong stage. Applications were over-the-top (OTT) or directed (D)*

| Treatment | Roundup Applications | | | Lint yield bales/ha |
|---|---|---|---|---|
| 1 | 4 leaf$^{OTT}$ | | | 3.4 |
| 2 | 4 leaf$^{OTT}$ | First square$^{D}$ | First flower$^{D}$ | 3.6 |
| 3 | 4 leaf$^{OTT}$ | 6 leaf$^{OTT}$ | First flower$^{D}$ | 2.9 |
| 4 | 4 leaf$^{OTT}$ | First square$^{OTT}$ | First flower$^{D}$ | 2.8 |
| 5 | 4 leaf$^{OTT}$ | 6 leaf$^{OTT}$ | First flower$^{OTT}$ | 1.2 |

*Note. The applications in treatments 3, 4 and 5 are contrary to the label directions.*

## Strategies for applying Roundup over-the-top

One of three strategies can be used to avoid the problem of missing the over-the-top application window. Firstly, growers may elect to apply the over-the-top application earlier than the fourth leaf stage, as a way of ensuring that the application occurs. Some weeds will emerge after the Roundup application and will need to be controlled. A second over-the-top application before four leaves is possible in some situations, where the first application occurs at one or two leaves. The difficulty with this approach is that it may leave only one Roundup application available to control weeds for the rest of the season.

An alternative strategy is to continue to use residual herbicides applied pre-planting or at planting. These herbicides will control most weeds, greatly reducing the pressure on the Roundup application. This strategy has the drawback of increasing the cost of weed control compared to a Roundup only system, but is much better suited to dirty fields.

A compromise strategy, using a reduced program of residual herbicides, would seem to be the best option, especially on cleaner fields. With this approach, growers might, for example, use half-rates of Cotoran and Stomp on a 30% band behind the planter. This would ensure reasonable weed control in the crop plant-line, at a reduced cost, allowing Roundup and/or cultivation to be effectively used to control all in-furrow weeds. Roundup would also be used to control weeds that emerged later in the season after the residual herbicides ran-out. A lay-by application of residual herbicide may also be used.

## Salvage applications of Roundup over-the-top

Incorrectly applied Roundup primarily affects the flowers of Roundup Ready cotton, but over-the-top applications, even late in the season, can still be disastrous.

The photo below shows a set of Roundup Ready plots that were heavily infested with both nutgrass and Italian cockleburr. The Italian cockleburr emerged above the crop and were almost completely covering the shorter cotton plants. An over-the-top Roundup application would seem to be an easy way to manage these weeds, with minimal contact with the cotton expected. Any damage to the Roundup Ready cotton from the Roundup could be expected to be far less than the damage caused by the weeds.

*A severe infestation of nutgrass and Italian cockleburr in Roundup Ready cotton. The cockleburrs were almost completely covering the cotton.*

This proved not to be the case, with major yield reductions resulting from the Roundup applications (Table 4). A single over-the-top Roundup application in late January reduced the cotton yield by 32%, while two applications reduced yield by 78%.

*Table 4. Yields after late, over-the-top Roundup applications to severely weed infested Roundup Ready cotton.*

| Roundup applied over-the-top 11 Jan | 27 Jan | 15 Feb | Yield (bales/ha) |
|---|---|---|---|
| - | - | - | 3.7 |
| - | 2 L | - | 2.5 |
| 2 L | - | 2 L | 0.8 |

Even in a salvage situation, applying Roundup outside the application window can result in massive yield losses.

## Species shift

Some of the features of Roundup are that it has a broad weed spectrum, it is translocated to the root system and so kills most weeds (doesn't just burn off the foliage), and has no residual activity, reducing off-target and environmental problems. However, weeds continue to emerge throughout the cotton season and consequently continue to emerge after the initial Roundup application. Roundup can be safely applied later in the season as a directed spray, but must be applied so as to avoid contact with cotton foliage. This effectively reduces the area to which Roundup can be applied to the furrow area and the base of the cotton plants.

*Italian cockleburrs emerging in the plant line of a Roundup Ready system that relied only on Roundup for weed control.*

A problem that became apparent over time in the systems experiment was the buildup of Roundup tolerant weeds, particularly in the system using only Roundup (System 5 – RR, Table 1). The weed causing the most problems in this system in the fifth year of Roundup Ready cotton was Italian cockleburr. Italian cockleburr is not strictly speaking a Roundup tolerant weed and is easily controlled with Roundup. Italian cockleburrs were not detected in this treatment in the first couple of seasons.

However, Italian cockleburrs that emerged after the over-the-top Roundup application and were in the crop row, missed the later directed or shielded Roundup applications and emerged above the crop canopy late in the season. By this time, they are quite large and very difficult to control. If left, these cockleburrs set a lot of seed, increasing the problem over time. Removal by hand or control with MSMA were both very expensive options.

While it is unlikely that Italian cockleburr will become an industry-wide problem in Roundup only fields, this result clearly shows the effect of relying too heavily on a single method of weed control. Relying too heavily on any single method of weed control will inevitably select out a weed or weeds that tolerate that management tool. Problems weeds such as nutgrass, sesbania and cowvine have been selected by the conventional weed management systems that have been used in the past. Other weeds are likely to become serious problems as the weed management systems change.

Roundup doesn't control all weed species and so the more the system relies on Roundup, the more the Roundup tolerant species will become difficult to control. The simplest way to reduce these problems is to continue to use an integrated approach to weed management, using a range of weed management tools in combination.

Cotton growers also need to take heed of the lessons from the grain farming systems where a large number of weeds have developed resistance to specific herbicides. Some weeds are now resistant to almost every available herbicide. Resistance to glyphosate has already developed in a few paddocks where glyphosate has been used as almost the only weed management tool over a number of years. The loss of glyphosate to the farming system would be very costly, but the solution is simple. Herbicide resistant weeds have not been a problem in the Australian cotton industry to date because of the adoption of an integrated approach to weed management. Continuing this approach will ensure that resistance does not become a problem in the future.

**More information on integrated weed management (IWM) is included in the IWM guidelines in WEEDpak.**

## Developing a Roundup Ready management system

In many ways, the introduction of Roundup Ready cotton contributes little to weed management, except the ability to apply Roundup over-the-top between crop emergence and the four-leaf stage. In-crop shielded applications of glyphosate can be made to conventional and Roundup Ready cotton varieties alike. The major advance is in the improvement in crop safety from the Roundup applications.

However, Roundup Ready cotton brings the opportunity to develop new weed management systems that rely less heavily on residual herbicides, inter-row cultivation and hand chipping. The introduction of new weed management systems should not be attempted on a property-wide basis. Like all new technology, it takes time to learn how best to use Roundup Ready cotton. Growers can safely introduce Roundup Ready cotton as an additional weed management tool to all fields, but should introduce new management systems far more slowly.

One of the best ways to learn to use Roundup Ready cotton can be to use herbicide test strips in a few fields. The test strips could, for example, be used to compare conventional cotton, Roundup Ready cotton using a conventional herbicide regime with the addition of Roundup, and various modified systems, where the rates of some residual herbicides are reduced or herbicides are eliminated. This could be compared with a Roundup only system.

The importance of adopting this test strip approach was highlighted by the results given earlier in the section "Managing annual weeds", where in the 1997/98 season, the Roundup only system (System 5 – RR) was completely overrun by weeds and unmanageable. Management of this system improved with experience.

The Roundup Ready system offers real opportunities to modify weed management systems, but the optimal solutions will vary between valleys and farms. Only experience can develop the best system for a given field and farm.

## Economic comparison of the systems

The most optimal Roundup Ready system is the one that gives the best net return and maintains or reduces the weed population. A system that results in an increase in the weed population may give good yields and good returns in the very short-term, but will have reduced yields and will not be sustainable in the long-term. Table 5 gives a comparison of the net return for the weed management systems presented in Tables 1 and 2.

*Table 5. Comparison of production costs, yields and gross returns from conventional and Roundup Ready® systems. The gross return is compared with System 1. The analysis assumes that the cost of the herbicides is the only difference in production costs between the systems.*

| System | Cost of inputs: Herbicides | Cost of inputs: Roundup Ready license | Yield (bales/ha) | Net return ($/ha) |
|---|---|---|---|---|
| 1 - C | $138 | | 4.7 | - |
| 1 - RR | $131 | $49 | 5.1 | $362 |
| 2 - C | $126 | | 3.3 | -$587 |
| 2 - RR | $125 | $49 | 4.7 | $130 |
| 3 - RR | $81 | $49 | 4.7 | $169 |
| 4 - RR | $196 | $49 | 5.1 | $269 |
| 5 - RR | $60 | $49 | 5.4 | $555 |

The Roundup only system (System 5 – RR) had both the best yields and the best net return. However, this system was not sustainable, as it did not adequately control the Italian cockleburr problem. System 1 - RR, a combination of conventional herbicides and Roundup Ready cotton, was the optimal system, giving the second best yield and net return, and the best weed control. This system was the most likely to be sustainable in the long-term. Lower rates of Cotoran at planting may have improved the net return without compromising weed control.

While the Roundup Ready systems did give good returns in this experiment (on a weedy field), there is no guarantee that similar results will be achieved on cleaner fields or even other dirty fields, where a different spectrum of weeds will be present.

One thing that is clear from this analysis, is that cotton yield has by far the largest impact on the net value of a system. A small increase or decrease in crop yield will more than compensate for the cost of herbicide inputs. Time spent in putting down herbicide test strips and in determining crop yield from these strips will be a very valuable investment in a production system.

Consequently, it is important that cotton growers develop their weed management systems primarily based on these two factors: the cotton yield achieved on a system, and the level of weed control, which measures the sustainability of the system.

To do otherwise would be like adopting an insect management strategy where all cotton fields on all farms receive the same insecticide on the same day, regardless of what insects were actually present on a given field. Like insect management, weed management should be tailored to the needs of each field and each farm.

## Summary

- Weed management must continue to use an integrated approach, not relying too heavily on any one management tool.
- A weed management system should respond to weed pressure on a season by season and field by field basis.
- Roundup Ready cotton should allow growers to reduce their dependence on residual herbicides, but changes to the weed management system should be made gradually, based on personal experience.
- Timing is critical for the over-the-top Roundup application. Never rely solely on this application for early season weed control.
- Be on the lookout for weeds that are tolerant of Roundup. Other weed management tools will be needed to control these weeds.

# MANAGING ROUNDUP READY® COTTON

Ian Taylor and Graham Charles
(NSW Agriculture)

Contents



## Introduction

The introduction of cotton varieties that have the capacity to continue to grow and function normally after over-the-top applications of Roundup Ready® herbicide offers enormous benefits to the Australian cotton industry in terms of weed management. These benefits include:

- Reduced dependence on residual herbicides.
- Improved control of some of the more difficult to control weeds.
- Greater flexibility in weed management programs.
- Reduced chipping and cultivation expenses.
- Potential to improve establishment and vigour of young cotton seedlings by reducing the pre-emergence use of residual herbicides.

The level of performance obtained from Roundup Ready cotton and ultimately yield and lint quality, are governed by the management and agronomic practices used in the cotton farming system. It is therefore essential, that growers and agronomists are aware of the benefits and limitations of this technology and how best to use the technology so that a comprehensive weed management plan is developed. It should be stressed from the outset that Roundup Ready cotton is not by itself the answer to weed management problems. It should be seen as another tool in the weed management program and must form part of an integrated weed management package. A sustainable weed management program cannot be based solely on Roundup Ready herbicide.

## Over-the-top applications of Roundup®

As well as potential benefits, Roundup Ready technology has some constraints. These include:

- Currently, Roundup Ready herbicide is registered for over-the-top applications up to the fourth true leaf and prior to the unfolding of the fifth true leaf of the cotton crop. Up to two applications can be made during this window.
- Sequential applications of Roundup Ready herbicide must be applied at least 10 days apart, and with at least two nodes of crop growth between applications.
- Under hot growing conditions, such as in Central Queensland, the four true leaf stage can be attained within two to three weeks of sowing. Consequently, the useful window for over the top applications of Roundup Ready herbicide in these locations may be quite narrow.

Over the top applications of Roundup Ready herbicide are particularly useful for controlling weeds that emerge at planting or just after planting. In warmer areas where the fourth leaf stage may be reached quite rapidly it may be more appropriate to apply Sprayseed at planting and then an over the top application of Roundup Ready herbicide prior to the four-leaf stage. This will enable growers to apply a further two directed or shielded applications of Roundup Ready herbicide in-crop thus, increasing the duration of effective weed control. In addition, using a herbicide from a different chemical group will delay or prevent the onset of herbicide resistance.

## Directed and shielded applications of Roundup®

The Roundup Ready herbicide label permits three applications of Roundup Ready herbicide in-crop within a single season, with a maximum of 1.5 kg/ha being applied in any single spray event. It is likely that one or two of these applications will be applied as a shielded or directed spray. Roundup Ready cotton is sensitive to Roundup drift after the four-leaf stage and boll loss can occur if Roundup Ready herbicide contacts the leaves of cotton plants. Cotton is particularly sensitive during square formation and flowering. Roundup affected cotton plants may produce sterile pollen, resulting in poor boll retention. Extreme cases can result in deformed bolls, as shown in Figure 1.

The most important fact to remember with spraying is that spray nozzles always produce some fine particles, and these particles always move (drift). The aim of spraying a herbicide within a herbicide susceptible crop canopy is to manage the movement of these spray particles (spray drift) to minimise their impact on the crop.

The following guidelines are included to assist growers with shielded and directed applications of Roundup Ready herbicide.

- Shields need to be set at a height that minimises spray drift. Shields may be lifted later in the season to allow spray to penetrate to the top of the hill, but it is essential to ensure that spray does not contact the cotton foliage. The higher the shield, the more spray drift is likely to result.
- The susceptibility of the shield to spray drift depends on the shield design; the more open the design, the more susceptible to drift problems. Shielded sprayers that have open sides (most commonly top, front or back) can have material such as flywire or shade cloth fitted to reduce spray drift. Material should be fitted to the rear of the shields to capture fine droplets that escape as the sprayer travels along the furrow.
- Attention needs to be given to environmental conditions at the time of spraying. Temperature, wind speed, wind direction, and humidity all impact the movement of spray droplets as they leave the sprayer and the rate of spray evaporation. High temperatures and low relative humidity result in increased volatilisation of spray droplets, increasing the likelihood of spray drift.
- As a general rule shielded sprayers should not be operated when wind speeds are greater than 8 km/hr. Open shields and directed sprays have a lower safety factor than this. Crop growth stage and susceptibility also affect the safety factor.
- Tractor speed is also a major contributor to air movement. A tractor operating at 12 km/h will already be operating outside the 8 km/h guideline for spraying.
- Spray drift can also be minimised by using low drift nozzles or 80° flat fan nozzles, operated at low pressure (a maximum pressure of 2 bars). Higher water volumes will also assist in reducing the production of fine droplets.

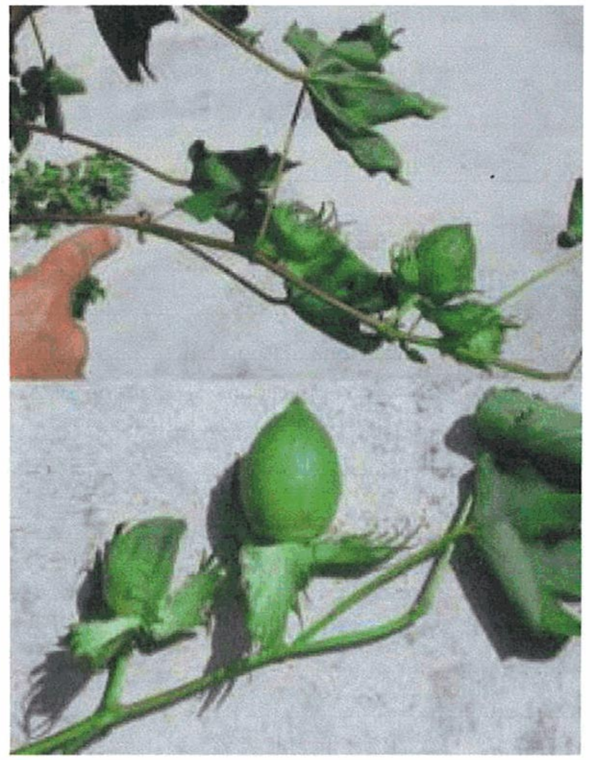


*__Figure 1.__ Suspected Roundup Ready herbicide drift damage to Roundup Ready cotton plants. Roundup damage can cause a loss of first position fruit (top) and parrot-beaking due to pollen sterility (bottom).*

Directed sprays can be effective for managing weeds in Roundup Ready cotton. However, it is very difficult to accurately apply Roundup through a directed spray without some contact with the cotton foliage, either from spray drift or from over-spraying.

Spray drift is almost inevitable with directed sprays, and will occur if there is any air movement around the nozzle. Spraying in calm conditions is equally hazardous, as some fine particles remain suspended until they eventually contact something, generally a cotton plant.

Over-spraying is also a likely outcome with a directed spray as it is very difficult to direct a nozzle to spray against the crop plant-line without contacting the crop. Low branches on the cotton plant often droop into the furrow area. These branches should be brushed aside by the spray shield, but are likely to be sprayed by a directed spray. Also the spray nozzles often bounce or swing as the spray boom moves down the field, resulting in occasional contact with the crop.

## Limitations with using Roundup® in-crop

Shielded and directed applications of Roundup Ready herbicide can be very effective in controlling weeds in cotton. However, there are a few limitations to the use of this technology. These limitations are not necessarily a disadvantage, but must be considered in a weed management plan using Roundup Ready herbicide. These include:

- The potential for spray drift can be a major limitation to the aerial application of Roundup over-the-top of young Roundup Ready cotton. Some spray drift will always occur with aerial applications. Potential drift onto conventional cotton, crops, pastures or other sensitive areas cannot be tolerated.
- Roundup is most effective against young, actively growing weeds, especially grass weeds. Roundup can be ineffective on stressed weeds; especially moisture stressed weeds and may not be effective on large, broadleaf weeds.
- Shielded and directed applications of Roundup are likely to be ineffective in controlling weeds that emerge in the crop line after the four-leaf stage of the cotton crop. Weeds in the crop line are not normally controllable using this technology. In fields where a significant number of weeds are likely to emerge in the crop line, it is essential that they be managed using another herbicide, such as a residual herbicide at planting.
- Roundup is a non-residual herbicide. It will only control weeds present at the time of spraying. Subsequent germinations of weeds require repeat applications of the herbicide.
- Roundup does not control all weeds. Some weeds are naturally tolerant of Roundup and must be managed some other way.
- Roundup is inactivated on contact with soil. Roundup efficacy can be greatly reduced by dust when spraying in very dusty conditions or when spraying weeds that are covered in dust. Spray shields that drag on the ground can generate a lot of dust, reducing spray effectiveness.
- Roundup may be used to replace inter-row cultivation, but cultivation may be necessary to maintain irrigation furrows. With some weeds such as nutgrass, it is desirable to allow the weed to grow for about four weeks before treating with Roundup and another couple of weeks after treatment, before cultivation. Juggling irrigation, cultivation and Roundup applications over a number of fields, under changing weather conditions, can be very difficult.

## Thresholds for spraying weeds

Several benefits can flow from using Roundup Ready technology to manage weeds, and from the decrease in the use of residual herbicides that may result from the use of this technology in the cotton production system. These benefits include:

- Improvement in establishment and vigour of young cotton seedlings from reducing the pre-emergence use of residual herbicides.
- Reduced herbicide application costs.
- Reduced likelihood of contaminating waterways with residual herbicides either leaching through soil profiles or by overland flows.

Researchers at ACRI are attempting to determine weed thresholds where it may be appropriate to modify, reduce or eliminate the use of residual pre-plant and pre-emergent herbicides using Roundup Ready cotton technology.

Trials to date show that it can be practical to grow cotton without the addition of residual herbicides. However, on fields with high weed pressure, not using residual herbicides can lead to major problems and can exacerbate the weed problem. A weed control failure not only leads to dirty fields during the season but more importantly, replenishes the soil seed bank (number of weed seeds in the soil), creating problems in future years.

On fields where no residual herbicides are used, weed control is most likely to break down when seasonal conditions prevent the over-the-top Roundup application, and weeds in the crop line become unmanageable. The timing of the first Roundup application can be critical, as growers will be tempted to leave the application as late as possible before spraying. However, if wet or windy conditions prevent this spray, weeds in the plant line can be almost impossible to control. Spraying over-the-top after the fourth true cotton leaf can result in crop damage and reduced cotton yield.

The decision whether or not to use pre-plant herbicides is likely to be based on economic rationale. Obviously, growers and managers want to maximise profits and minimise input costs. The cost of weed control alone should not be the underlying factor on which the decision is made. Increases or decreases in production, fibre quality and weeds that contribute to the seed bank load all need to be included in the decision making process. As well, the decision may be quite different for each field. A knowledge of the weed pressure and species composition of each field is crucial to the decision making process as there is often great variation in weed numbers and the species that pose problems between fields.

Species composition in the field is also important for deciding on a weed management plan. Some species, such as red pigweed and common sowthistle, are tolerant of Roundup Ready herbicide, and are difficult to manage in a Roundup based system. The use of Roundup Ready herbicide in fields that have high numbers of Roundup tolerant weeds will result in these species becoming more prevalent and competing with the cotton (known as species shift). The addition of residual herbicides such as Cotogard or Diuron pre-plant will alleviate this problem.

This decision maybe further complicated by the ability of the grower to spray all fields planted with Roundup Ready cotton in the required time-period prior to the four-leaf stage of crop growth.

Growers may consider the use of reduced or half rates of residual herbicides rather than a full residual herbicide program which may not be needed. Reduced herbicide rates provide some level of weed control, but for less of the season, and reduced risk of crop damage. This would be better than eliminating residual herbicides, as this can exacerbate weed problems.

In clean fields where the weed pressure is light, residual herbicides may be safely eliminated. These fields should be monitored over time to ensure that weed problems are not developing.

## Species shift

No weed management tool controls all weeds equally well. Some species are very susceptible to control using a given management tool, while other species are naturally tolerant. For example, inter-row-cultivation effectively controls most grass and broadleaf weeds but is ineffective on the perennial weeds such as nutgrass and ploymeria takeall.

The effect of using any weed management tool or set of weed management tools is to select out the species that are most tolerant of the tools. These species will quickly spread and will dominate the weed spectrum in a field, termed species shift. This is not a new phenomenon, but is constantly occurring. The weed species that are currently in cotton fields are the species that have been most tolerant of the management tools used in the past.

Where Roundup is used in-crop as an additional management tool, there is likely to be little change in the weed spectrum. However, if Roundup is used to replace other management tools, such as residual herbicides, inter-row cultivation or chipping, there is likely to be a relatively rapid change in the in-field weed spectrum towards those weeds that were previously controlled by the alternative management tools, but are relatively tolerant of Roundup. This change may become apparent within three or four seasons of using Roundup Ready cotton.

A change in the weed spectrum (species shift) is inevitable where Roundup is used to replace other weed management tools. However, the change should be easily identified and easily managed. Regular field observations will identify changes in the weed spectrum. Changes in management will then need to be targeted to address these problems.

In the long-term, a sustainable weed management system will be one that employs a range of weed management tools in combination so that all weeds are controlled by some management tools.

## Herbicide resistance

As distinct from species shift, which relates to naturally tolerant weed species, herbicide resistance is a factor of the very small number of individual plants within a weed species that have natural resistance to a herbicide. These individuals may occur at very low frequency within a population where all other individuals are easily killed by the herbicide. Herbicide resistance occurs when repeated use of a herbicide selects out these individuals such that the resistant individuals spread and eventually dominate the weed population. The herbicide is no longer of any value for controlling the weed when this happens.

At present, there are no known herbicide resistant weeds in the Australian cotton industry. However, herbicide resistance can occur. There are numerous examples of herbicide resistant weeds in some of the other cropping systems in Australia.

The primary reason for herbicide resistance not being a problem in Australian cotton production has been the traditional philosophy of weed management and the reliance on a combination of weed management tools. Inter-row cultivation and especially hand hoeing have been the most important resistance management tools as both these tools are relatively non-selective. Any weeds that were not controlled by herbicides, and so were potentially herbicide resistant, were removed by the combination of cultivation and chipping. The philosophy of using these tools to remove all weed escapes from the field has prevented the emergence of herbicide resistant weeds.

The development of herbicide resistance is influenced by a number of factors including:

- the intensity of the selection pressure
- the frequency of herbicide resistant genes within a particular species
- the fitness of the resistant biotype
- and the biology of the particular weed species

With the introduction of Roundup Ready cotton, it is likely that one or two additional Roundup applications will be introduced to the cotton production system. This increased herbicide use will slightly increase the selection pressure for Roundup resistant weeds. Additionally, a reduction in the use of alternative control methods will accompany the widespread introduction of Roundup Ready cotton. This reduction will greatly increase the selection pressure on Roundup, and greatly increase the likelihood of Roundup resistant weeds developing (being selected out by a management system that relies too heavily on glyphosate).

The situation now exists where good weed control in some fields can be achieved with just Roundup Ready herbicide. Consequently, the temptation exists to forgo all other weed control methods in favour of using this technology alone. From a short-term economic perspective this may make sense, and good weed control may be achieved (in the short-term), but in the long-term, species shift and herbicide resistant weeds will be a reality. Dealing with herbicide resistant weeds will be far more costly to the entire industry than maintaining weed susceptibility through an integrated approach to weed management.

To slow or prevent the development of herbicide resistance, it is important that growers maintain an integrated approach to their weed management. The Roundup Ready Management Guide requires that after growers apply their final in-crop Roundup application, they:

- assess the occurrence of surviving weeds on three 100 m lengths of row per 40 ha crop
- take remedial action to stop seed set of these weeds
- report any adverse findings (potential resistance problems)

This resistance management plan appears to be very simple, but is technically sound. It is based on the principle that any weed that is not controlled by the Roundup application (potentially resistant) is controlled by some other means before it is able to set seed. This plan will prevent the occurrence of herbicide resistance if it is properly implemented.

The resistance management plan also makes good farming sense. Weeds that are controlled before they set seed don't contribute to future weed problems, maintaining the stability of the system. Weeds that survive the Roundup application may or may not be resistant, but will contribute to a larger problem in future years of weeds that are not controlled by Roundup if they are allowed to set seed.

More specific information on herbicide resistance is provided in section C2.1 of WEEDpak.

## Economics of production

A study evaluating the economic aspects of using Roundup Ready technology in comparison to conventional cotton varieties and herbicide systems is being undertaken. Case studies have been included (Appendix A) that may serve as a useful guide on the economics of growing Roundup Ready cotton. Growers using both Roundup Ready and conventional cotton varieties during the 2001/2002 season provided the herbicide regimes used in the case studies.

It should be stressed that yield gains or penalties have not been included in the figures provided as these are currently unknown and may have a profound bearing on the way that the data is interpreted. In addition, there is no provision in the data set to allow for a rating of the effectiveness of the weed control program for the current year.

Results from research trials from previous seasons showed that production could be economically competitive using Roundup Ready technology. In some treatments, improvements in cotton establishment, weed control and cotton yield more than compensate for the cost of the technology.

## Control of volunteer and ratoon cotton

The control of volunteer and ratoon cotton in successive cotton crops is one of the major difficulties associated with using the Roundup Ready technology. An article dealing specifically with volunteer and ratoon cotton control can be found in section F4 Controlling Volunteer Cotton in WEEDpak. Volunteer and ratoon Roundup Ready cotton plants continue to express the Roundup Ready gene in successive seasons and are difficult to control in crop and particularly within the plant line. Control is required due to varietal purity, insect and disease pressures associated with the reduced fitness of volunteer plants and the likelihood that ratoon cotton may act as a refuge for insect pest species.

Control of volunteer cotton may be achieved by pre-irrigating fields to encourage seed germination, then using pre-plant or pre-emergent applications of Sprayseed @1.5-2.2L/ha depending on growth stage. Hammer® (carfentrazone), a new product being registered by Crop Care Australia may offer a new alternative. Hammer can be mixed with glyphosate and has no residual plant back. This herbicide can't be used as an over the top application in either Roundup Ready or conventional cotton crops.

Ratoon cotton is more difficult to control. Effective control may be achieved with root cutting and/or centre busting at the end of the season. Herbicide control alone is very difficult. Various farmers have used 2-4,D Amine, Starane and Dicamba, but with limited success.

## Roundup Ready® Audit

Growers of Roundup Ready cotton are required to perform an audit of the effectiveness of the weed control achieved. This audit includes:

1) An assessment of the weeds that have not effectively been controlled by the Roundup Ready herbicide following, the final Roundup Ready application. Three rows of 100m should be assessed for every 40 ha of cotton that is planted prior to seed set of those weeds.
2) The remedial action taken to prevent seed set of those weeds that have "escaped" the Roundup Ready treatment.
3) Details of the weed management program during the season (includes herbicides used, rates of application and number of applications).
4) Comments on the level of weed control achieved.
5) Adverse event reporting

It is important that farmers conduct this audit within three weeks of the last in-crop Roundup application, to accurately determine the success or otherwise of the spray application. If the assessment occurs more than three weeks after spraying, it is quite possible that new weeds will have emerged by this time. These weeds may be counted when they have never been exposed to glyphosate. This result will indicate a spray failure, when no failure occurred. The audit is designed only to find weeds that have been exposed to glyphosate, to try to detect any potential resistant weeds that are developing. Control of all weeds before they set seed is the aim of good management.

*Appendix A. Case studies describing herbicide regimes and associated costs of using Roundup Ready Technology.*

| Field | License Fee | Preplant herbicide | | Planting herb | Post emergence herbicide | | | Chipping | Lay -by | No of Cultivat-ions | Total costs/ha |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Conventional dirty | | 2.2 L/Ha Triflur + application | 3.5 L/Ha Cotoran 50% band + application | 1.7 kg/Ha diurex + application | | | | | 1.5 L/Ha Gesagard 1.5 kg diuron + application | 2 | |
| Cost $/Ha | | $22.20 | $30.05 | $30.80 | | | | $40.00 | $61.85 | $16 | $200.90 |
| | | | | | | | | | | | |
| Roundup Ready dirty | | 2.2 L/Ha Triflur + application | 3.5 L/Ha Cotoran + application | 1.7 kg/Ha Diurex + application | 1.5 kg/Ha Roundup + application | 1.5 kg/Ha Roundup + application | 1.5 kg/Ha Roundup + application | | 1.5 L/Ha Gesagard 1.5 kg diuron + application | 2 | |
| Cost $/Ha | $49 | $22.20 | $30.05 | $30.80 | $22.25 | $22.25 | $22.25 | | $61.85 | $16 | $276.65 |
| | | | | | | | | | | | |
| Moderately Dirty Roundup Ready | | | | 1.5 kg/Ha Roundup + application | 1.5 kg/Ha Roundup + application | 1.5 kg/Ha Roundup + application | | | 1.5 L/Ha Gesagard 1.5 kg diuron + application | 2 | |
| Cost $/Ha | $49 | | | $22.25 | $22.25 | $22.25 | | | $61.85 | $16 | $193.60 |
| | | | | | | | | | | | |
| Clean Field Roundup Ready | | | | Sprayseed 1.5L/ha + application | 1.5kg/Ha Roundup + application | 1.0kg/Ha Roundup + application | Staple 60g/Ha 40% band + application | | | 2 | |
| Cost $/Ha | $49 | | | $23.21 | $22.25 | $17.50 | $33.20 | | | $16 | $161.16 |
| | | | | | | | | | | | |
| Clean field conventional | | Diuron 1.5kg + cotogard 2.0l + application | | Sprayseed 1.5l?ha + application | Cotogard 50% band + application | | Staple 60g/Ha 40% band + application | | | 2 | |
| Cost $/Ha | | $52.90 | | $23.21 | $20.40 | | $33.20 | | | $16 | $145.71 |

| Field | License Fee | Preplant herb 1 | Preplant herb 2 | Planting herb 1 | Post emerg | Post emerg | Post emerg | Lay -by | Chipping | No. of Cultivat-ions | Total Costs / ha |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Roundup Ready | | 2.3L Triflur 480 1.0kg Diuron + Application | | 2.3L Convoy 0.5kg Diuron + Application | 1.5kg/Ha Roundup + Application | 1.5kg/Ha Roundup + Application | | 1.5kg Roundup 1.9kg Convoy 2.0L Liase + Application | | 2 | |
| Cost $/Ha | $49 | $36.35 | | $57.64 | $23.25 | $23.25 | | $58.36 | $8.44 | $16.00 | $272.29 |
| Conventional | | 2.3L Triflur 480 1.0kg Diuron + Application | 2.0L Roundup + Application | 2.3L Convoy 0.5kg Diuron + Application | | 2.8L MSMA + Application | | 2.0L MSMA 2.0L Prometryn + Application | | 2 | |
| Cost $/Ha | | $36.35 | $18.80 | $57.64 | | $41.20 | | $68.96 | $50.85 | $16.00 | $289.80 |
| Roundup Ready | | | Roundup CT @ 1.3l/Ha + Application | Slomp @ 3.5l + Cotoran @ 2kg/ha 40% band | 1.5kg/Ha Roundup Ready Herbicide + Application | Select @375mls/ha 40%band + application | | Cotogard WG @ 1.9kg/HA 85% Band | | 1 | |
| Cost $/Ha | $49.00 | | $7.20 + $9 | $29.00 | $12.40 + $9 | $13.60 + $9 | | $36.30 | | $12 | $186.50 |
| Conventional | | | Triflur@2.3l + Cotoran @2l | Cotogard@ 1.4kgs/Ha 40% band | | | | Gesagard @ 3l/ha 85% band | | 3 | |
| Cost $/Ha | | | $41.90 | $12.60 | | | | $39.00 | $68 | $36 | $197.5 |

## Summary

Roundup Ready cotton offers a number of benefits to the Australian cotton industry however, there are a few limitations when using this technology and for optimum results, Roundup Ready cotton needs to be managed within these limitations. Roundup Ready cotton is only registered for over the top applications up to the fourth true leaf and prior to unfolding of the fifth true leaf of the cotton crop. Sequential applications of Roundup Ready herbicide must be applied at least 10 days apart, and with at least two nodes of crop growth between applications.

Shielded and directed applications of Roundup Ready herbicide can be very effective in controlling weeds in cotton, however there is always potential for spray drift when applying Roundup ready herbicide in this manner. Shields must be designed to minimise drift and to prevent fine spray droplets from contacting the leaves. Likewise, when applying directed applications the nozzles must be angled such that none of the spray contacts the lower leaves of the cotton plants.

To minimise the impacts of both species shift and herbicide resistance an Integrated Weed Management approach to weed control must be adopted.

# RESEARCH RESULTS WITH ROUNDUP READY® COTTON

Graham Charles
(NSW Agriculture)

Contents



## Introduction

Roundup Ready® is a transgenic, herbicide tolerant cotton developed by Monsanto. It has been genetically modified to increase its tolerance to Roundup (glyphosate) herbicide, but is otherwise substantially equivalent to conventional cotton. The Roundup Ready genetic material can be transferred to conventional cotton varieties through conventional plant breeding. Consequently, a range of cotton varieties is available in conventional or Roundup Ready options. These varieties may also include a genetically modified, insect resistance gene (Ingard™).

Roundup Ready cotton varieties are tolerant to Roundup applied over-the-top of young cotton (up to four true leaves), but older cotton is less tolerant and Roundup applied in older cotton must be directed to avoid contact with the leaves of the crop. This is normally done using a directed spray, with spray nozzles directed away from the cotton plant, or through a shielded sprayer, where a metal or plastic shield surrounds the spray, preventing the spray coming in contact with the crop plants.

A weed pressure index has been used to compare the over-all weed control achieved under various weed management systems. This index was derived from actual weed numbers per square metre on trial plots and fields. The weed count for each species has then been modified to take into account the competitiveness of the different species. The data are combined to form the weed pressure index. An index of 0 indicates a weed-free system, while a high number indicates a weedy system. A typical clean field would have an index of around 0.1 to 2, while a dirty field may have an index between 50 and 100, or even higher.

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.

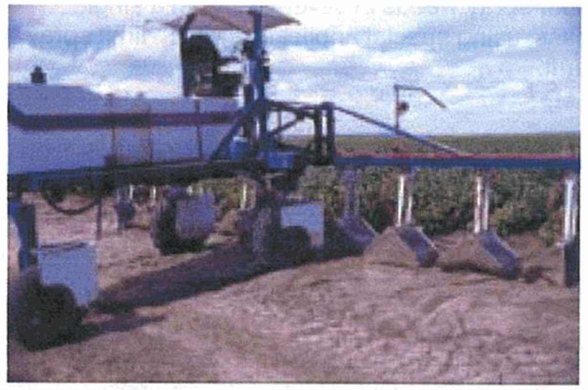
A weed control program based on non-residual herbicides may need to be repeated at 4-weekly intervals. Such a program may be impractical due to high cost, time and labour constraints. A period of wet or windy weather could be a disaster for a weed control program based solely on non-residual herbicides.

## Post-emergence and lay-by herbicides

The residual broad-leaf herbicides discussed earlier (diuron, fluometuron and prometryn) are commonly also applied post-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-row area 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 commonly used in dryland cotton, where large inter-row strips are present, but where stubble destruction and soil moisture losses resulting from cultivation are undesirable.



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

The use of herbicides such as glyphosate through a shielded sprayer is relatively safe, but extensive crop damage can occur if the herbicide does make 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.

## Spot-spraying

Spot-spraying is ideally suited to situations where large weeds are present at low densities. Herbicides such as glyphosate and MSMA 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 Staple®, Sempra®, Zollar® 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 have multiple operators, each of whom can spot-spray weeds in several rows in a single pass, using special applicators which limit spray drift.

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

## 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 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.

## Crop agronomy and 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. Operations such as cultivation, chipping, 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.

## Transgenic cotton varieties

*Small plots of transgenic, Roundup Ready® cotton sown amongst conventional cotton and sprayed with Roundup herbicide.*

Transgenic, herbicide tolerant cotton varieties are becoming available. Roundup tolerant, Roundup Ready® cotton varieties are now commercially available. Herbicide tolerant varieties have been genetically modified to enhance their tolerance of specific herbicides. These herbicides can't normally be used with conventional cotton varieties. The use of transgenic varieties provides opportunities to use a new range of herbicides in cotton with improved crop safety. In many instances, this technology allows cotton growers to substitute non-residual herbicides for residual herbicides, reducing potential re-cropping problems. These herbicides may 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.

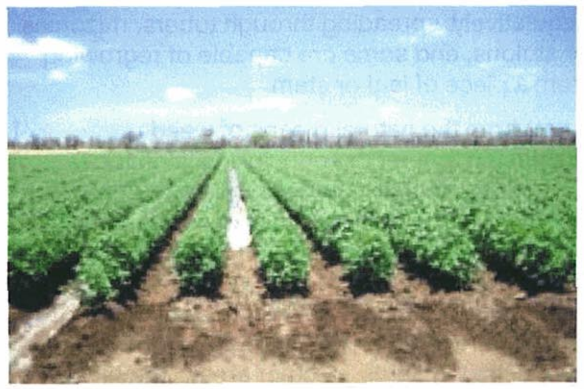
Later in the season, irrigation, chipping, cultivation and herbicide applications must be coordinated to minimise stress to the cotton crop but maximise weed control and weed control opportunities.

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.

## Inter-row cultivation

Inter-row cultivation is a relatively cheap and effective method of removing weeds from the inter-row area. In irrigated cotton, cultivation is also an important tool for re-delving and maintaining the irrigation furrow.

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 have been damaged during the cultivation pass.



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

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

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 cotton. 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.

## Flame and other weeders

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

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.

## Hand chipping

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

However, hand chipping can be extremely expensive. Chipping 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 chipping. Care should be taken to ensure that the cost of chipping does not become excessive.

*Hand chipping is an important part of an integrated weed management program.*

## 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.

## 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 pea, 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. Diuron and glyphosate are the main herbicides used. Diuron is applied after the final irrigation in autumn and incorporated by rain. Channels may need to be flushed in spring to remove excess chemical if insufficient rainfall occurs over winter. Glyphosate is applied as needed to control established weeds.

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.

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

## Ultra-narrow row cotton

The ultra-narrow row planting configuration has become feasible in cotton due to new cotton picker head design, improved cotton varieties, and transgenic herbicide tolerant cotton. Irrigated, ultra-narrow row cotton is more competitive than conventional cotton, 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.

## 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 rainfall, seedbed soil conditions, and other environmental factors, there is no guarantee that a treatment will give the result indicated in the tables.

ALWAYS READ THE LABEL OF THE PRODUCT BEFORE USE.

*Ultra-narrow row cotton. A range of planting configurations is being used.*

The information supplied here is only a guide. Product registrations vary between states and 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

Information on the herbicide group to which the product belongs is included on the product label. This information is essential for developing an integrated weed management strategy which avoids developing herbicide resistant weeds. The herbicide groups are indicated by a lettering system, as shown in Tables 3, 4 and 5.

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

## 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 probably be 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), 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 three broad categories.

- 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.
- herbicides with moderate risk (groups C to H).
- herbicides with low risk (groups I to N).

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.

## Rotation of herbicide groups

One approach to reducing the likelihood of herbicide resistance developing is to rotate herbicides, using different herbicide groups over time, so that weeds are exposed to a range of different herbicidal actions. 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 Falcon®, 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 (Zollar®). Use of these herbicides in rotation allows the opportunity to expose weeds to totally different herbicide groups, greatly reducing the risk of the development of herbicide resistance.

Overall, the most effective approach to reducing the development of herbicide resistance and a species shift to herbicide tolerant individuals, is to ensure that herbicides are used correctly and that an integrated approach to weed management using components from each of the weed management options is adopted. Special care needs to be taken when making repeated use of group A or group B herbicides.

## Developing an integrated weed management system

Each of the weed management tools has advantages and disadvantages, and needs to be integrated with 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, all 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 stimulate weed germination, but not sufficiently activate the herbicides. In this situation, non-residual herbicides and cultivation may be needed to supplement residual herbicides.

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 the 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.

*Table 3. A guide to the weeds controlled by soil residual herbicides.*

| Active ingredient | trifluralin | pendimethalin | metolachlor | fluometuron | prometryn | fluometuron + prometryn |
|---|---|---|---|---|---|---|
| Typical use rate | 1.4-2.8 L/ha | 3.5-4.5 L/ha | 2 L/ha | 4.5-6.0 L/ha | 3.3-4.5 kg/ha | 3.5-5 L/ha |
| Herbicide group | D | D | K | C | C | C |
| **Grass weeds** | | | | | | |
| Annual grasses general | S | S | S | MS | MS | MS |
| Barnyard grass | S | S | S | MS | MS | MS |
| Liverseed grass | S | S | S | MS | MS | MS |
| Johnson grass from seed | S | MS | MS | PS | T | T |
| Volunteer cereals | MS | MS | MS | S | S | S |
| Volunteer sorghum | S | S | S | S | S | S |
| Nutgrass | T | T | T | T | T | T |
| **Broad-leaf weeds** | | | | | | |
| Amaranthus | S | S | PS | S | S | S |
| Anoda weed | T | T | T | - | | - |
| Australian bind weed | T | T | T | T | T | T |
| Bathurst burr * | T | T | T | S | S | S |
| Bellvine | T | T | T | MS | S | S |
| Blackberry nightshade | T | MS | PS | S | S | S |
| Black bindweed | MS | T | T | - | S | MS |
| Bladder ketmia | T | T | T | S | S | S |
| Caltrop | S | MS | PS | S | S | S |
| Caustic weed | T | T | T | S | S | S |
| Cowvine (peachvine) | T | T | T | MS | S | S |
| Deadnettle | MS | T | PS | S | S | S |
| Devils claw | T | T | T | T | MS | S |
| Emu-foot | T | T | T | T | T | T |
| Ground cherry | T | T | T | S | S | S |
| Jute | PS | | PS | MS | MS | MS |
| Mintweed | MS | MS | MS | MS | S | S |
| Mung bean * | T | T | T | MS | T | MS |
| Native rosella | T | T | | S | - | S |
| Native vigna | T | T | T | - | - | - |
| Noogoora burr * | T | T | T | S | S | S |
| Parthenium weed | T | T | T | S | S | S |
| Pigweed | S | S | T | S | S | S |
| Polymeria | | | | | | |
| Prickly paddymelon | T | T | T | S | S | S |
| Raspweed | T | T | T | | | - |
| Rattlepod | T | T | T | S | S | S |
| Rynchosia | T | T | T | | | - |
| Sesbania | T | T | T | MS | MS | MS |
| Spineless caltrop | S | MS | PS | S | S | S |
| Small-flowered mallow | T | T | T | T | T | T |
| Common sowthistle | T | T | T | S | S | S |
| Sunflower * | T | T | T | S | MS | MS |
| Thornapples * | T | T | T | S | S | S |
| Wireweed | S | S | PS | - | S | MS |
| Wild gooseberry | T | T | T | S | S | S |
| Wild melon * | T | T | T | S | S | S |
| Wild turnip | T | T | T | - | S | - |

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

** 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 herbicides (continued).*

| Active ingredient<br>Registered trade name<br>Typical use rate<br>Herbicide group | diuron<br>various<br>1.8-3.5 L/ha<br>C | norflurazon<br>Zoliar**<br>2-4 Kg/ha<br>F | Pyrithiobac sodium<br>Staple*<br>30-120 g/ha<br>B | MSMA<br>various<br>1-2.8 L/ha<br>K | glyphosate<br>various***<br>1-2 L/ha<br>M |
|---|---|---|---|---|---|
| **Grass weeds** | | | | | |
| An[redacted]sses general | MS | MS | T | S | S |
| Barnyard grass | MS | MS | T | S | S |
| Johnson grass from seed | T | MS | T | MS | S |
| Liverseed grass | MS | MS | T | S | S |
| Volunteer Cereals | S | MS | T | - | S |
| Volunteer sorghum | MS | MS | S | MS | S |
| Nutgrass | T | MS | T | MS | MS |
| **Broad-leaf weeds** | | | | | |
| Amaranthus | S | T | S | T | S |
| Anoda weed | - | T | S | T | MS |
| Australian bind weed | - | T | T | T | MS |
| Bathurst burr | S* | T | S | S | S |
| Bellvine | MS | T | S | T | PS |
| Blackberry nightshade | S | T | - | T | MS |
| Bladder ketmia | MS | T | T | T | MS |
| Black bindweed | - | T | T | T | MS |
| Caltrop | MS | T | T | T | S |
| Caustic Weed | MS | T | T | T | S |
| Cowvine (peachvi[redacted] | T | T | S | T | MS |
| Deadnettle | S | T | T | T | S |
| Devil's claw | - | MS | T | T | S |
| Emu-foot | - | T | T | T | MS |
| Ground cherry | MS | T | S | T | S |
| Jute | PS | - | T | T | S |
| Mintweed | MS | T | T | T | S |
| Mung bean | MS | T | T | T | S |
| Native rosella | - | T | T | T | MS |
| Native vigna | - | T | T | T | S |
| Noogoora burr | S* | T | S | S | S |
| Parthenium weed | S | T | T | T | MS |
| Pigweed | S | T | T | T | S |
| Polymeria | T | T | T | T | PS |
| Prickly paddymelon | S | T | T | T | PS |
| Raspweed | - | T | T | T | PS |
| Rattlepod | S | T | T | T | MS |
| Rynchosia | - | T | T | T | MS |
| Sesbania pea | MS | T | S | T | MS |
| Small-flowered mallow | T | T | T | T | PS |
| Common sowthistle | S | T | T | T | S |
| Spineless caltrop | MS | S | S | T | S |
| Sunflower | MS | T | S | T | S |
| Thornapples | S* | T | S | T | S |
| Wireweed | MS | T | T | T | S |
| Wild gooseberry | MS | T | S | T | S |
| Wild melon | S | T | S | T | S |
| Wild turnip | S | T | T | T | S |

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

* *These weeds have large seeds and may germinate below the herbicide band, reducing the level of control.*

** *Zoliar® is a residual herbicide that requires thorough incorporation, and needs to be applied for 2 or 3 consecutive seasons for nutgrass control.*

*** *Glyphosate is toxic to conventional (non-Roundup Ready®) cotton and can only be safely applied to conventional cotton post-emergence through a well-constructed shielded sprayer, under suitable operating conditions with regard to wind, nozzle pressure, shield design, ground speed etc. For more information, refer to the section on* ***Directed and shielded applications of Roundup in Managing Roundup Ready® Cotton in WEEDpak.***

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

| Active ingredient | butroxydim | clethodim | fluazifop-butyl | haloxyfop-ethoxy-ethyl | propaquizafop | sethoxydim |
|---|---|---|---|---|---|---|
| Registered trade name | Falcon® | Select® | Fusilade® | Verdict® | Correct® | Sertin® |
| Typical use rate (mL/ha) | 120-180 | 250-375 | 750 | 1.0-1.5 | 0.2 – 0.9 | 120-180 |
| Herbicide group | A | A | A | A | A | A |
| **Grass weeds** | | | | | | |
| Annual grasses general | S | S | S | S | - | S |
| Barnyard grass | S | S | S | S | S | S |
| Johnson grass from seed | S | S | S | S | S | S |
| Liverseed grass | S | S | S | S | S | S |
| Volunteer cereals | S | MS | S | S | S | S |

*S Susceptible MS Moderately susceptible - Not known*

## Residual grass herbicides

The most commonly used residual grass herbicide is trifluralin, applied as a pre-planting, soil-incorporated herbicide. It has activity on most grass weeds, and some broad-leaf weeds such as amaranthus, caltrop, and mintweed. Its application window is from 6 weeks pre-planting to immediately prior to planting. Trifluralin is relatively inexpensive, but may inhibit the development of surface roots of emerging cotton seedlings and requires thorough soil incorporation to be effective. 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.

If trifluralin is not used prior to planting, pendimethalin or metolachlor will normally be applied at planting as an alternative. It is also common to apply a band of pendimethalin as a 'top-up' behind the planter, even when trifluralin has previously been applied. This most often occurs on fields that are pre-irrigated, where a layer of dry soil is skimmed off the top of the irrigation hill at planting to allow cotton seed to be planted into moist soil. The herbicide treated soil ends up in the furrow. A band of pendimethalin is then applied to the area disturbed by planting, to replace the trifluralin that has been removed.

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

Pendimethalin and metolachlor have similar activity on grass and broad-leaf weeds when compared with trifluralin. The main advantages of these herbicides 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 immediately after planting, washing herbicide into the cotton seed zone. Both herbicides require some incorporation, with finger harrows behind the planter, or either by rainfall or irrigation. Both herbicides have some volatility (metolachlor less than pendimethalin), and are degraded by sunlight (metolachlor more than pendimethalin).

## 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 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.

*Fluometuron damage on seedling cotton (yellowing of the inter-venial leaf area). Fluometuron was applied at planting but damage did not become obvious until this growth stage.*

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.

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

Because they do 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.

*Zoliar® applied to a severe nutgrass infestation. The white areas in the foreground were caused by Zoliar®, which affects photosynthesis.*

An alternative to these herbicides is Zoliar®, a highly residual soil applied herbicide with activity against some broad-leaf and most grass weeds. 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, Zollar® needs to be applied over several consecutive seasons and should be used in conjunction with other management tools such as inter-row spraying with glyphosate or Sempra®. Zollar® 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, Zollar® does give effective suppression of the weed but will not eliminate the problem.

Zollar® 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 Zollar® 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 Zollar® applied to consecutive cotton crops.

## 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 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.

*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.*

Trifluralin and diuron are examples of relatively inexpensive but effective herbicides often used with dryland cotton, but which greatly reduce the growers' planting options should cotton not be planted or should the crop fail to establish. Minimum re-cropping intervals for cotton herbicides are shown in Tables 6 and 7. Judicious use of soil residual herbicides enable growers to consider other crop options for a December-January planting such as sorghum, sunflower, and mung beans.

One possible strategy to avoid problems with pre-plant 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 and a residual herbicide may be applied later in the season. Should 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® 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 may be of concern over time. Reliance on glyphosate as the primary weed control tool will result in a shift in the weed spectrum to those weeds that are more tolerant of glyphosate and may ultimately lead to glyphosate resistant weeds. This strategy may fail in weedy fields, where weeds that emerge in the plant-line after the over-the-top Roundup application may be difficult and expensive to control.

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.

*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.*

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

* *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 sorgum seed* - *No information available*

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

| | fluometuron + prometryn | diuron | norflurazon Zoliar®* | pyrithiobac Staple®** |
|---|---|---|---|---|
| Barley | 6 | 12 | 30 | 5 |
| Canola | 6 | 12 | - | - |
| Chickpea | 6 | 12 | 9 | - |
| Cotton | 0 | S | 0 | 0 |
| Cowpea | 6 | 12 | - | - |
| Faba Bean | 6 | 12 | 30 | - |
| Lablab | 6 | 12 | - | - |
| Linseed | 6 | 12 | 9 | - |
| Lucerne | 6 | 12 | - | - |
| Maize | 6 | S | 27 | 22 |
| Millet | 6 | 12 | - | - |
| Mung Bean | 6 | 12 | 27 | 11 |
| Oats | 6 | 12 | 30 | 5 |
| Sorghum | 6 | S | 27 | 22 |
| Soybean | 6 | 12 | 9 | 22 |
| Sunflower | 6 | 12 | 27 | 22 |
| Triticale | 6 | 12 | 30 | - |
| Wheat | 6 | 12 | 30 | 5 |

* *Re-cropping interval relates to a single application. Longer intervals will be necessary following applications over more than one season.*

** *Re-cropping intervals relate to no more than a total of 120 g/ha of Staple® applied in one season. A maximum of 240 g/ha may be applied in back-to-back cotton.*

*S The spring following application in cotton*

*- No information available.*

## Pre-emergence, post-irrigation herbicides

In irrigated cotton production, the crop 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 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 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 in 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.

*Inter-row cultivation is 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, 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, but will only control weeds present at the time of application and so are unable to control weeds from later germinations. 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.

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 with sequential applications. Consequently, MSMA should only be applied over-the-top of cotton in situations of heavy weed infestation, where the potential damage from the herbicide is far less than the potential damage from the weeds. MSMA should be applied as a directed spray where possible. MSMA is not commonly used, except for early-season control of nutgrass.

Staple® (Table 4) is a more recently registered herbicide that is 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 Tables 6 and 7.

# MANAGING WEEDS IN COTTON

Graham Charles
(NSW Agriculture)

Contents | Page



## 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 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.

A sustainable system for cotton production will necessarily include a well-developed weed management program. Weed management is an important issue for Australian cotton production, and requires a dedicated and long-term approach. The principles of management remain the same over time, over fields and over environments. However, the selection of weed management tools must be made on a week-by-week and field-by-field basis. Decisions made at any one time will affect outcomes in future seasons.

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, 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.

## 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 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 control by hand-chipping is approximately 1 thornapple per 73 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.

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

## Weed competition

Cotton seedlings have relatively poor vigour and compete poorly against weeds early in the cotton season. Even moderate weed infestations 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 plants. 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 in the cooler, southern areas, seedlings initially have very small requirements. Resource use rapidly increases as the seedlings grow. There has been no measurable reduction in cotton yield when weeds were removed within 4 weeks of emergence. However, yield reductions have been recorded when weeds were allowed to remain for longer than 4 weeks after emergence. The precise length of this critical period of competition of approximately 4 weeks depends on the growth rate of the weeds and scarcity of resources. Ideally, weeds should be controlled within 4 weeks of emergence, before they become well established and begin to compete strongly with the cotton crop.

Weed control needs to be maintained for at least 10 to 14 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 older than 14 weeks may still be small and not sufficiently well developed to be able to compete strongly with weeds. Consequently, 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 required by cotton later in the season, and so compete directly with the crop. Mid- and late-season control of these weeds is important.

*Cotton seedlings emerge slowly from spring planting and compete poorly with weeds.*

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

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

## Other effects of weeds

Weeds impact on cotton production in other ways. Weeds can act as hosts of cotton pests and diseases, and volunteer cotton can itself be a 'weed' in cotton. This is particularly important in managing Ingard® cotton crops, where heliothis caterpillars can grow and develop on weeds such as bladder ketmia, pigweed, the senecios or 'conventional' cotton, and then migrate onto Ingard® cotton.

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

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 pea 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 affect cotton yield directly.

## Weed identification

Common names for weeds 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. Generally, small weeds can be identified after finding larger examples in the field or surrounding areas.

The Weed Identification and Information Guide at the front of 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 available through extension officers in NSW Agriculture and the Queensland. Department of Primary Industries, cotton consultants, and chemical company representatives. Alternatively, positive identification of flowering plants can be obtained from the herbariums located in the Botanical Gardens in each state.

*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 WEEDpak 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 | *Hibiscus trionum* | 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 |

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.

## Weed management tools

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

- management of fallows
- crop rotations
- 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 (chipping)
- flame weeding
- field hygiene of
  - machinery
  - seed and other inputs
  - vehicles and water
- 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, and planting configuration 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 cost of damage resulting from 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 control measures have the potential to cause some damage to cotton. Inter-row cultivation, for example, prunes some surface cotton roots and damages the cotton. 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. 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 application and the use of well set up equipment. Crop, soil and weather conditions must also be taken into consideration.

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 chipping and spot sprayers are particularly valuable tools for managing low densities of larger weeds.

## Weed management in fallows

Where a field to be planted to cotton is fallowed prior to cotton, opportunity exists to control weeds. 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 using herbicides, this strategy has the added advantage of retaining stubble cover and maximising the retention of soil moisture. 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.

*Weed control can be difficult in broad-leaf rotation crops. This lablab crop failed due to poor establishment and poor weed control*

## 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.

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

| Product | Active ingredient | Applied rate per hectare | Re-cropping interval to cotton |
|---|---|---|---|
| 2,4-D amine (various names) | 500 g/L 2,4-D amine | up to 0.7 L<br>0.7 - 1.4 L<br>above 1.4 L | 10 days after a minimum of 15 mm rainfall<br>14 days after a minimum of 15 mm rainfall<br>21 days after a minimum of 15 mm rainfall |
| Tillmaster® | 180 g/L 2,4-D amine + 90 g/L glyphosate | up to 2.0 L<br>2.0 - 4.0 L<br>4.0 - 6.0 L | 10 days after a minimum of 15 mm rainfall<br>14 days after a minimum of 15 mm rainfall<br>21 days after a minimum of 15 mm rainfall |
| atrazine (various names) | 500 g/L atrazine | 2.5 L<br>2.5 - 6 L | 6 months<br>18 months |
| chlorsulfuron (various names) | 750 g/kg chlorsulfuron | 15 - 20 g | 18 months with a minimum of 700 mm rainfall where soil pH is 6.6 - 7.5<br>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<br>do not use where soil pH is above 8.5 |
| clopyralid (various names) | 300 g/L clopyralid | Up to 0.3 L<br>0.3 – 0.5 L<br>Above 0.5 L | 9 months<br>12 months<br>2 years |
| dicamba (various names) | 500 g/L dicamba | up to 0.2 L<br>0.28 – 0.56 L | 7 days after a minimum of 15 mm rainfall<br>21 days after a minimum of 15 mm rainfall |
| Sandoban® | 60 g/L dicamba + 150 g/L glyphosate | up to 2.0 L<br>above 2.0 L | 7 days after a minimum of 15 mm rainfall<br>21 days after a minimum of 15 mm rainfall |
| 2,4-D ester (various names) | 800 g/L 2,4-D ester | up to 0.35 L<br>0.35 - 0.7 L<br>above 0.7 L | 10 days after a minimum of 15 mm rainfall<br>14 days after a minimum of 15 mm rainfall<br>21 days after a minimum of 15 mm rainfall |
| fluroxypyr (various names) | 300 g/L fluroxypyr | up to 0.75 L<br>0.75 – 1.5 L | 14 days<br>28 days |
| metsulfuron (various names) | 600 g/kg metsulfuron | 5 - 7 g | Cotton should not be planted on land previously treated with Ally. Tolerance of cotton grown through to maturity should be determined on a small scale before sowing into larger areas |
| Tordon 75-D® | 75 g/L picloram + 300 g/L 2,4-D | 0.3 – 1 L | 12 months |
| Tordon 242® | 26 g/L picloram + 420 g/L MCPA | 1.0 L | 12 months |
| triasulfuron (various names) | 750 g/kg triasulfuron | 10 - 35 g | 15 months where soil pH is up to 7.5 with 700 mm of rain<br>18 months where soil pH is 8.5 with 700 mm of rain<br>24 months where soil pH is above 8.6 with 500 mm of rain |
| Amber Post® | 20 g/kg triasulfuron + 600 /kg terbutryn | 250 - 500 g | 14 months |
| trichlopyr (various names) | 600 g/L triclopyr | 80 - 160 mL | 14 days |
| Harmony M® | 682 g/kg thifensulfuron + + 68 g/kg metsulfuron | 40 g | Cotton should not be planted on land previously treated with Harmony M.<br>Tolerance of cotton grown through to maturity should be determined on a small scale before sowing into larger areas |

## Herbicides for fallows and rotation crops

The wider range of herbicides available for use in fallows and rotation crops provides an opportunity to control weeds which are 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. Table 2 gives a guide to re-cropping intervals to cotton. Most 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.

*Cotton can be damaged by herbicides used on rotation crops. This damage (distorted growth) was caused by 2,4-D herbicide.*

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. These same herbicides break down very slowly or may not break down at all under 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.

*Chick pea and wheat rotation crops planted into cotton trash.*

## 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, and remain effective for weeks or months after application. They can be applied in anticipation of a weed problem and they control weeds before they emerge. They are generally less expensive than their non-residual alternatives, particularly when multiple non-residual applications are required to replace a single residual herbicide application.

However, residual herbicides have two major drawbacks. Firstly, they must be applied in anticipation of a weed problem, whether or not a problem actually occurs. In situations of low weed pressure, their use may result in damage to cotton plants without any real benefit. Secondly, 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.

# INTEGRATED WEED MANAGEMENT

## Introduction

The advent of insecticide resistance precipitated a 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, Integrated Weed Management (IWM) will also need to be adopted if growers are to prevent herbicide resistance. However, IWM is more than just preventing herbicide resistance, it is about using many methods of weed control in synergy. The result of IWM will reduce the reliance on herbicides, minimise the development of herbicide resistance and species shift 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 introduce the concepts of IWM in detail and provide an overview of the weed management principles available for cotton production.

This section contains the following documents:

### B2 Integrated Weed Management Guidelines

This document introduces the concept of managing cotton weeds with Integrated Weed Management (IWM). It provides an understanding of why IWM will be important for the future of Australian cotton weed management and the importance this concept will have when growing herbicide tolerant cotton. A summary table of weeds that have developed herbicide resistance is included, along with a table of weeds that have resistance to the herbicide glyphosate. A description of the components of IWM is provided. This document will encourage cotton growers to educate themselves about the principles of IWM, evaluate their own farms and implement an IWM program.

### B3 Managing Weeds in Cotton

This document is a comprehensive overview of managing weeds in cotton. It describes the impact of weeds, common weed identification problems and a description of the weed management tools that can be used in the Australian cotton system. There are important summary tables on:

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

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

# INTEGRATED WEED MANAGEMENT (IWM)

## Guidelines for Australian Cotton Production

Grant Roberts and Graham Charles
(CSIRO & NSW Agriculture)

Contents Page



## IWM is best practice in weed management

### The impact of weeds

Weeds adversely impact cotton in many ways. Primarily, weeds compete for available nutrients, water and light. They can also directly impact cotton quality through contamination of cotton fibre or 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 thornapple (*Datura ferox*) can compete strongly with cotton. The economic threshold for control by hand-chipping is approximately one thornapple per 73 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 also impact cotton production indirectly, as the tools used to manage weeds are expensive and may adversely affect cotton to some extent. All the currently used herbicides can cause some degree of leaf or root damage to cotton. Many of the more commonly used 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 herbicides alone. An IWM program uses a range of methods of weed control in combination so that all weeds are controlled by at least one component of the weed management system.

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.

Weed management approaches that rely on a limited number of strategies 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. 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. Eventually herbicide resistance develops such that the herbicide no longer controls the target weed.

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 will soon dominate the weed population, and the weed spectrum will shift 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 below (Figure 1). All the individual components of the system contribute to a total weed management system.

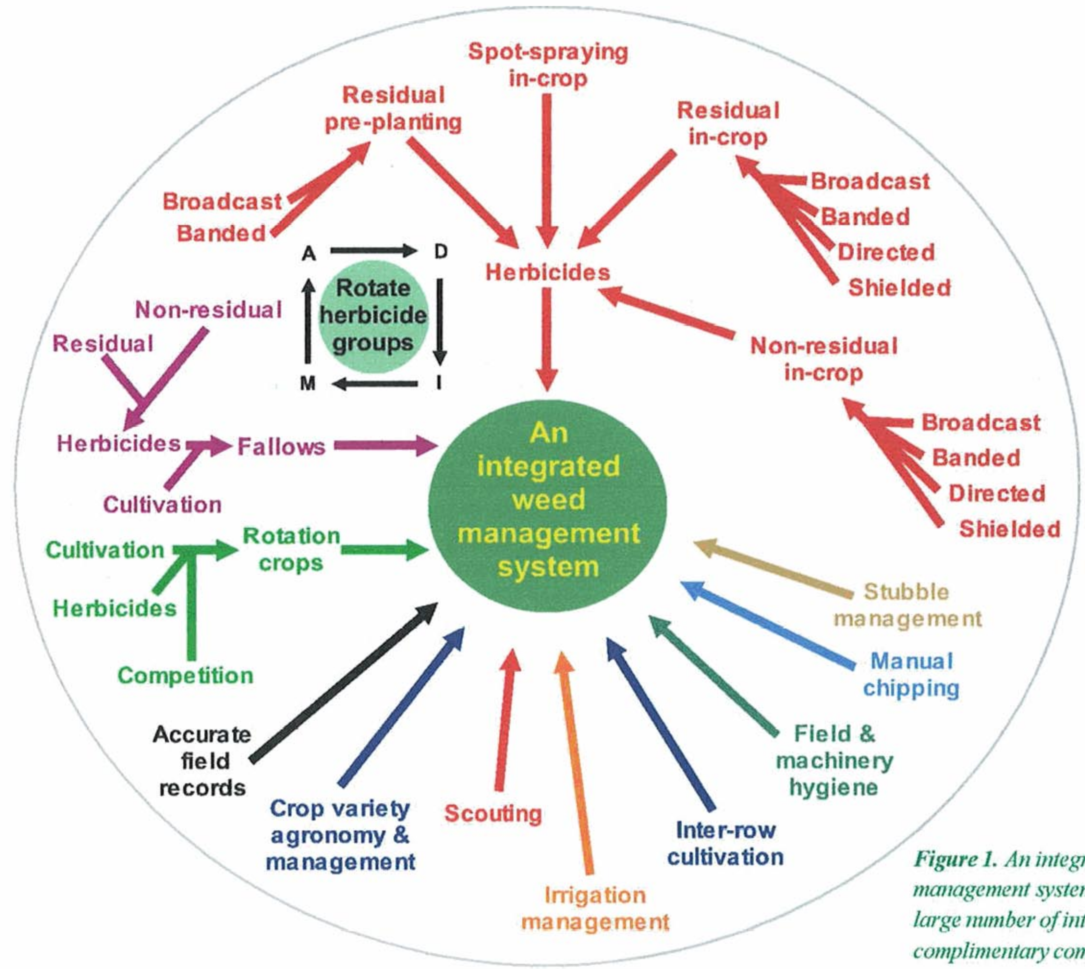



*Figure 1. An integrated weed management system uses a large number of interrelated, complimentary components.*

## 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 herbicide resistant weeds is a threat that has already had a major deleterious impact on many other cropping systems in Australia and elsewhere.

## Herbicide resistant weeds

Currently, there are 156 weed species and 257 biotypes that have developed resistance to herbicides worldwide. Resistant species occur in 53 different countries.

A total of 37 weed species have developed resistance to a range of herbicides in Australia, some of which are 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.

Some weeds also have multiple resistance, with a single plant containing more than one resistance mechanism, making it resistant to more than one herbicide. Weeds with multiple resistance can be very difficult to control with herbicides.

Four weed species have developed resistance to glyphosate as shown in Table 2. More weeds can be expected to develop resistance to glyphosate if it becomes the primary method of weed control in a farming system.

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

| Weed | Species | Herbicide mode of action | Herbicide Group | Examples[1] |
|---|---|---|---|---|
| Wild oats | *Avena fatua and sterilis* | Inhibitors of acetyl coA carboxylase | A | Hoegrass |
| Wild turnip | *Brassica tournefortii* | Inhibitors of acetolactate synthase | B | Glean |
| Brome grass | *Bromus diandrus* | Inhibitors of acetyl coA carboxylase | A | Nugrass |
| Dirty dora | *Cyperus difformis* | Inhibitors of acetolactate synthase | B | Londax |
| Paterson's curse | *Echium plantagineum* | Inhibitors of acetolactate synthase | B | Logran |
| Black bindweed | *Fallopia convolvulus* | Inhibitors of acetolactate synthase | B | Glean |
| Fumitory | *Fumaria convolvulus* | Inhibitors of tubulin formation | D | trifluralin |
| Prickly lettuce | *Lactuca serriola* | Inhibitors of acetolactate synthase | B | Ally |
| Wimmera ryegrass | *Lolium rigidum* | Inhibitors of acetyl coA carboxylase | A | Glean |
| | | Inhibitors of acetolactate synthase | B | diuron |
| | | Inhibitors of photosystem II | C | trifluralin |
| | | Inhibitors of tubulin formation | D | amitrole |
| | | Inhibitors of carotenoid biosynthesis | F | glyphosate |
| | | Inhibitors of EPSP synthase | M | Fusilade |
| Paradoxa grass | *Phalaris paradoxa* | Inhibitors of acetyl coA carboxylase | A | Verdict |
| Wild radish | *Raphanus raphanistrum* | Inhibitors of acetolactate synthase | B | Ally |
| | | Inhibitors of photosystem II | C | atrazine |
| | | Inhibitors of carotenoid biosynthesis | F | amitrole |
| Turnip weed | *Rapistrum rugosum* | Inhibitors of acetolactate synthase | B | Ally |
| Charlock | *Sinapis arvensis* | Inhibitors of acetolactate synthase | B | Glean |
| Indian hedge mustard | *Sisymbrium orientale* | Inhibitors of acetolactate synthase | B | Glean |
| Sowthistle | *Sonchus oleraceus* | Inhibitors of acetolactate synthase | B | Glean |
| Liverseed grass | *Urochloa panicoides* | Inhibitors of photosystem II | C | atrazine |

(List compiled from Chris Preston, Weeds CRC, Adelaide and Ian Heap, USA 2002 www.weedscience.org)
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 (Group M).*

| Weed | Species | Country |
|---|---|---|
| Annual ryegrass [redacted] | *Lolium rigidum* | Australia (NSW, VIC, SA and WA), USA (California), & South Africa |
| Italian ryegrass | *Lolium multiflorum* | Chile |
| Goosegrass (crowsfoot grass) | *Eleusine indica* | Malaysia [redacted] |
| Horseweed (Fleabanes in Australia) | *Conyza canadensis* | USA (Delaware) |

(Adapted from: Ian Heap 2002 www.weedscience.org)

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

The use of a combination of different weed control methods in Australian cotton fields (IWM) has up to this point prevented the appearance of resistant weed populations. 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 over reliance on one type of weed control method could quickly change this situation.

## Components of Integrated Weed Management in cotton:

1. **Scouting**
   Regularly check fields (cotton and rotations), 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 are not controlled by a herbicide must be controlled by some other method before they are able to set seed. Weeds may need to be closely examined, as some are capable of setting seed while the weeds are 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® 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 positively identified.

4. **Closely follow herbicide recommendations**
   No herbicide controls every weed. Ensure that the herbicide you use will control the target weeds at the rates you are using. Ensure that the appropriate wetters, correct nozzles, nozzle pressure and water volumes are used. Always consider weather conditions and never spray when there is a risk of the herbicide moving off-target.

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. **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.

7. **Rotating herbicide groups**
   All herbicides are classified into groups, ranging from A to N, 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 K have a

moderate risk level and groups L to N are low risk, although resistant weeds already exist for some of these herbicides. 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 C2 in WEEDpak for more information.

8. 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 potential 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.

9. Herbicide tolerant cotton varieties
Consider 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 before setting seed. Herbicide resistance MUST be prevented. Detailed information on the use of Roundup tolerant, Roundup Ready cotton, is given in Monsanto's "Roundup Ready® Cotton technical Manual" and in Managing Roundup Ready Cotton, section E2 in WEEDpak.

10. 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.

11. Shielded spraying
Utilise shielded sprayers with non-selective herbicides such as glyphosate and Spray.Seed® (a mixture of paraquat+diquat) to control herbicide tolerant weeds and reduce the need for chipping 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.

12. Hand chipping
Hand chipping is one of the most effective weed management tools for preventing the development of herbicide resistant weeds. Hand chipping 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 chipping 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.

13. 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.

14. 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.

15. 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.

16. 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.

17. 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.

18. 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.

19. 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.

20. 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.

21. 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 (non-Roundup Ready varieties only) or Spray.Seed (ground-rig application only). Drop-Ultra can also assist with defoliation and subsequent weed control.

22. 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.

### Herbicide Tolerant Crops – WARNING!

A range of herbicide tolerant crops is being developed throughout the world. Australia will see many of these crops over the next decade. Triazine and imazapic + imazapyr tolerant canola (Clearfield®) are already widely grown in Australia. There are also plans to introduce imazapic + imazapyr tolerant wheat varieties and both glyphosate and glufosinate tolerant canola varieties into Australia.

The introduction of glyphosate tolerant cotton (Roundup Ready® cotton) brings herbicide tolerance technology to cotton fields and offers both advantages and potential problems. Roundup tolerance can be a very useful tool when incorporated into an IWM program, but will lead to problems if the technology is used to replace IWM. Reliance solely on the use of glyphosate in any system will inevitably lead to a species shift and may lead to the development of glyphosate resistant weeds.

**Always utilise the IWM principles when growing Roundup Ready® cotton.**

**Always ensure weeds that survive an application of glyphosate do not set seed.**

It is essential that Roundup Ready® crops be scouted soon after the last Roundup application to assess whether any weeds have survived the Roundup applications (scouting). This must occur before new weeds have had a chance to emerge. It is then essential that any survivors be controlled using a method other than a glyphosate application before they set seed. Survivors can be controlled by a different herbicide, cultivation or chipping (response).

This approach (scouting and response) is the most effective resistance management plan possible and should prevent the build-up of herbicide resistant weeds. It will work equally well in conventional crops, and results in a more effective and responsive weed management system.

Tables 3 and 4 are examples of the range of IWM options that should be considered with back to back plantings or cotton/rotation crop plantings.

## 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 techniques together such that each technique compliments the other. 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**

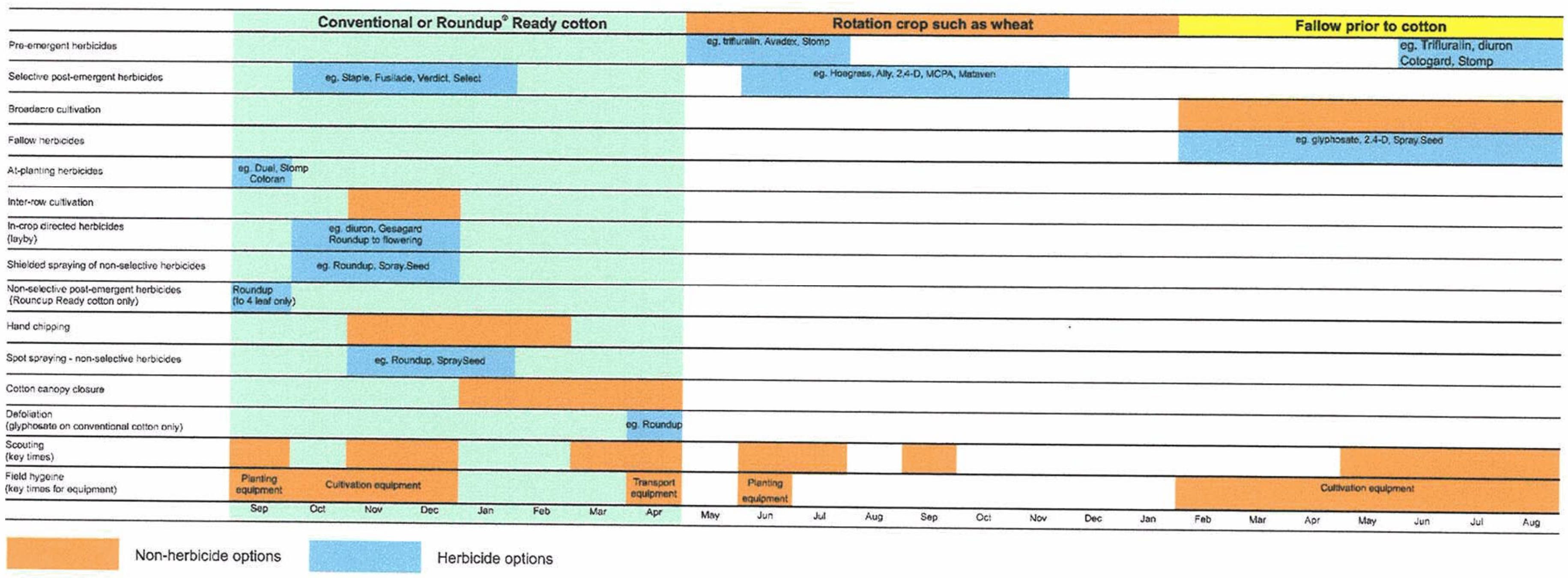
*Table 3. Integrated weed management calendar for back-to-back cotton. The timing of operations will vary between seasons and regions.*

| | Conventional or Roundup® Ready cotton (Sep–Apr) | Fallow (May–Aug) | Conventional or Roundup Ready® cotton (Sep–Apr) |
|---|---|---|---|
| Pre-emergent herbicides | | eg. Trifluralin, diuron Cotogard, Stomp | |
| Selective post-emergent herbicides | eg. Staple, Fusilade, Verdict, Select | | eg. Staple, Fusilade, Verdict, Select |
| Broadacre cultivation | | | |
| Fallow herbicides | | eg. Glyphosate, Spray.Seed, 2,4-D | |
| At-planting herbicides | eg. Dual, Stomp Cotoran | | eg. Dual, Stomp Cotoran |
| Inter-row cultivation | | | |
| In-crop directed herbicides (layby) | eg. diuron, Gesagard Roundup to flowering | | eg. diuron, Gesagard Roundup to flowering |
| Shielded spraying of non-selective herbicides | eg. Roundup, Spray.Seed | | eg. Roundup, Spray.Seed |
| Non-selective post-emergent herbicides (Roundup Ready cotton only) | Roundup (to 4 leaf only) | | Roundup (to 4 leaf only) |
| Hand chipping | | | |
| Spot spraying - non-selective herbicides | eg. Roundup, SpraySeed | | eg. Roundup, SpraySeed |
| Cotton canopy closure | | | |
| Defoliation (glyphosate on conventional cotton only) | eg. Roundup | | eg. Roundup |
| Scouting (key times) | | | |
| Field hygeine (key times for equipment) | Planting equipment; Cultivation equipment; Transport equipment | Cultivation equipment | Planting equipment; Cultivation equipment; Transport equipment |
| | Sep Oct Nov Dec Jan Feb Mar Apr | May Jun Jul Aug | Sep Oct Nov Dec Jan Feb Mar Apr |

Non-herbicide options — Herbicide options

WEEDpak

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



# 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 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.

Weed control in pigeon pea trap crops is covered in an article devoted to this topic.

## 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 National Registration Authority (refer to CRDC or the NRA 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.

# HERBICIDES FOR PIGEON PEA TRAP CROPS

**Graham Charles**
(NSW Agriculture)

Contents | Page



*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 pendimethalin (Stomp 330 E®, StompXtra ®, and Pendimethalin 330 EC®) in pigeon peas is covered by registration. A range of other products (as indicated below) may be used under permit (contact CRDC for details). 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 for use with pigeon pea trap crops grown in conjunction with Ingard 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 | | |
| pendimethalin (455 g/L) @ 1.8 to 2.2 L/ha | Falcon WG (250 g/kg) @ 180 g/ha | prometryn (500 g/L) @ up to 4.5 L/ha |
| trifluralin (400 g/L) @ up to 2.8 L/ha | Fusilade (212 g/L) @ 1 L/ha | prometryn (900 g/kg) @ up to 2.5 kg/ha |
| trifluralin (480 g/L) @ up to 2.3 L/ha | Sertin Plus (120 g/L) @ 1.6 L/ha | |
| prometryn (500 g/L) @ up to 4.5 L/ha | Verdict (130 g/L) @ 0.6 L/ha | |
| prometryn (900 g/kg) @ up to 2.5 kg/ha | Sencor 480 (480 g/L) @ 750 ml/ha | |
| Sencor 480 (480 g/L) @ 750 ml/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 Ingard® 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 |
| Treflan | 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).*

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 Ingard 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.

*Another weedy pigeon pea crop infested with broad-leaf weeds including wild sunflower and sesbania.*

## 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 | Weed index 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 Trifluralin. 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.*

| Treatment | 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.*

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.

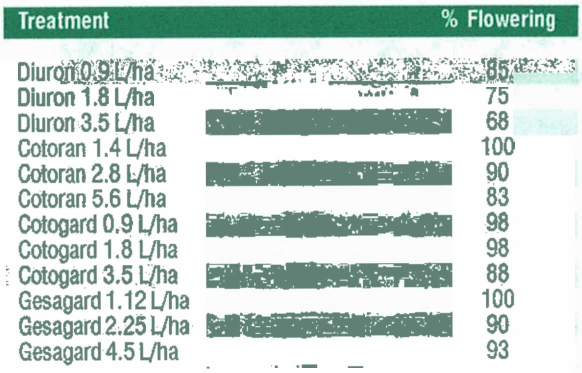
All the broad-leaf herbicides damaged the pigeon peas, with diuron causing the most damage and Gesagard the least damage (Table 5).

*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.*




## 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 National Registration Authority (refer to CRDC or the NRA 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.

## 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 about 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 in the first season of application. Nevertheless, some polymeria shoots are still emerging after three seasons of applications. Grazon is suited to spot-applications in fallow fields and non-cotton areas.

*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).*

| Treatment | Initial<br>10 Dec 99 | Visual assessment of weed rating at:<br>208 days<br>5 Jul 00 | 678 days<br>18 Oct 01 | 861 days<br>19 Apr 02 |
|---|---|---|---|---|
| Untreated | 33 | 43 | 40 | 77 |
| Roundup CTXtra 6 L/ha (Sept) | 47 | 60 | 50 | 77 |
| Roundup CTXtra 6 L/ha (Sept & Dec) | 87 | 23 | 37 | 43 |
| Roundup CTXtra 6 L/ha (Nov & Jan) | 53 | 3 | 20 | 17 |
| Roundup CTXtra 6 L/ha (Mar) | 70 | 30 | 40 | 77 |
| Roundup CTXtra 6 L/ha (Sept, Dec & Mar) | 47 | 20 | 0 | 1 |
| Roundup CTXtra 18 L/ha (Nov) | 23 | 10 | 58 | 53 |
| Roundup CTXtra 18 L/ha (Nov & Jan) | 60 | 3 | 1 | 0 |
| Starane 2 L/ha (Mar) | 50 | 32 | 57 | 63 |
| Starane 2 L/ha (Dec & Feb) | 33 | 0 | 2 | 5 |
| Grazon 2 L/ha (Dec & Feb) | 80 | 3 | 1 | 2 |
| Tordon 75D 3 L/ha (Mar) | 33 | 3 | 2 | 43 |

*Glyphosate can be an effective tool for in-crop management of polymeria. At this crop stage, glyphosate must be applied using spray shields to prevent the herbicide contacting the crop foliage.*

## Glyphosate (eg. Roundup®)

Glyphosate kills most plants, including conventional cotton. 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 cotton. Glyphosate can be applied pre-cotton emergence, in-crop as a shielded spray, at defoliation, or after picking.

Roundup can be applied over-the-top of Roundup Ready cotton up to the 4th true cotton leaf stage, but must not be applied to the foliage of older Roundup Ready plants. Roundup must be applied as a directed or shielded spray after the 4th leaf stage. Glyphosate cannot be applied to Roundup Ready cotton at defoliation.

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

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.

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.
- glyphosate cannot be effectively applied to the cotton plant-line, as conventional cotton is not tolerant of glyphosate. Roundup can be applied to Roundup Ready cotton up to the 4th true leaf of the crop.
- polymeria can re-establish from seed.

## Glyphosate rate

Glyphosate is generally ineffective in controlling polymeria when applied at rates of 1 or 2 L/ha, but control improves as rates are increased (Tables 4). Similar results were observed in the field, where Roundup CT was applied as an in-crop, directed spray (Table 5), and in actively growing polymeria in a fallow (Table 6).

*Table 4. 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 |
| 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 |
| Atrazine 5 L/ha | 1015 | 43 |
| Atrazine 10 L/ha | 585 | 77 |
| Basagran 2 L/ha | 898 | 49 |
| Basagran 6 L/ha | 551 | 69 |

*Table 5. Polymeria control in cotton using directed spray applications. Weed density was assessed 19 and 60 days after treatment.*

| Treatment (applied Jan 17, 1997) | Weed rating after 19 days | 60 days |
|---|---|---|
| Untreated | [redacted] | [redacted] |
| Roundup CT 4 L/ha | [redacted] | [redacted] |
| Roundup CT 8 L/ha | 33 | 37 |
| Roundup CT 16 L/ha | 7 | 17 |

Glyphosate rates between 3 and 6 L/ha 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 6).

Results from repeated applications in fallow have been very variable, with multiple applications 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.

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.

*Table 6. 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 |

Split applications of glyphosate 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 split application of 4 L/ha in November and January (Table 7). Poorer control was observed from 3 applications of 4 and 8 L/ha.

*Table 7. Control of polymeria using in-crop directed spray applications of glyphosate. 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 | Weed rating after 104 days | 364 days |
|---|---|---|---|---|---|
| Untreated | - | - | - | 97 | 75 |
| Roundup CT | 4 | - | - | 100 | 85 |
| Roundup CT | 8 | - | - | 100 | 85 |
| Roundup CT | | 4 | 4 | 43 | 22 |
| Roundup CT | 4 | 4 | 4 | 53 | 43 |
| Roundup CT | 8 | 8 | 4 | 33 | 37 |

The reduction in control caused by the additional herbicide application probably occurred because the first October application was ineffective in controlling the polymeria (possibly due to cool temperatures), but stressed the weed, making it less receptive to the November application.

Aside from the direct effect on the polymeria, the Roundup 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 on the polymeria patches. The additional yield on these plots easily justified the expense of the herbicide application. The degree of polymeria control with Roundup was primarily limited by the need to apply the herbicide as a shielded spray, leaving unsprayed polymeria in the cotton row.

## Timing of glyphosate applications

Glyphosate applications during December and January have generally been the most effective, with poorer results from earlier applications (Table 7).

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 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.

Similarly variable results were observed from a second in-crop experiment, were plots were sprayed over two seasons (Table 8). The best results where 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 also gave a reasonable result. Overall, polymeria density was substantially reduced on the trial area over the 2 seasons, with some evidence of Roundup translocating well beyond the treated areas.

*Glyphosate is effective in controlling polymeria in-crop, enabling the crop to establish and yield even in thickly infested patches.*

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.

*Table 8. Control of polymeria using repeated shielded applications of Roundup in the cotton crop. Applications were made in December 1998, and January and February 1999. Weed density was assessed 64, 372 and 483 days after the December 1998 treatment.*

| Treatment | Application date(s) Dec | Jan | Feb | Visual assessment of weed rating 64 days | 372 days | 483 days |
|---|---|---|---|---|---|---|
| Untreated | - | - | - | 70 | 62 | 94 |
| Roundup CTXtra | - | | 3 L/ha | 76 | 38 | 43 |
| Roundup CTXtra | - | 3 L/ha | 3 L/ha | 80 | 58 | 67 |
| Roundup CTXtra | 3 L/ha | 3 L/ha | 3 L/ha | 54 | 48 | 49 |
| Roundup CTXtra | - | - | 6 L/ha | 72 | 43 | 45 |
| Roundup CTXtra | - | 6 L/ha | 6 L/ha | 32 | 26 | 25 |
| Roundup CTXtra | 6 L/ha | 6 L/ha | 6 L/ha | 45 | 56 | 48 |
| Roundup CTXtra | - | - | 12 L/ha | 100 | 39 | 28 |
| Roundup CTXtra | - | 12 L/ha | 12 L/ha | 43 | 31 | 32 |
| Roundup CTXtra | 12 L/ha | 12 L/ha | 12 L/ha | 43 | 50 | 41 |

One of the main difficulties encountered in these experiments was unacceptable damage to the cotton, 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 3 L/ha could achieve much improved cotton yields and a year-by-year reduction in the polymeria infestation.

## Additives to enhance glyphosate efficacy

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 is available for use with glyphosate, some of which may improve 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 9), while the addition of Turbo® Plus at 5% improved control in a second experiment (Table 10). The control from Roundup CTXtra without additive was also very good in both experiments.

*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).*

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.

*Tables 9. Polymeria control in a pot trial using Roundup CTXtra with extra 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% Pulse | 0 | 100 |
| Roundup CTXtra @ 3 L/ha + 1% Turbo Plus | 898 | 82 |
| Roundup CTXtra @ 3 L/ha + 1% Bond | 3425 | 33 |

A lower rate of glyphosate was used in a third experiment (Table 11), 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 10. Polymeria control in a pot trial using Roundup CTXtra and extra 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 | 9[illegible] |
| Roundup CTXtra 3 L/ha + 0.2% Pulse | 426 | 9[illegible] |
| Roundup CTXtra @ 3 L/ha + 1% Pulse | 104 | 9[illegible] |
| Roundup CTXtra @ 3 L/ha + 5% Pulse | 145 | 9[illegible] |
| Roundup CTXtra @ 6 L/ha + 1% Turbo Plus | 544 | 9[illegible] |
| Roundup CTXtra @ 3 L/ha + 5% Turbo Plus | 0 | 100 |
| Roundup CTXtra @ 3 L/ha + 5% Bond | 292 | 96 |

*Table 11. 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 C[redacted]@ 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 |

## 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 12).

*Table 12. 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 |

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.

## 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. Results have been generally poor from applications to moisture stressed polymeria, and in cool spring conditions,
- at-planting applications of glyphosate have enabled cotton to establish in polymeria patches,
- in-crop glyphosate applications must be through well constructed shielded sprayers, with competent operators. High rates of glyphosate can cause unacceptable damage to cotton when poorly applied,
- spot-spraying is the preferred in-crop option, minimising the risk of accidental damage to cotton, and
- attention to crop agronomy is important to enable satisfactory cotton establishment and growth in polymeria 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 4). Control improved to 94% when Starane was applied at 6 L/ha.

Poor results in the field were observed with Starane at 1 and 2 L/ha sprayed in December (Table 13), and at 2 and 6 L/ha sprayed in October (Table 2). A single application of Starane at 2 L/ha in March also gave poor results, but good control was achieved with repeated applications of 2 L/ha in December and February (Table 3) (both sets of applications were repeated over 3 seasons). Growers report that best results have generally been achieved with applications in February and March.

*Table 13. Polymeria control in fallow, sprayed on December 22, 1987, and assessed after 65 days. This trial was conducted by Max McMillan.*

| Treatment | Weed rating after 65 days |
|---|---|
| Untreated | 90 |
| 2,4-D Amine 1 L/ha | 78 |
| 2,4-D Amine 2 L/ha | 56 |
| 2,4-DP 1.7 L/ha | 88 |
| 2,4-D Amine 1 L/ha + Ally 10 g/ha | 84 |
| MCPA Amine 1 L/ha | 78 |
| Basta 3 L/ha | 94 |
| Starane 1 L/ha | 46 |
| Starane 2 L/ha | 38 |

As with all herbicide applications, some viable polymeria rhizomes remain after treatment. A polymeria management plan based on Starane will require repeated strategic applications and spot treatments over many seasons.

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.

## 2,4-D amine

2,4-D amine has been widely trialled for controlling polymeria. It is 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 substantiated. 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 14.

*Table 14. 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 | Weed rating at 112 days |
|---|---|
| Untreated | 23 |
| 2,4-D Amine 2 L/ha | 0 |
| 2,4-D Ester 1.25 L/ha | 1 |
| Dicamba 1.4 L/ha | 24 |
| Roundup 2 L/ha | 13 |
| Tordon 50-D 1.4 L/ha | 1 |
| Roundup 2 L/ha + 2,4-D Ester 1.5 L/ha | 0 |
| Tordon 50-D 1.4 L/ha + 2,4-D Amine 2 L/ha | 1 |
| Tordon 50-D 1.4 L/ha + Dicamba 1.4 L/ha | 1 |
| Dicamba 1.4 L/ha + 2,4-D Amine 2 L/ha | 1 |
| Weedazol TL Plus 5.6 L/ha | 13 |
| Glean 30 g/ha | 34 |

However, the weed may 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 (Table 15). 2,4-D amine applied at 1 or 2 L/ha earlier in the season also gave no long-term control of polymeria (Table 13). Further work is being undertaken to evaluate the long-term control of polymeria with 2,4-D.

*Table 15. Polymeria control using a range of herbicide combinations in a fallow, sprayed on June 26, 1995.*

| Treatment | Visual assessment of weed rating 104 days | 340 days |
|---|---|---|
| Untreated | 41 | 51 |
| 2,4-D Amine 4 L/ha | 27 | 49 |
| Roundup 4 L/ha | 26 | 64 |
| Starane 2 L/ha | 31 | 60 |
| Roundup 1.5 L/ha + 2,4-D Amine 2 L/ha | 38 | 43 |
| Roundup 3 L/ha + 2,4-D Amine 2 L/ha | 35 | 63 |
| Roundup 1.5 L/ha + 2,4-D Ester 1.5 L/ha | 29 | 52 |
| Roundup 2 L/ha + Goal 0.75 L/ha | 62 | 67 |
| Roundup 1.5 L/ha + Starane 1 L/ha | 34 | 36 |

*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.*

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.

## Using 2,4-D in the field

The opportunity to apply 2,4-D 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 this herbicide,
- 2,4-D must be applied to actively growing polymeria. Polymeria growing in cotton will be moisture stressed, and not likely to respond to herbicide unless rain occurs at picking, and,
- 2,4-D must be applied before frosts in autumn burn off the foliage, stressing the plant.

## Herbicide combinations

Combinations of Roundup and 2,4-D, and Roundup and Starane were trialled, but gave no improvement in control (Table 15). 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.

## Summary

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 National Registration 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.

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.

# A grower's experience with polymeria

## Polymeria (take-all) control on Colly Farms

**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. **Fluroxypyr (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 fluroxypyr 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.

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 crop.

The improvements in crop yields after treatment would probably have been even better if better designed equipment and/or Roundup Ready 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. This is equally true whether using conventional or Roundup Ready cotton varieties.

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 (kg/ha) | Tubers /m² | Lint yield |
|---|---|---|---|---|---|
| 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 (kg/ha) | Tubers /m² | Lint yield |
|---|---|---|---|---|---|
| 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 (L or Kg /ha) | Rate | Applications | Tubers/m² (kg/ha) | Lint yield |
|---|---|---|---|---|---|
| 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 cotton in a heavy nutgrass infestation. Treatments directly used for nutgrass control are shown in bold type. An additional glyphosate application could replace the deep ripping operation if the soil is wet and the nutgrass is actively growing.*

| | Operation | Crop |
|---|---|---|
| September | **cultivation**<br>planting | Cotton |
| October | | |
| November | **MSMA application**<br>inter-rowcultivation | |
| December | **glyphosate application** | |
| January | **glyphosate application**<br>lay-by herbicide | |
| February | | |
| March | **glyphosate application at defoliation** | |
| April | picking<br>slashing | |
| May | **deep ripping**<br>**Zoliar application**<br>**incorporation** | Fallow |
| June | listing | |
| 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 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 adequately effective.

*Table 23. A management plan for back-to-back Roundup Ready cotton in a heavy nutgrass infestation. Treatments directly used for nutgrass control are shown in bold type. An additional glyphosate application could replace the deep ripping operation if the soil is wet and the nutgrass is actively growing.*

| | Operation | Crop |
|---|---|---|
| September | **cultivation**<br>planting | Cotton |
| October | | |
| November | **Roundup application**<br>inter-row cultivation | |
| December | **Roundup application** | |
| January | **Roundup application**<br>lay-by herbicide | |
| February | | |
| March | defoliation | |
| April | picking<br>slashing | |
| May | **deep ripping**<br>**Zoliar application**<br>**incorporation** | Fallow |
| June | listing | |
| 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 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 of nutgrass over time. Glyphosate should ideally be applied in-crop twice each season. It must be applied through a well constructed, properly set up shielded sprayer, operating under favourable conditions, when applied in conventional cotton. Roundup Ready Herbicide can be applied with much greater safety in Roundup Ready 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 Zollar, which was incorporated into the control program. The worst areas were attacked first. The cost of Zollar 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. Zollar was applied both at planting and picking and it was discovered that it wasn't until about the third year into the Zollar 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.

Zollar 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 Zollar 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 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 Zollar 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.

Zollar 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, howerver the results are encouraging.

# MANAGING POLYMERIA (TAKE-ALL) IN COTTON

**Graham Charles and Stephen Johnson**
**(NSW Agriculture & University of New England)**

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, which occurs through many of the Queensland and New South Wales cotton growing areas. 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 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.*

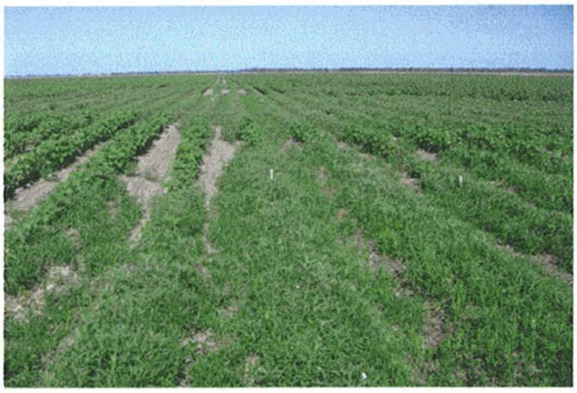
Polymeria can grow all year round in warmer areas, but is frost sensitive and is burnt by frosts. Some shoots will persist through winter

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.

and new shoots 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/m² or more can reduce cotton yield by 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.



*Polymeria forms dense patches. Cotton generally doesn't grow to maturity in these patches.*

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 should be 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.

*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 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 on polymeria, over a number of seasons with mixed and often poor results. Many herbicides will 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.

No herbicides are registered for controlling polymeria.

Best results have been obtained with applications of Arsenal, Grazon, Roundup, and Starane. A range of other herbicides, including Ally, Atrazine, Basagran, dicamba, Garlon, Glean, and Staple have been trialled, but do not satisfactorily control polymeria. Assessment of the efficacy of 2,4-D is continuing.

**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, polymeria persisted in areas sprayed with Arsenal, even when applied at rates as high as 6 L/ha.

*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) 20 Dec | Application(s) 15 Jan | Weed rating[1] after 63 days |
|---|---|---|---|
| Untreated | | | 100 |
| Roundup CT | 2.4 L/ha | | 80 |
| Roundup CT | | 2.4 L/ha | 57 |
| Roundup CT | 2.4 L/ha | 2.4 L/ha | 47 |
| Staple | | 240 g/ha | 100 |
| Staple | 120 g/ha | 120 g/ha | 93 |
| Arsenal | 0.5 L/ha | | 50 |
| Arsenal | 1 L/ha | | 47 |
| Arsenal | 2 L/ha | | 17 |

*Weed rating[1] is a percentage rating from 0 (no live polymeria) to 10 (100% of plot covered in live plants) based on a visual estimation.*

*Table 2. Polymeria control in fallow, sprayed on October 10, 1996. Treatments were assessed after 97 and 376 days.*

| Treatment | Weed rating after 97 days | Weed rating after 376 days |
|---|---|---|
| Untreated | 100 | 90 |
| Arsenal 2 L/ha | 21 | 17 |
| Arsenal 6 L/ha | 8 | 1 |
| Starane 2 L/ha | 42 | 64 |
| Starane 6 L/ha | 30 | 35 |
| Garlon 100 mL/ha | 83 | 76 |
| Garlon 300 mL/ha | 56 | 73 |
| Glean 20 g/ha | 48 | 47 |
| Glean 60 g/ha | 94 | 100 |
| Ally 10 g/ha | 71 | 36 |
| Ally 30 g/ha | 70 | 76 |
| Express 30 g/ha | 78 | 76 |
| Express 90 g/ha | 64 | 54 |

***Arsenal must never be used in a crop area.***

*Arsenal used to control polymeria on a channel bank.*

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.

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 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.*

## Herbicide efficacy on the major species

Zollar is effective against all nutgrass species, as it is effective against both tubers and seedlings. Heavy rates of Zollar are necessary to control plants growing from tubers, but much lighter rates of Zollar 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<br>2.8 L | 0<br>25 |
| | Sempra | 70 g<br>140 g | 46<br>100 |
| | Roundup CTXtra | 1 L<br>2 L | 96<br>100 |
| 8 weeks | Daconate | 1.4 L<br>2.8 L | 0<br>0 |
| | Sempra | 70 g<br>140 g | 8<br>0 |
| | Roundup CTXtra | 1 L<br>2 L | 81<br>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.

*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<br>2.8 L | 29<br>50 |
| | Sempra | 70 g<br>140 g | 67<br>75 |
| | Roundup CTXtra | 1 L<br>2 L | 92<br>100 |
| 8 weeks | Daconate | 1.4 L<br>2.8 L | 44<br>50 |
| | Sempra | 70 g<br>140 g | 11<br>25 |
| | Roundup CTXtra | 1 L<br>2 L | 94<br>100 |

Glyphosate gave good control of all species at both growth stages, although results in the field are not always so consistent.

*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 | 100 |
| | | 2.8 L | 75 |
| | Sempra | 70 g | 69 |
| | | 140 g | 100 |
| | Roundup CTXtra | 1 L | 87 |
| | | 2 L | 100 |
| 8 weeks | Daconate | 1.4 L | 42 |
| | | 2.8 L | 50 |
| | Sempra | 70 g | 0 |
| | | 140 g | 37 |
| | Roundup CTXtra | 1 L | 100 |
| | | 2 L | 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 Zollar 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/m². Specific permit permission must be obtained from the NRA before pesticides can be used outside the label recommendation.*

| | Rate/ha | Tubers per m² | 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. The 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/m², but will have only about 2200 shoots/m². 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 shielded 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.

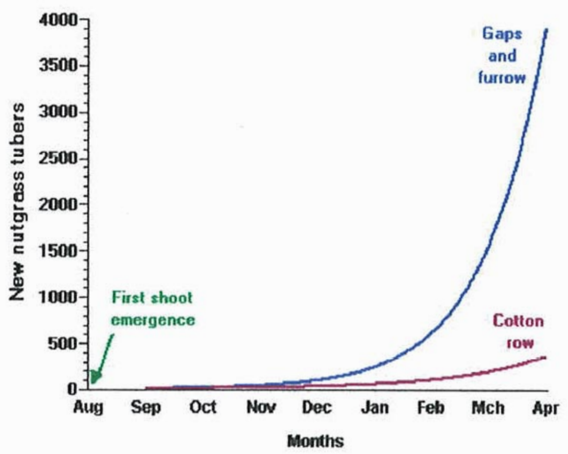



*Figure 1. Nutgrass tuber production in cotton starting from a single tuber in spring. Nutgrass is intolerant of shading and produces fewer tubers in the cotton row.*

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.

## 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.

*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 |

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.

## 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. Higher 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.

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.

*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 |

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 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 not be used with over-the-top glyphosate applications to Roundup Ready® 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 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 some 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 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 L 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 in December, with a follow-up application of glyphosate in January. Both applications must be made through a shielded sprayer. 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 cotton, which can be sprayed over-the-top with Roundup up to the fourth true leaf, in compliance with the product label.

Glyphosate can be applied in-crop 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.

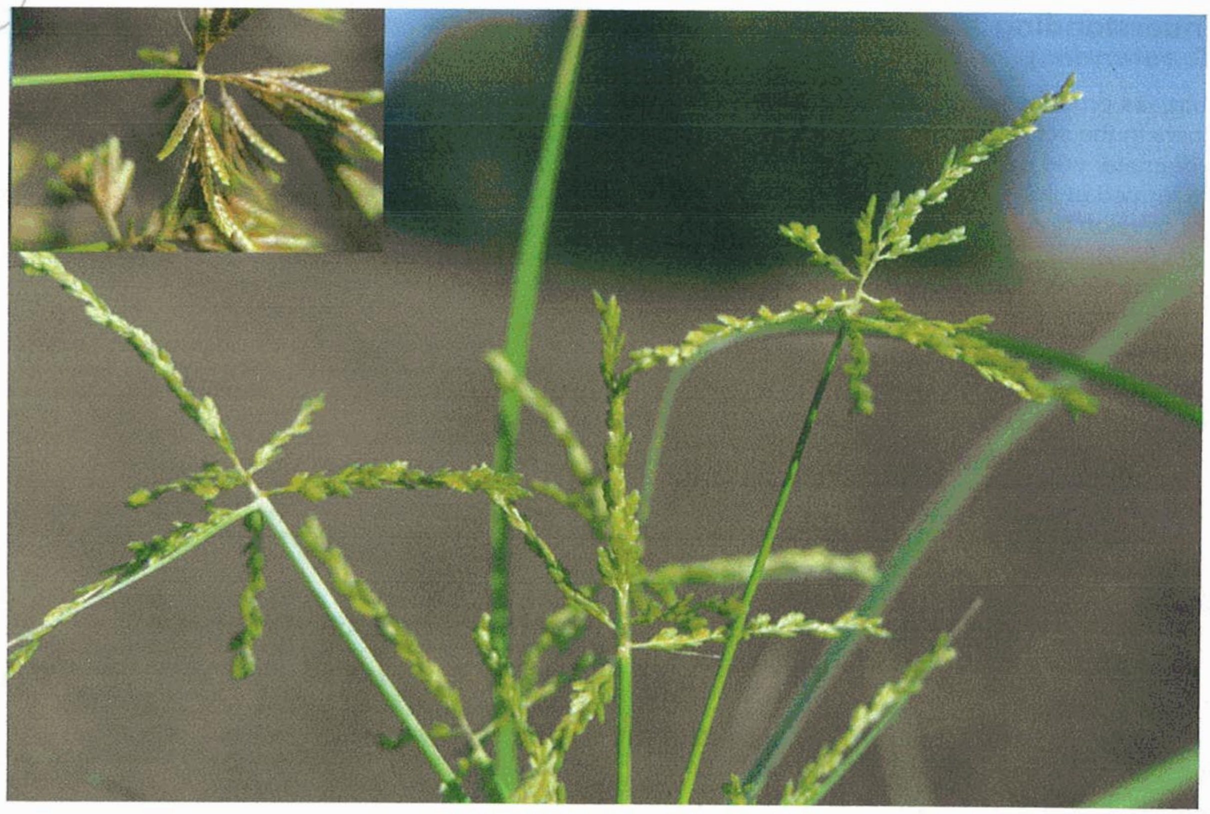
Results from field experiments conducted over a number of seasons and a number of sites are shown in Tables 18 to 21. These results allow comparison of some treatments and treatment combinations.

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.

*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.*

## 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 1 m 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 cr~~acks 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 truncuienta*). 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 only be managed using a long-term, integrated weed management (IWM) approach. 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 for Australian Cotton Production 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.

*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.*

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.

## Residual herbicides

### Norflurazon (Zoliar®, Group F)[1]

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[2]. 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.

*1 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** *in* **WEEDpak**.
*2 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.*

Zollar'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.

Zollar 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 Zollar 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 Zollar 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.*

Zollar 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. Zollar also has the advantage of being equally effective across both hills and furrows.

*The wheat in this patch was killed by Zoliar that was applied in an earlier season.*

In addition to controlling nutgrass, Zollar controls a broad range of grass and broadleaf weeds. Zollar is relatively expensive, but the cost can be partly offset by substituting Zollar 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 Zollar.

Unfortunately, Zollar 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. Zollar 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<br>Temperature (°C) | 14 | 22 | 26.5 |
| Yield reduction (%) | 20 | 22 | 26 |
| 22 December<br>Temperature (°C) | 19.9 | 26 | 35 |
| Yield reduction (%) | 24 | 22 | 19 |

## 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.

*Sempra® applied through a shielded sprayer (foreground plot) controlled nutgrass in the furrow (sprayed area), but gave little control of the unsprayed plant-line.*

*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, 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. Roundup Ready Herbicide® can be applied over-the-top of Roundup Ready® cotton up to the $4^{th}$ true cotton leaf, but must not be applied to the foliage of older Roundup Ready plants. Glyphosate cannot be applied to Roundup Ready cotton at defoliation. For more information, refer to Managing Roundup Ready® Cotton and SPRAYpak/ Spray Application in WEEDpak.

# MANAGING COWVINE IN COTTON

**Graham Charles**
**(NSW Agriculture)**

**Contents** | **Page**



*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.*

## 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 plebela*) 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 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 | | 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/m² in the 0 – 30 cm soil zone. Seeds occur predominantly in this soil zone (0 – 30 cm) in a cultivated field, corresponding to the plow-zone, although some seeds may be 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.*

| 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. Seeds deeper than 5 cm in the soil may emerge through soil cracks, or emerge after re-distribution in the soil profile following deep cultivation or re-listing of a field. This means that only about 25% of the cowvine seeds present in an infested field are potentially able to germinate at any one time. In a field infested with 1500 seeds/m² for example, this would equate to 375 seedlings/m² 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.

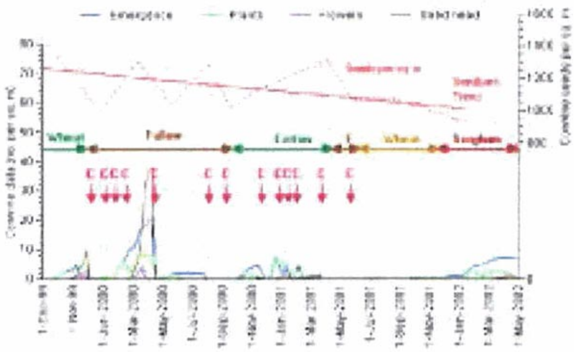



*Figure 1. Population dynamics of cowvine in an irrigated cotton field. The cropping sequence over the 3 seasons in indicated. The sorghum crop was grown to allow the use of atrazine herbicide to manage the cowvine problem. Cultivation events are indicated by a "C" with an arrow.*

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/m² over the three seasons. A total of 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/m², in the cotton crop in mid-December, 2000. The cowvine plants that established produced a total of 176 new seeds/m² over the three seasons, with most seeds produced during a summer fallow in March and April 2000.

## Strategies for managing cowvine

Cowvine plants are readily controlled by shallow cultivation (to 5 cm) and herbicides in fallows, and herbicides in 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 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/m² 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 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 3), and herbicide combinations that included these herbicides (Table 4). Of these herbicides, only diuron and prometryn can be safely used in cotton. Atrazine and simazine can be used with some rotation crops.

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.

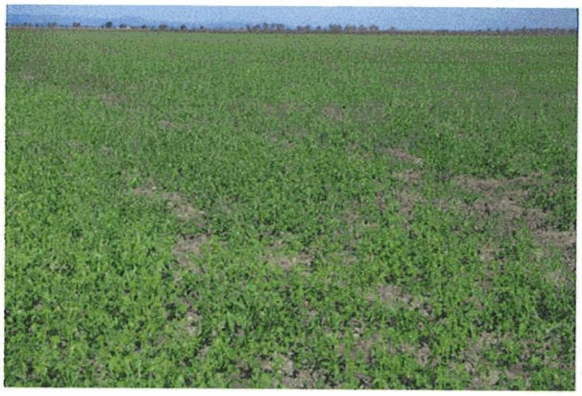
*Table 3. Percentage kill of cowvine plants that emerged on the border of a field following rain in March 2000. Control was assessed on May 1, 28 days after spraying.*

| Treatment | % Weed kill |
|---|---|
| Atrazine 2 L/ha | 97 |
| Atrazine 4 L/ha | 97 |
| Diuron 1 L/ha | 100 |
| Diuron 2 L/ha | 97 |
| Gesagard 1 L/ha | 87 |
| Gesagard 2 L/ha | 87 |
| Grazon 0.25 L/ha | 57 |
| Grazon 0.5 L/ha | 40 |
| Grazon 1.0 L/ha | 90 |
| Simazine 1L/ha | 50 |
| Simazine 2L/ha | 80 |
| Zoliar 1.5 kg/ha | 30 |
| Basta 0.5 L/ha | 63 |
| Basta 1.0 L/ha | 80 |
| Basta 2.0 L/ha | 93 |
| MSMA (800 g/L) 1 L/ha | 7 |
| MSMA (800 g/L) 2 L/ha | 27 |
| Oxytril 0.5 L/ha | 90 |
| Oxytril 1.0 L/ha | 97 |
| Oxytril 2.0 L/ha | 100 |
| Roundup CT 2 L/ha | 20 |
| Roundup CT 4 L/ha | 53 |
| Starane 0.25 L/ha | 20 |
| Starane 0.5 L/ha | 20 |
| Starane 1.0 L/ha | 43 |
| 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 4. Percentage kill of cowvine plants in a fallow using herbicide combinations. Details are given in Table 3.*

| 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/ha | 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 |



*A fallow field heavily infested with cowvine and bladder ketmia. The cowvine plants were very small (below) but 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 are effective in controlling cowvine pre-emergence. Zoliar gives the best suppression of cowvine in cotton, but the results were variable and less than ideal (Table 5).

*Table 5. 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 trials, 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 trials in irrigated cotton at Moree and Dirranbandi (Table 5), but this still left 3 seedlings/m², 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 trial sites gave the best cowvine control with a combination of diuron and Zoliar, or prometryn and Zoliar (Table 6). These combinations gave similar levels of cowvine control, but with improved crop safety, compared to the results from the high levels of diuron and Zoliar alone.

*Table 6. Control of cowvine seedlings with pre-planting, soil incorporated, residual herbicide combinations. Cowvine emergence was recorded from cotton planting to mid-January 2002, on trials, 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 in cotton

Diuron and prometryn are 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 7 and 8, for example). 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.

*Table 7. 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 |

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 8). Staple was ineffective in controlling cowvine, even when applied at the maximum rate. Glyphosate gave poor control at the lower rates, but good control when applied at the highest rate, even on larger plants (Table 8).

*Table 8. 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. 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 ineffective 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 appeared to be the case. The 2 L/ha application of glyphosate (Table 8) 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 9) and 22 leaves (Table 10).

*Table 9. Control of cowvine in a pot trial 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 full spray | 10 Leaves 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 10. Control of cowvine in a pot trial 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<br>2 leaves full spray | 9 leaves full spray | 22 leaves 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 | [redacted] | 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 9 and 10), 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 11). Future work will test the effect of this surfactant on the efficacy of other glyphosate formulations.

*Table 11. Control of cowvine in a pot trial 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<br>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 trial. 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.

*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.*

Similarly variable results were observed with diuron, Cotoran and Gesagard (Tables 7 and 8). 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 could become available for 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 1L/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 much lower rates (Table 3).

These two herbicides have the advantages that they are safe to use at any growth stage on the 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 9 and 10).

## 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 trial 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.

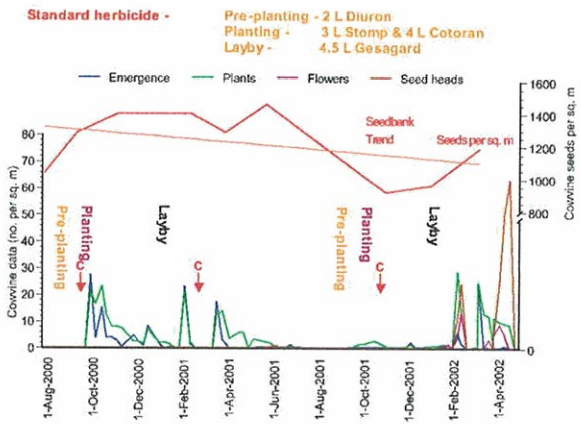



*Figure 2. Population dynamics of cowvine under a standard herbicide regime. Cultivation events are indicated by a "C" with an arrow.*

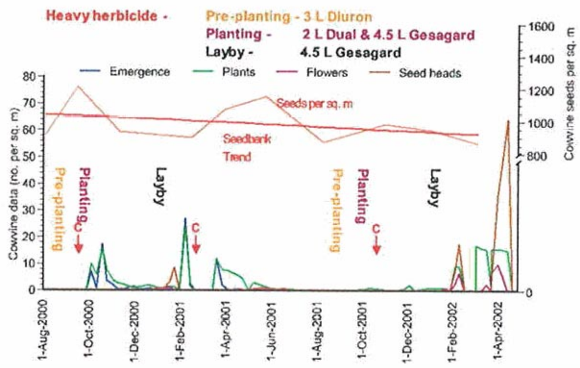



*Figure 3. Population dynamics of cowvine under a heavier herbicide regime. Cultivation events are indicated by a "C" with an arrow.*

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 trial. 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.

# 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: -



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.

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.

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.

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 ENTOpak, 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.

# MANAGING WEEDS ON ROADS, CHANNELS AND WATER STORAGES

Graham Charles, Anne Sullivan, Ingrid Christiansen and Grant Roberts
(NSW Agriculture, QDPI, QDPI & CSIRO)

Contents



## 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 waterlogging, 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.

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

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.

## 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 chippers, 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 the Integrated Weed Management (IWM) Guidelines for Australian Cotton Production and Managing Herbicide Resistance in Cotton 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 by Sandra Deutscher*

*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<br>220 g/L | 0.28 – 4.5 L / 100 L water | Controls a wide range of plants from seedling grasses, at low rates, to perennial grasses at high rates.<br>Controls young broadleaf plants.<br>Check the label for details. |
| diuron | 500g / L SC<br><br><br>800 g / kg WP<br>900 g / kg WG | 70-150 L / ha<br>20-40 L /ha<br><br>45-90 kg / ha<br>22 kg / ha | Qld and WA registration.<br>NSW registration only.<br>Controls most weeds but not brown beetle grass (*Leptochloa fusca*), redshank (*Amaranthus* spp.), and Johnson grass.<br>Check the label for details.<br>Channels must be flushed after application. |
| glyphosate | 360 g / L AC<br>450 g / L AC<br>490 g / L AC<br>680 g / kg | 0.5-9 L / ha<br>0.4-2.4 L / ha<br>0.4-2.0 L / ha<br>1.0-4.5 kg / ha | Controls most weeds. Low rates for annual grasses.<br>High rates for perennials and broadleaves.<br>Mix only as directed on the label.<br>Check label for details, |
| pendimethalin | 330 g / L EC<br>440 g / L EC<br>455 g / L | 4.5-9 L / ha<br>3.4-8.1 L /ha<br>3.3-8.1 L / ha | If 25-50 mm rain has not fallen within 14 days, flush channel (1 day) and drain off. |
| 2,2-DPA | 740 g / kg WP | 10-20 kg / ha | Controls annual and perennial grasses.<br>Controls cumbungi, phragmites, rushes and sedges. |

## 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,
- soil incorporated residual herbicides are difficult to apply 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, and
- 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.

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 Deutscher.*

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 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.

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

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.

## Residual herbicides

The residual herbicides provide longer-term control of weeds, 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 are 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.

Chipping of channels is sometimes done where large weeds such as sesbania, bladder ketmia, the burrs or Roundup Ready cotton 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.

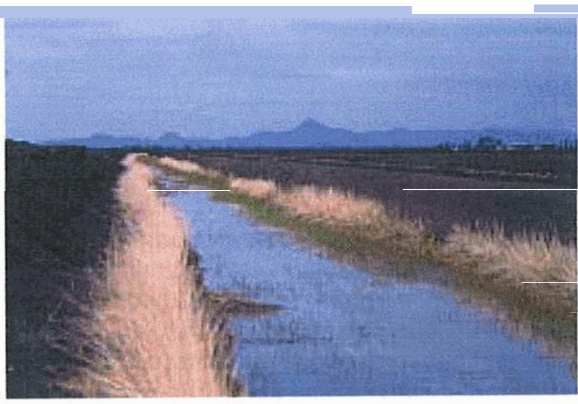
## Common weeds of roads and channels

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 | conventional and Roundup Ready plants |

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.

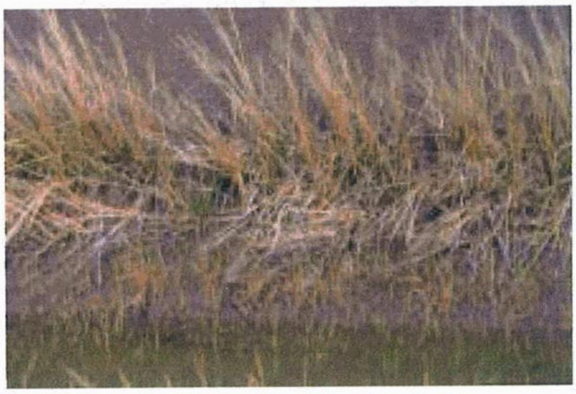


*An irrigation channel heavily infested with brown beetle grass.*

Brown beetle grass is a major weed of irrigation channels and is increasingly becoming a problem in cotton. 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 some 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 Zollar. Brown beetle grass is 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.



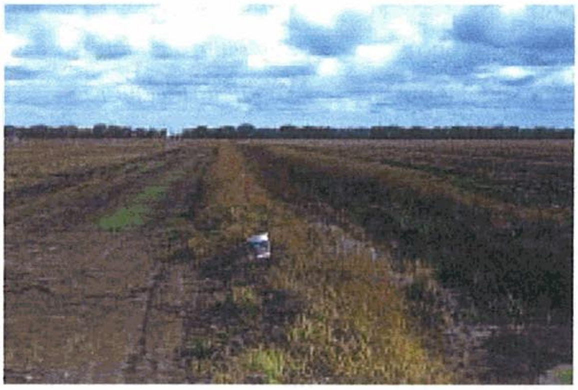
*Brown beetle grass produces masses of seed that germinate and grow in moist places such as channels and irrigation furrows.*

Cumbungi and knotweed are not commonly problems in irrigation channels, 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.

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

*Knotweed can form an almost impenetrable mass.*

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.



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

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 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.

Use non-residual herbicides as often as necessary to control weeds that emerge during the cotton season.

# 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 to control weeds can be adequately managed in the cotton farming system by using an integrated weed 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 by normal farming practices. These weeds can spread and become progressively worse year after year, in spite of the cotton growers efforts.

Specific management strategies are required to manage these problem weeds. Management guides for cowvine, nutgrass and polymeria follow.

## 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; a short generation period; 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.

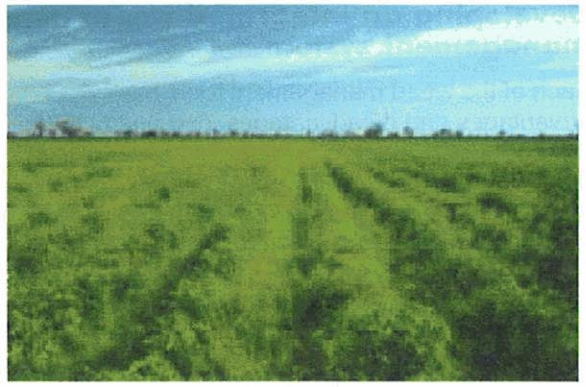
## H4. Managing Polymeria (Take-all) in Cotton

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 National Registration 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.



*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.*

## 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.


## 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 chipping, 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.

These tools need to be integrated into a cost effective, sustainable management system that maximises crop yield and quality, while minimising the impact of the weeds. Attention to weed management in fallows and rotation crops, and on irrigation structures and roads is critical to the whole farm system. The potential plant-back periods from residual herbicides used in cotton and rotation crops must be considered in the whole system. Movement of weed seeds and residual herbicides in the irrigation system must also be taken into account.

# 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.

No herbicide resistant weeds are currently known to exist in the Australian cotton industry. It is the aim of the cotton industry to maintain its position as free of resistant weeds, enabling it to make use of the full spectrum of available herbicides.

This resistance-free status can best be maintained by 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 ensure the continuation of the resistance-free status are covered in the following article.

## 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.

# MANAGING HERBICIDE RESISTANCE IN COTTON

**Graham Charles**
**(NSW Agriculture)**

| Contents | Page |
|---|---|


## 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 occurs.

## Genetic variability

Genetic variability is a characteristic of all populations. Even in a plant population (within a plant species), where all individuals may 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, 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 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 156 weeds are resistant to herbicides. 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 six 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, while there is a relative increase in the frequency of species that are more tolerant of the herbicide. Species shift is a common occurrence. 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 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
- 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,
- 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, 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 avoids 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 three broad categories.

- herbicides with high risk (groups A and B).
- herbicides with moderate risk (groups C to H).
- herbicides with low risk (groups I to N).

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 completely dominated by individuals that are resistant to the herbicide.

*Table 1. The herbicide groups of the herbicides commonly used in the cotton farming system. Examples of products containing these active ingredients are shown. A complete list of products is given in the **Herbicide and formulation lists** in **WEEDpak**.*

| | Herbicide group | Active ingredient | Example |
|---|---|---|---|
| High risk | A | butroxydim | Falcon |
| | | 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 |
| Moderate risk | C | atrazine | |
| | | diuron | |
| | | fluometuron | Cotoran |
| | | prometryn | Gesagard |
| | D | pendimethalin | Stomp |
| | | trifluralin | |
| Low risk | F | norflurazon | Zoliar |
| | G | oxyfluorfen | Goal |
| | I | 2,4-D | |
| | | dicamba | |
| | | fluroxypyr | Starane |
| | | MCPA | |
| | K | metolachlor | Dual |
| | | MSMA | Daconate |
| | L | diquat | Reglone |
| | | paraquat | Gramoxone |
| | M | glyphosate | |
| | | glyphosate-trimesium | Touchdown |

The post-emergence grass herbicides and Staple® are also in this category. Resistance to these products is likely to occur if they are used repeatedly without other weed management tools.

The herbicides in the moderate risk category (Groups C to H) are less specific in their mode 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 trifluralin, have been used repeatedly over many years without any apparent resistance problems occurring. Nevertheless, resistance can occur.

Weeds are unlikely to develop resistance to the herbicides in the low risk category (Groups I to N), as these herbicides have very general modes of action, or multiple modes of action.

Nevertheless, over-reliance on these herbicides can still lead to resistance. For many years, it was believed that resistance to glyphosate (Group M) could not occur, yet there are now examples of three weeds that have developed resistance to glyphosate. Resistance to glyphosate has developed in a number of different annual ryegrass populations in Australia. Resistance has developed in ryegrass populations where glyphosate was used as the main or only form of weed control over a number of years, with multiple applications each year. There is every reason to believe that further weeds can develop resistance to herbicides in this category if these herbicides are over-used.

Once herbicide resistance develops, an alternate management system 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 would have 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.

## Herbicide modes of action

Similar herbicides often have similar modes of action. For example, the post-emergence grass herbicides (Group A) are all herbicides that act through inhibiting acetyl-coA carboxylase, an enzyme that is involved in fatty-acid synthesis in plant cells. This inhibition leads to membrane disruption in the plant cells and causes plant death.

Consequently, although six chemically distinct herbicides are listed in Group A in Table 1, they all act on the same plant pathway. In practice, a weed that develops resistance to one of these herbicides may be resistant to all six herbicides, even though it may never have been exposed to the other five herbicides. This is called cross-resistance.

However, 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 is extremely unlikely to have resistance to metolachlor.

## 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®, Falcon®, 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 (Zollar®). 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.

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 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.

## 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. This approach of scouting and rotating weed management tools as necessary, will not only result in an effective weed management system, but will also prevent the development of 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, or too little herbicide hit the target 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.
- 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.

## Suspected herbicide resistance

Most apparent 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 extremely 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 Agriculture 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 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.

## Summary

The development of herbicide resistance is not inevitable. There has not yet been a single case of a herbicide resistant weed in the Australian cotton industry, due largely to the long-term use of an integrated weed management strategy using a combination of herbicides, cultivation, chipping and good crop agronomy.

Failure to use an integrated weed management program will lead to the development of herbicide resistance. Herbicide resistant individuals can occur naturally in a 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 may eventually result in the development of herbicide resistant weeds

Prevention is the simplest way of managing herbicide resistance. The development of herbicide resistance can be prevented by using an integrated weed management system. Integrated weed management is based on regular scouting for weeds and treating problems with a range of management tools.

# ROUNDUP READY® COTTON

## Introduction

The introduction of Roundup Ready® cotton offers tremendous advantages to the Australian cotton industry for weed management. When used as a component of an integrated weed management system some of the benefits that may arise from its introduction include:

- reduced dependence on residual herbicides;
- improved control of some of the more difficult-to-control weeds;
- greater flexibility in weed management programs; reduced chipping and cultivation expenses and,
- the potential to improve establishment and vigour of young cotton seedlings by reducing the pre-emergence use of residual herbicides.

While Roundup Ready® cotton has many benefits, this technology has only been recently introduced and currently has some limitations. As a consequence, two articles have been prepared to enable growers and agronomists to obtain the best results from the varieties of Roundup Ready® that they plant.

The first article *Managing Roundup Ready® Cotton* provides general guidelines on using this technology as well as providing information on herbicide resistance and species shift. The article also includes an economic comparison to illustrate the costs of weed management using this technology in comparison to conventional farming systems. The second article *Research Results with Roundup Ready® Cotton* provides additional information on the performance of the Roundup Ready® technology and some of the experiences researchers have had in trials using Roundup Ready® cotton varieties.

## E2. Managing Roundup Ready® cotton

Roundup Ready cotton offers a number of benefits to the Australian cotton industry however there are a few limitations when using this technology and for optimum results Roundup Ready® cotton needs to be managed within these limitations. Roundup Ready® cotton is only registered for over-the-top applications up to the fourth true leaf and prior to unfolding of the fifth true leaf of the cotton crop. Sequential applications of Roundup Ready® herbicide must be applied at least 10 days apart, and with at least two nodes of crop growth between applications.

Shielded and directed applications of Roundup Ready® herbicide can be very effective in controlling weeds in cotton, however there is always potential for spray drift when applying Roundup ready herbicide in this manner. Shields must be designed to minimise drift and to prevent fine spray droplets from contacting the leaves. Likewise when applying directed applications the nozzles must be angled such that none of the spray contacts the lower leaves of the cotton plants.

To minimise the impacts of both species shift and herbicide resistance an Integrated Weed Management (IWM) approach to weed control must be adopted.

## E3. Research results with Roundup Ready® Cotton

The weed management system adopted by growers and consultants should be able to respond to weed pressure on a season by season and field by field basis. The addition of Roundup Ready® cotton to a crop management plan should allow growers to modify their systems and reduce their dependence on residual herbicides. Any changes to the weed management system, however, should be made gradually, based on personal experience.

Results from 5 seasons of back-to-back Roundup Ready® cotton are examined. Yields and the level of weed control from a range of Roundup Ready® systems are compared to the results from more traditional weed management systems that rely on residual herbicides.

The results highlight the potential benefits from using the Roundup Ready® technology, but also show some of the possible traps with relying too heavily on this technology. Timing of the over-the-top Roundup application was especially critical.

# MANAGING NUTGRASS IN COTTON

**Graham Charles**
**(NSW Agriculture)**

Contents



*A heavy "nutgrass" infestation in cotton. The field was infested with four different species. The cotton was infested with downs nutgrass and yelka. Dirty Dora and umbrella sedge infested the head ditch.*

## 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. Nutgrass species occasionally found around cotton fields.*

| Botanical 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.

### 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

1 Lazarides M. Cowley K. and Hohnen P. (1997). CSIRO handbook of Australian weeds, CSIRO Publishing, Collingwood, Vic.

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)

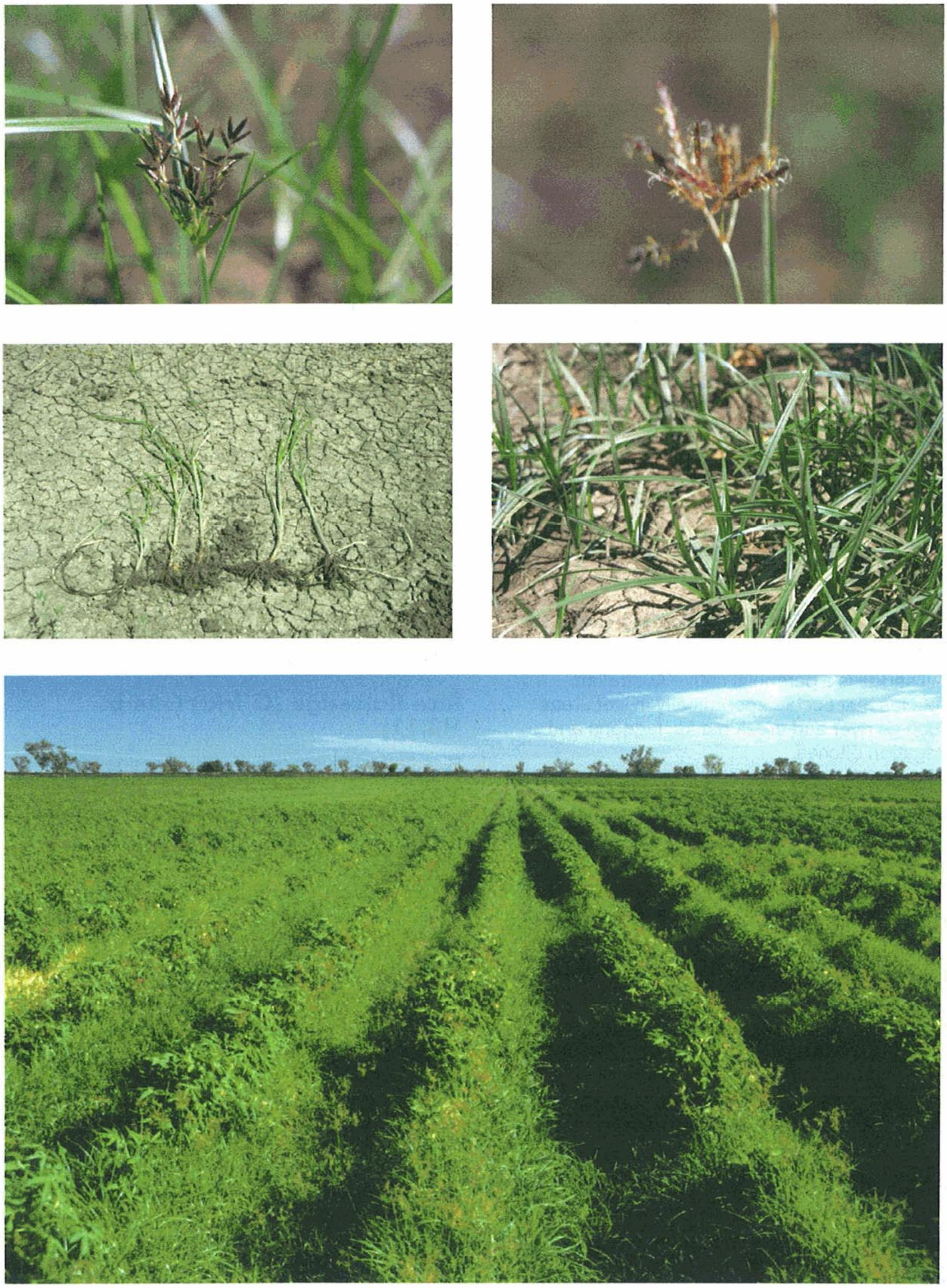
Umbrella sedge is an introduced species that invades wet areas and can be a problem in water storages and irrigation channels.

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.

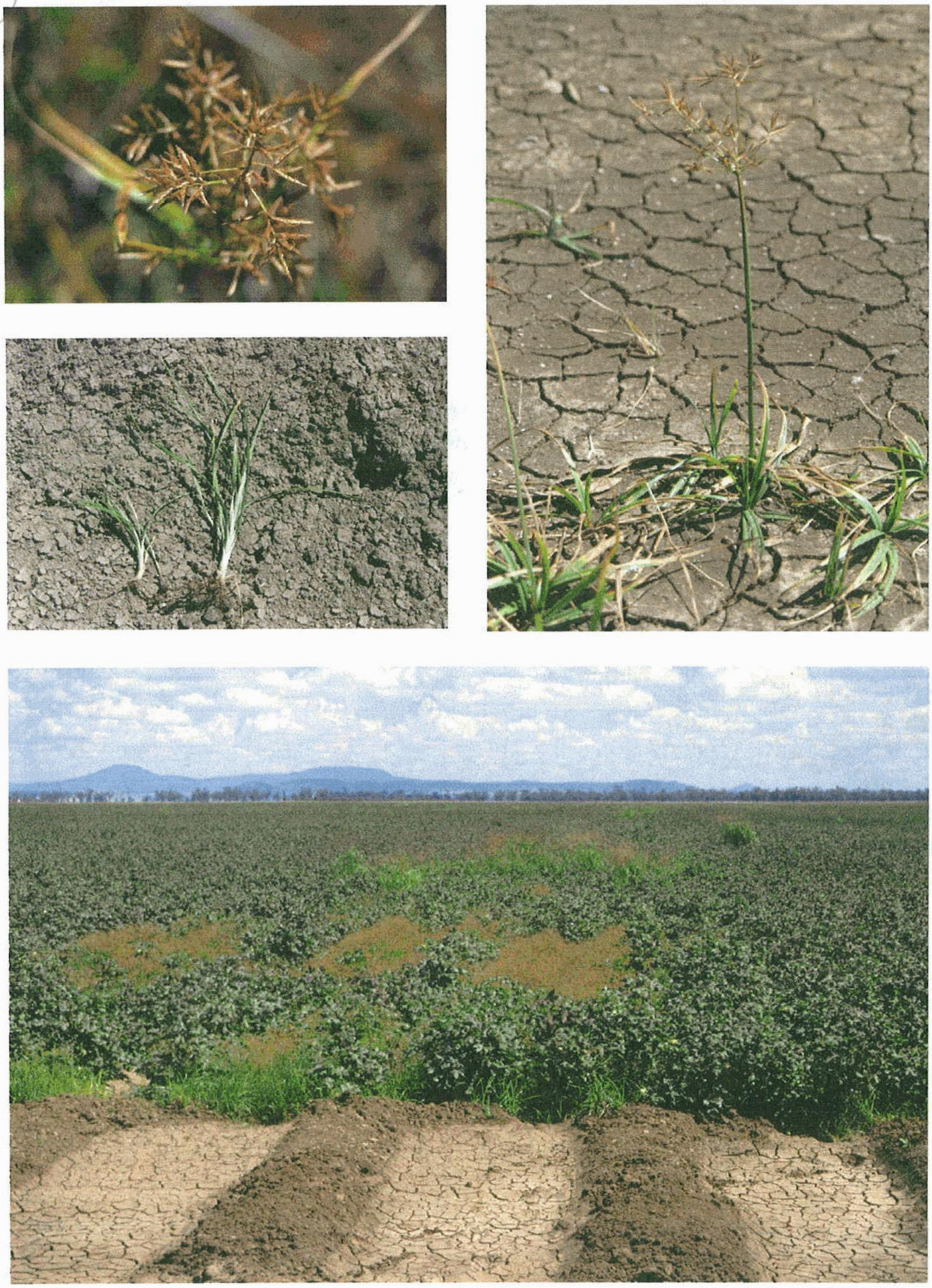
Once established, umbrella sedge plants can grow to form a large tussock.

### 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.



*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.*