Cotton Catchment Communities CRC

FINAL REPORT

Part 1 - Summary Details

Cotton CRC Project Numbers: **1.01.09 (2005/6) & 1.01.49 (2006/9)**

Project Title (1.01.09): Development of sustainable IWM strategies for use with low input cotton systems – the critical period for weed control strategy, and

Project Title (1.01.49): Development of weed control thresholds and management of herbicide damage in cotton

Note* Project 1.01.09 was approved as a 3 year project, July 2005 – June 2008, but was reduced to a 1 year project after the principle researcher (Dr. Ian Taylor) left. The work was continued and expanded in Project 1.01.49. This report covers both projects.

Project 1.01.09 Commencement Date: 1 July 2005

Project Completion Date: 30 June 2006

Project 1.01.49 Commencement Date: 1 July 2006

Project Completion Date: 30 June 2009

Cotton CRC Program: The Farm

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Abbreviations used in this document:

ACRI	the Australian Cotton Research Institute, situated near Narrabri
CRC	Cotton Catchment Communities Cooperative Research Centre
CPWC	the Critical Period for Weed Control (when period during which weeds must be controlled to prevent yield losses)
WRT	the Weed Removal Time (the start of the critical period)
WFP	the Weed Free Period (the end of the critical period)
UNR	ultra narrow row planting configuration. Eg., 6 rows on a 2 m bed.
WEEDpak	the Integrated Weed Management Guide for cotton. Available in hard copy, on the **COTTONpaks CD** & on the CRC web.

Signature of Research Provider Representative: ______________________________

Background – Project 1.01.09

The introduction of Roundup Ready Flex® cotton and other herbicide tolerant cotton varieties in 2007/08 is likely to result in significant changes to the way weeds are managed in irrigated and dryland cotton farming systems. Glyphosate will be able to be applied 'over the top' to cotton plants up to the 16 node developmental stage and then as a directed or shielded application. This may result in growers increasing the total number of glyphosate applications, as well as reducing other weed management options currently utilised. An increase in the number of glyphosate applications will increase selection pressure on weeds, possibly leading to the evolution of herbicide resistant weeds. Additionally, it is likely with increased glyphosate applications and the reduction in alternative control methods that significant species changes may occur within cotton fields.

The timing of herbicide applications is crucial to maximise the potential of these herbicide technologies, but avoid uneconomic or unnecessary use, or the risks associated with herbicide resistance and species shift. The development of an integrated weed management program utilising the critical period for weed control concept is an important step in preventing the development of herbicide resistance and species shift. This concept, initially developed by Nieto *et al.* (1968), is well suited for application in farming systems using herbicide tolerant crops and is designed to optimise weed management and herbicide use in systems reliant on post-emergent herbicides. In many ways, this concept is similar to the IPM system already adopted by the Australian cotton industry.

The critical period for weed control concept consists of three elements:

- Weed removal time (WRT), is the start of the period during which weeds should be removed to prevent yield loss. This will vary with weed type and density.
- Weed free period (WFP), is the end of the period over which the WRT applies, after this the weeds will no longer affect yield.
- The critical period for weed control (CPWC), is the period between the WRT and the WFP.

This is best explained through the use of a schematic diagram (Fig 1.), which illustrates how the concept is derived and its application in cotton systems. The green line running across the top of the graph is the potential yield if there were no weeds in the field (weed free yield). The red line is the yield loss due to the presence of uncontrolled weeds at a particular density. In this example, the density is equivalent to one thornapple plant per metre of row. The point at which the red line deviates from the green line and intersects the yellow line (economic threshold), is where the particular weed species will cause an economic loss for the grower and therefore control measures should start. The blue line represents the yield expected should weeds emerge at different times in the cotton crop. For example, if the weed emerges with the crop and is left uncontrolled, the expected yield would be only 20% of the weed free yield. If the same weeds were to emerge some 100 day degrees later, then the expected yield would be approximately 70% of the weed free yield, and so on until a time where if the weed emerges there will be no yield loss. Where the blue line intersects with the yellow is the point where control is no longer needed. The area between these 2 lines is the critical period for weed control and is where that particular weed species at that particular density will compete with cotton and cause yield loss.

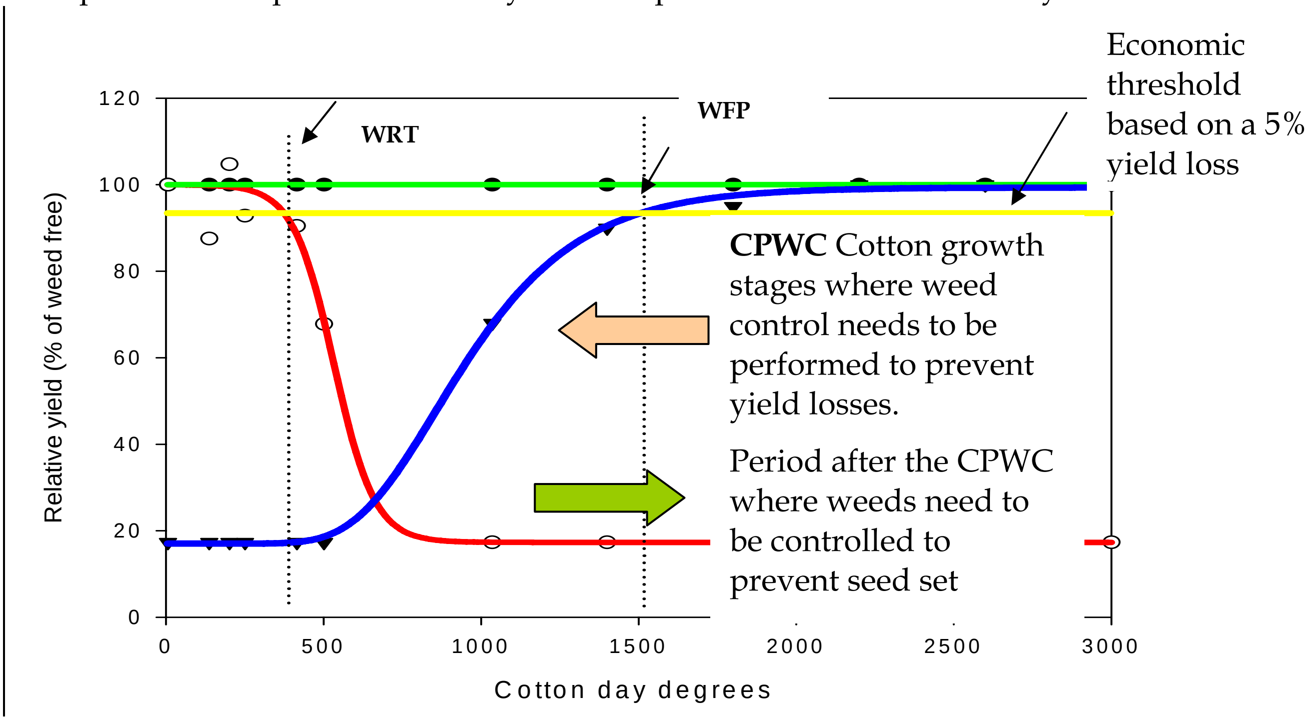


Fig. 1. Determination of the critical period for weed control for thornapple (see text). The critical period for weed control is based on a weed density of 1 thornapple per meter of row.

Background – Project 1.01.49

The critical period for weed control

The introduction of Roundup Ready Flex® cotton and other herbicide tolerant cotton varieties in 2007/08 is likely to result in significant changes to the way in which weeds are managed in both irrigated and dryland cotton farming systems. Glyphosate will be able to be applied 'over the top' to cotton plants till the 16 node developmental stage and then as a directed or shielded application. This may result in growers increasing the total number of glyphosate applications as well as reducing other weed management options utilised. An increase in the number of glyphosate applications will increase selection pressure possibly leading to the evolution of herbicide resistance. Additionally, it is likely with increased glyphosate applications and the reduction in alternative control methods that significant species changes will occur within cotton fields.

The potential of herbicide resistance is a real threat to the cotton industry, with glyphosate the most heavily used herbicide in the system. The development of glyphosate resistance in weeds, such as liverseed grass, barnyard grass, sow thistle or fleabane, would have major consequences for the cotton system, especially in UNR and stubble retention systems, and would seriously compromise minimum tillage and fallow weed control strategies. Already, 5 different weeds have developed resistance to glyphosate elsewhere in the world. A better understanding of the timing of herbicide applications is crucial to maximise the potential of these herbicide technologies, but avoid uneconomic or unnecessary use, or the risks associated with herbicide resistance and species shift. The development of an integrated weed management program utilising the critical period for weed control concept is an important step in preventing the development of herbicide resistance and species shift.

A single seasons data for the critical period for weed control were collected for highly competitive broad leaf weeds and grass weeds in the 2005/06 season, but needs to be confirmed with a 2nd seasons data and the work still needs to be undertaken for moderately competitive broad leaf species in the 2006/07 and 2007/08 seasons. Additionally, the timing of the herbicides, as indicated by the models, needs to be validated in the field, to ensure that control of the weeds is achieved and to refine the proposed techniques.

Herbicide damage

Herbicide damage has been an ongoing issue for the Australian cotton industry over many years. Damage occurs every season from residual herbicides applied on a fallow or preceding crop, and from residual herbicides applied prior to or at planting. Increasingly, herbicide damage is also occurring from drift from a herbicide or herbicide combination not directly applied to the cotton crop, but applied to another field which may be kilometres away. This damage is most commonly from 2,4-D and increasingly, from glyphosate, applied to a fallow, or a glyphosate tolerant cotton crop. Damage has also occurred from herbicides applied to the wrong field, from poor application with inappropriate nozzle pressures, poorly designed and/or setup equipment, from applications made during unsuitable conditions with shielded or conventional sprayers, and from contaminated pesticides or application equipment.

Little information is available regarding the identification and assessment of herbicide damage and the management of a damaged field.

The main questions asked by growers with herbicide damage have been:

1. Which herbicide(s) have caused the damage, and at what approximate rate?
2. What damage will the herbicide cause? What is the likely yield impact? Should the crop be terminated, or could it still achieve an acceptable yield?
3. What management can be applied to best assist the crop to recover from the damage?

Surprisingly little information is available to answer these questions. Limited information is available to guide a grower in establishing the cause of herbicide damage, with personal experience the best current guide. Glyphosate damage is especially difficult to determine in cotton, with few if any visible symptoms of damage. Published information is available relating the yield impacts of some herbicides, including glyphosate and 2,4-D, applied at different crop growth stages and known herbicide rates on cotton yields. However, it is difficult to relate this information to an unknown drift rate, and none of the information relates to the high yielding crops now being grown in the Australian industry. No information is available on the impact of glyphosate and 2,4-D combinations. Also, no information is available on the value of increased nutrition or watering frequency on the recovery of these damaged crops.

This research will begin to address these questions. A pilot experiment was initiated this season (2005/06) at ACRI using detailed plant mapping during the growing season to determine the impact of glyphosate and 2,4-D on plant growth, in terms of photosynthesis, fruit production etc. This approach has been previously been used by Dr. Mike Bange and Dr. Steve Milroy at ACRI to look at other aspects of crop growth and development. Measurements were taken prior to herbicide exposure and will continue throughout the season. It is hoped that these measurements will allow an understanding of the actual impact of these herbicides on the crop. Possible scenarios are, for example, a rate dependant maturity delay with no other impact, growth delay and loss of pollen, or growth delay and shedding of squares and small bolls.

Research in later years will include water use by herbicide damaged cotton and the possible value of additional water and nutrition on plant recovery.

Objectives – Project 1.01.09 for 2005/6

- To determine and quantify threshold levels for different weed species leading to a reduction in the reliance on residual pre-plant and pre-emergent herbicides.
- To further develop the critical period for weed control concept for use in Australian cotton production systems.

These objectives were achieved in the 12 months of the project.

Objectives – Project 1.01.09 for 2006-2008

- To develop integrated weed management strategies for use in low input fields that will minimise the risks associated with herbicide resistance and species shift.
- Develop a decision support framework for the integration of threshold data and population dynamics data for use in low weed pressure fields that will enable growers to make more informed decisions relating to herbicide use.
- To continue to monitor Roundup Ready fields for evidence of species shift and herbicide resistance.
- To quantify the impact of residual pre-emergent and pre-plant herbicides on the establishment and disease incidence/severity of seedling cotton associated with adverse environmental conditions.

No work was undertaken against these objectives as the project was concluded after only 12 months.

Objectives – Project 1.01.49 for 2006-2009

• To develop the critical period for weed control concept for use in low input fields that will minimise the risks associated with herbicide resistance and species shift.	• A weed control threshold was developed and promoted through **WEEDpak**, the Australian CottonGrower, CottonTails, meetings etc. See **Appendix** pg. 85-97, 106-113, 148-183.
• To validate the timing of herbicide applications (glyphosate and/or glufosinate ammonium) in herbicide tolerant cotton farming systems.	• Validation experiments were undertaken but have not yet been analysed.
• To develop additional competition data for a set of real weeds for inclusion in the model.	• Two seasons data were collected on this objective but have not yet been analysed.
• To develop seed production data for a set of real weeds for inclusion in the model.	• Plant growth and development data sets have been developed for 18 weeds and extended in **WEEDpak.** See **Appendix** pg. 309-316.
• To develop a decision support framework for the integration of threshold data and population dynamics data for use in low weed pressure fields that will enable growers to make more informed decisions relating to herbicide use.	• A weed control threshold was developed and promoted through **WEEDpak,** the Australian CottonGrower, CottonTails, meetings etc. See **Appendix** pg. 85-97, 106-113, 148-183.
• To develop guidelines for herbicide application timing in the form of a software package based on the palm pilot.	• Discussion with a weed modeller established that this step was unachievable and unnecessary at this point. This objective was changed to an evaluation of an electronic sensor to estimate weed biomass. Two seasons work were undertaken with the sensor.
• To determine the effect of a range of herbicides including 2,4-D and glyphosate on the growth and yield of cotton plants exposed at varying growth stages.	• This work has been undertaken and completed. Sets of herbicide damage data have been placed on the CRC website and promoted. See **Appendix** pg. 191-308, 317-331.

• To explore best-bet management options for herbicide damaged cotton in research and commercial fields.	• Three seasons of work were undertaken on this objective, but data have not been fully analysed as yet.

Methods - Project 1.01.09

The critical period for weed control was defined using a large field experiment, with 2 model weeds, Japanese millet and sunflower (mimicking awnless barnyard grass and thornapple), planted into cotton at 6 densities (0, 1, 2, 5, 10 & 20 sunflowers/m cotton row, and 0, 10, 20, 50, 100 & 200 millet/m cotton row), with 4 different times of weed addition (roughly at planting, 3, 6 & 9 weeks post-planting) and 4 times of weed removal (roughly 3, 6, 9 & 12 weeks post-weed addition), and 4 replicates. This gave a total of 768 plots.

A metre of cotton and weed plants were removed from the appropriate plots at each time of weed removal, 48 plots per removal. Plants from these samples were destructively harvested, recording height, nodes, leaf number and area, number of squares, flowers and bolls, and the wet and dry weights of the plant components. Individual plots were picked at harvest and seed and lint cotton yields determined.

This design produced an appropriate set of data in an efficient manner. The use of the model weeds rather than real weeds was well justified. Most real weeds are hard-seeded and it is very difficult to achieve satisfactory plant establishment using real weeds, especially in a limited time frame. By contrast, the model weeds established well. Introducing this number of thornapples to a field, for example, would have created a logistical nightmare, as well as a huge, ongoing problem, due to the large proportion of hard seeds produced by this weed.

Methods - Project 1.01.49

This project used a combination of field, glasshouse and laboratory studies, with some observations in a commercial cotton field. Replicated field and glasshouse experiments were undertaken at the ACRI, Narrabri, to define the critical period for weed control, relative weed competitiveness, and seed production, and to determine the impact of herbicide rates at varying crop stages. Experiments used 4 to 6 replicates and were structured as randomised complete block experiments, or factorials according to the nature of the experiments. Detailed plant mapping information was undertaken to complete the picture for the critical period for weed control and herbicide damage and was completed over several seasons. Experiments recorded details of plant growth and development, plant height, node number, light interception, leaf area index, and fruit production and retention. All recorded data were related back to untreated comparisons. Detailed plant mapping measurements were initially undertaken with the guidance and assistance of Dr. Mike Bange (CSIRO) and his team.

Plant mapping was carried out every 2 weeks post-herbicide damage throughout the season in the herbicide damage experiments, and maturity picks were also undertaken at the end of the season to quantify the impacts of herbicides on crop maturity. All plots were picked at harvest and seed and lint cotton yields determined. Samples were also assessed for lint quality using HVI techniques through the assistance of CSIRO.

Data were analysed using the REML routine in GENSTAT. This routine allows data to be analysed in a simple 2-dimensional array, taking account of row by column interactions. This approach is ideal in irrigated cotton, where the variation across irrigation rows is greater than the variation down a row (a column effect often due to irrigation) and influences such as the head- and tail-ditch ends of the field often give a row effect.

These techniques produced appropriate data sets in an efficient manner, although some difficulties were encountered during the 3 seasons of the project. These included predation of the sunflowers by birds, difficulties establishing the millet into an already established cotton crop, and delays in picking due to difficulties in getting the crops to cut-out and defoliate. Nevertheless, valuable and reliable data sets were achieved against all objectives.

Results for objectives from Project 1.01.09 for 2005/6

- **Determine and quantify threshold levels for different weed species leading to a reduction in the reliance on residual pre-plant and pre-emergent herbicides.**
- **Further develop the critical period for weed control concept for use in Australian cotton production systems.**

This work was part of an on-going project to define the critical period for weed control in cotton. The 2005/6 experiment was established by Dr. Ian Taylor, and jointly managed by Dr. Taylor and Mr. Charles in the later part of the season following Ian's resignation.

The experiment had 2 model weed species (sunflower and Japanese millet), 6 weed densities (sunflower at 0 – 20/m row and millet at 0 – 200/m row), 4 times of weed addition and 4 times of weed removal, with 4 replicates, giving 768 plots.

The experiment was successfully undertaken in this season, although there were some issues with the data. These included that the densities of weeds sown was known for each plot but the actual densities of established weeds were not recorded for the experiment. There were indications in the data that the densities of Japanese millet, particularly, may have been much lower than was indicated by the planting rate, as it was difficult to get millet to establish into a growing cotton crop. This problem was also apparent in the data sets from the earlier seasons, although the actual weed densities were not recorded in any of the 1st 3 seasons. Secondly, only two model weeds were used in this season, not the three model weeds required by the project.

The results of this season's work were processed and analysed by Mr. Charles and form part of the paper entitled 'Developing a threshold model for controlling weeds in glyphosate resistant cotton', presented by Mr. Charles at the 4th World Cotton Research Conference in Lubbock, Texas, in September 2007. The paper was published in the proceedings of this conference. The analysis and results from this experiment are presented in the paper which is included in **Appendix** pg. 62-83.

This work was also played an important part in establishing the weed control threshold, which has now been published in 6 articles in the Australian CottonGrower and Australian Cotton Conference proceedings and in **WEEDpak** on the CRC website. Copies of these articles are included in the **Appendix**, pg. 85-97, 106-113, 148-183.

These experiments were very labour intensive, but produced valuable results. The next step is to facilitate the adoption of this work by the industry.

The 'model' weeds, Japanese millet and sunflowers, were used to determine a weed control threshold for cotton. These 'weeds' were chosen because of their similarities to real weeds (barnyard grass and thornapple) and their uniform emergence and growth patterns.

Results for objectives from Project 1.01.49 for 2006-2009

1. **Develop the critical period for weed control concept for use in low input fields that will minimise the risks associated with herbicide resistance and species shift.**

2006/7

This objective continued the work from Project 1.01.09 to define the critical period for weed control in cotton. The 2006/7 experiment provided a full set of data, with the 3 model weed species, 6 weed densities, 4 times of weed addition and 5 times of weed removal, with 4 replicates, giving a total of 1440 plots. The additional 5th time of weed removal was included because analysis of the earlier data showed this was lacking. The 5th time was at crop harvest (weeds allowed to compete the whole season), allowing the model to define the impact of full season weed competition on crop yields. The earlier data assumed that the maximum reduction in crop yield had been achieved by the 4th time of weed removal, but did not provide a means to test this assumption. Actual densities of weeds were also recorded in this and following seasons.

The experiment was successfully undertaken in this season. The results of this seasons work have been processed and analysed and also contribute to the weed control threshold publications.

A sampling technique has also been developed to enable the weed pressure in each field to be assessed and compared to the weed control threshold. The sampling technique requires a small proportion of each field to be checked and the density of weeds determined. This density is then compared to a threshold density (taking crop growth stage into account) and determined to be above or below the control threshold. If the weed density is above the threshold, then weeds are already causing significant yield losses and need to be controlled as soon as possible. If the weed density is below the threshold, then weed control can be delayed to a later time, provided that weeds are controlled before they set seed.

2007/8

The 2007/8 experiment attempted to fill in some of the gaps in the earlier data (2003-2006), including the 3rd weed type (mungbean, simulating bladder ketmia), which was omitted in 2005/6. The experiment also increased the weed densities used, including some higher densities, as analysis of the earlier data indicated that the densities previously chosen did not sufficiently cover the full spectrum. Also, some cotton-free plots were included, which had only a small number of the model weed plants without competition, as full analysis of the data needed the comparison of the potential rate of weed growth without competition.

The experiment included the 3 model weed species (Japanese millet, mungbean and sunflower), 7 mungbean densities (0 – 50/m row), 4 sunflower and millet densities (0 – 50 sunflowers/m row and 0 – 500 millet/m row), 4 times of weed addition and 5 times of weed removal, with 4 replicates, giving a total of 1200 plots.

Treatments ranged from those causing little damage to the crop, to some where the crop plants were heavily shaded and stunted prior to the weed removal, such as in the foreground of this photo.

This project was very labour intensive, with many large samples removed later in the season.

The experiment was successfully undertaken in this season, although there were again some issues with the data. As in earlier seasons, problems were encountered in establishing millet into emerged cotton, with few millet plants establishing from the last 2 weed additions, especially on one replicate. Also, the cotton-free, low density weed plots were not fully successful, as the inability to apply residual or post-emergent contact herbicides and the lack of competition resulted in these plots being full of other weeds. Hand-hoeing was used to manage these weeds, but successive germinations challenged the integrity of these treatments.

The results of this seasons work have mostly been entered into the computer, but have not yet been analysed.

2008/9

Only the cotton-free, low weed density part of these experiments was repeated in 2008/9, with the 3 species (sunflower, Japanese millet and mungean), 4 times of weed addition, 4 times of weed removal, and 4 replicates, giving a total of 192 plots. The treatments were largely successful in this season, although problems with millet establishment again occurred. However, predation from birds became a major problem later in the season, with the sunflower and mungbean plants completely stripped by birds.

No results from this experiment have been processed as yet.

2006-2008

In addition to this work, a long-term field experiment was continued in 2006/7 and finished in 2007/8 in field C4 at ACRI. This experiment explored the long-term effects on yields and weed spectrum of adding a single pre-emergent herbicide to a Roundup Ready Flex cotton system which received only Roundup Ready Herbicide. An earlier experiment with Roundup Ready cotton (not Flex) had detected a build up of a range of glyphosate tolerant weeds where only glyphosate was used, and a build up of 1 or 2 species when a single residual herbicide was used.

However, no species shift was detected over 6 seasons in this experiment. This result partly reflects the improved level of weed control obtained with Roundup Ready Flex cotton, but also may reflect the limited range of weed species present on any given plot area. The experiment was terminated, as continuing the experiment was unlikely to provide additional useful data, and as the weed audit data collected by Monsanto from Roundup Ready Flex crops throughout the industry has providing a similar set of data, with a far broader scope.

Industry wide results from the 2008/9 season show that burr medic, fleabane and pigweed are building up under the Roundup Ready Flex system. Future research should explore the most cost effective options for managing these weeds in this system. Results from other research suggest that herbicides such as pendimethalin and prometryn may need to be added back into the system at least once every few years. Rotating cotton with sorghum and using atrazine once every 4 or 5 years may also be an effective strategy for pigweed control.

2. **Validate the timing of herbicide applications (glyphosate and/or glufosinate ammonium) in herbicide tolerant cotton farming systems.**

2007/8

A validation experiment for the critical period for weed control threshold was established in 2007/8 using a naturally occurring weed population, with 3 levels of weed pressure, 30 treatment combinations of varying weed free periods and 4 replicates, giving a total of 360 plots. Weeds were removed at 8 times (0, 125, 250, 375, 500, 750, 1000 or 1500 day degrees after crop emergence), with combinations of treatments ranging from weed-free (sprayed all 8 times), through to full season competition (unsprayed). These treatments were chosen to mimic and build on some of the treatments previously imposed in the critical period for weed control experiments. This experiment used Roundup Ready Flex cotton and Roundup Ready Herbicide to explore the effects of this range of weed free periods on cotton. The 3 levels of weed control were to be achieved using a broad-leaf residual herbicide (fluometuron) applied pre-planting on one set of plots, a residual grass herbicide (pendimethalin) on a 2nd set of plots, and no residual herbicide on the remaining third of the experiment, resulting in plots with predominantly grass weeds, predominantly broad-leaf weeds, and full weeds. Surprisingly, these residual herbicides had no detectible effect on the weed populations at all, with weeds establishing equally well on all plots.

A GreenSeeker™ infra-red sensor was also used with this experiment to explore the practicality of using this or a similar sensor to directly estimate crop and weed biomass/leaf area as an alternative way of assessing the weed control threshold and overcoming many of the sampling issues with the current weed control threshold. These sampling issues occur due to the large number of different weeds which occur in cotton and the often high degree of variability (patchiness) in their distribution in paddocks. Where weeds are very patchy, a large proportion of each field may need to be regularly assessed to accurately estimate the weed pressure and determine whether the weeds exceed the control threshold. This need makes the current survey technique relatively unfriendly, but sampling could be greatly simplified is a machine-mounted sensor could effectively do the sampling job, allowing a large area to be sampled fairly quickly.

This experiment was successfully undertaken but the data have not been processed or analysed as yet.

The impacts on cotton growth, development and yield of a range of weed-free periods were examined using naturally occurring weeds. This field had a heavy population of 'smaller' weeds, which still competed heavily with the cotton, as shown by the stunting of the crop in these weedy patches.

2008/9

The experiment was repeated from last season, although the 3 herbicides were omitted from the design, reducing the experiment back to 120 plots. However, further difficulties were encountered. The experiment was placed in a 'new' field, due to water limitations, but 'unfortunately' the field had very few naturally occurring weeds and insufficient weeds established in the early part of the season to be able to test the treatments. A cocktail of species was added to the site later in the season, resulting in strong weed pressure through the middle and later parts of the season.

This experiment was successfully undertaken but the data have not been processed or analysed as yet.

2008/9

A 2nd validation experiment was established in this season using the same approach, but with a broader set of weed competition periods. Weeds were removed at 17 different times post-crop emergence, with the most intensive treatment sprayed every 100 day degrees post-emergence, and the least intensive sprayed every 600 day degrees. Four replicates were used, giving a total of 96 plots.

The new design was chosen to more closely mimic the weed management practices that might occur in commercial cotton, and was guided by the analysis of simulated weed pressure reported in the CottonGrower articles.

This experiment was successfully undertaken but the data have not been processed or analysed as yet.

There were few naturally occurring weeds in this field. A cocktail of weeds was introduced later in the season, producing strong weed pressure.

A GreenSeeker™ sensor was used to estimate crop and weed biomass on the plots. The sensor was offset from the machine so the readings could be taken without running over the plots.

3. Develop additional competition data for a set of real weeds for inclusion in the model.

This experiment was used to validate the assumption that the model weeds (Japanese millet, sunflowers and mungbean) did in fact emulate the competition from the real weeds, barnyard grass, thornapple and bladder ketmia. The experiments were run in the 'polycage', a series of 112 soil boxes, approximately 1m by 1 m and 0.6 m deep. These boxes allowed plant competition to be assessed in a relatively realistic plant environment, while eliminating soil interactions with neighbouring plants and edge effects.

The experiment had been run in the 2003/4 and 2004/5 seasons, but the data had not been entered in the computer or analysed. Analysis of these data showed that issues with residual herbicide accidentally applied to the soil added to the plots in 2003/4 and drainage issues in 2004/5 had resulted in no meaningful data coming from these 2 seasons work.

The experiments were repeated in 2006/7 and 2007/8, with the 3 real weeds and 3 model weeds established into cotton, with 5 different densities of weeds used, as had been used in the field experiments. Difficulties of establishing the real weeds were overcome by 1) planting high numbers and hand-thinning the populations, and 2) by transplanting emerged seedlings, as necessary to achieve the required numbers. Plant growth and development were assessed during the season and cotton yield at the end of the season. The previous problems of poor crop growth and poor drainage were overcome by substantially upgrading the drainage system in the boxes and replacing the upper 40 cm of soil with cracking clay from the field (the boxes had been filled with a sand-peat moss potting mix which had relatively poor nutrient and moisture holding capacity).

The results from 2006/7 have been entered into the computer and preliminary analysis showed that the experiment had worked well, with comparable levels of competition between the model and real weeds. The data from 2007/8 are currently being entered in the computer.

These experiments were run in the ‘polycage’, a series of 112 soil boxes which were ideal for comparing the competition from real and model weeds.

4. **Develop seed production data for a set of real weeds for inclusion in the model.**

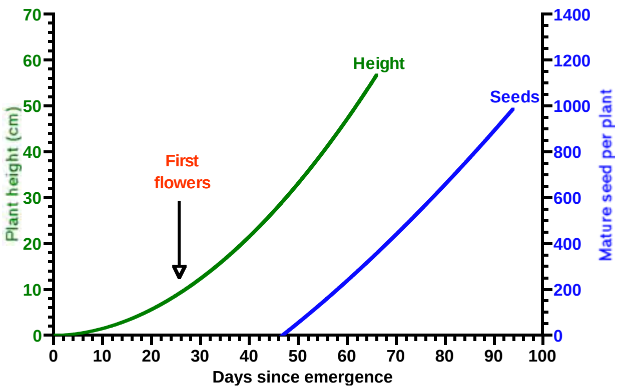
The intention behind this objective was to provide cotton growers with information on the consequences, in terms of seed production, of not controlling weeds before they started to set seed. It was intended that this experiment would be conducted using the ‘polycage’ in 2008/9. The experiment was initiated, but for a variety of reasons, many of the weeds planted in this season did not establish. Attempts were made to transplant weeds but most transplants died in the hot early-summer conditions and the experiment was abandoned.

As an alternative, data were compiled from a range of materials, including earlier glass-house work and weed ecology work undertaken by this and previous projects and also work undertaken by Dr. Stephen Johnson (funded by CRDC, UNE and NSW DPI). This allowed a valuable set of data to be compiled for 18 weeds.

The detail and value of these data goes far beyond what was originally planned for this objective and the data have been published in **WEEDpak**, **Section A3** on the CRC website. A copy of the publication is also included in the **Appendix**, pg. 309-316. The data sets are far from complete, but are a great start which should be extended in future work.

An example of the data sets follows, with a summary table giving detailed growth and development information for the weed (anoda in this case) and a graph showing a typical rate of weed growth and development over time.

Anoda (*Anoda cristata*)



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

The information can be used by cotton growers in a number of ways. For example:

1) The table indicates that growers have about 41 days between anoda emergence and the production of mature seeds. Consequently, a herbicide and/or cultivation needs to be planned within 6 weeks of anoda emergence. (Note, the time frames would be shorter in mid-summer and in the warmer cotton areas).

2) If the grower finds seedlings about 10 cm high (for example), then they are probably about 26 days old, are about to start flowering, and could have mature seed within another 2 weeks.

3) If the grower finds plants that have a number of flowers on them, but doesn't find any seed, the chances are that he has 1 - 2 weeks to control them before they have mature seed.

4) If a grower finds 50 cm high plants that already have mature seed on them, it is still worth controlling them as soon as possible. They are probably around 62 days old and may already have around 300 mature seeds/plant. If left uncontrolled, they are likely to triple the number of mature seeds over the next month, and will produce 10 times this amount of seed over the following weeks.

This is the first time information of this type has been made available to cotton growers.

5. Develop a decision support framework for the integration of threshold data and population dynamics data for use in low weed pressure fields that will enable growers to make more informed decisions relating to herbicide use.

2003-2006

The initial weed control threshold experiments were undertaken in the 2003/4 and 2004/5 seasons. The first step in this project was to enter and analyse the data from 2003/4, 2004/5 and 2005/6 seasons, which was a massive job, especially as I was not familiar with the earlier work and some details, such as plot length, took a lot of finding. The paper 'Developing a threshold model for controlling weeds in glyphosate resistant cotton', presented at the 4th World Cotton Research Conference in Lubbock, Texas, in September 2007, was developed from this combined data set. This paper is included in the **Appendix**, pg. 62-83.

This paper establishes the critical period for weed control for the model weeds (Japanese millet and sunflower) for the 2003-2006 seasons. Analysis of the data showed that the critical period for weed control was not, however, in itself a useful weed management tool, as the actual critical period was specific to a given weed type, weed density and season. Work by others has shown that the critical period could also be affected by crop density and growth rate, tillage systems, time of emergence, temperature and soil fertility. The paper went on to model the crop yield loss by relating weed competition to day degrees and weed biomass. This model was far more robust and formed the basis of the weed control threshold which has been released for the cotton industry.

One of the surprising outcomes of the modelling exercise was that the model was very sensitive to crop and weed biomass, or leaf area, but relatively insensitive to weed species. In practice, this is saying that weed competition at a point in time primarily relates to the size of the competing weeds, and their actual growth rate, rooting habit, height, leaf size and architecture have little impact on the level of competition. In many ways, weed size is a function of all these factors, but the individual factors are not of particular importance, only how they integrate to determine weed size. Consequently, weed competitiveness can be determined from weed size, without needing to separate species, etc.

2006-2009

The data from the 2006/7 season have also been processed and analysed, and a weed control threshold has been developed from the combined data sets (2003 – 2007) and released to the industry.

The weed threshold was applied to simulations from the 2004/5, 2005/6, 2006/7 and 2007/8 seasons. These simulations showed that all weed flushes could be controlled in each season, as required by the weed control threshold, within the label guidelines for Roundup Ready Flex cotton and Roundup Ready Herbicide. Any extra flushes of weeds could have been controlled using cultivation or alternative herbicides such as Staple® and Envoke®, diuron or prometryn.

A sampling method was developed for use with the weed control threshold and was tested by some of the cotton extension staff. Information on the critical period for weed control, the results of the simulations and the sampling method were published in CottonGrower articles, the Cotton Conference proceedings and in

WEEDpak on the CRC website. Copies of these articles are included in the **Appendix**, pg. 85-97, 106-113, 148-183.

6. **Develop guidelines for herbicide application timing in the form of a software package based on the palm pilot.**

This objective was changed during the life of the project to become:

Explore the use of an electronic sensor to refine the weed control threshold, delivering a more rapid, more accurate and more user-friendly weed control threshold.

The need for this change became apparent early in the life of the project. Discussion with Dr. David Thornby, a QDPI weed modeller in CRC project 1.01.34, indicated that in his opinion, the original task was far larger than was first envisaged and would be a complete project in itself. With the disbanding of the CSIRO software team, the original objective becomes unachievable in the current project.

An alternative approach to achieve this objective was to develop the system using an electronic weed sensor, which would effectively integrate a host of competition data in a simplistic but effective manner. This has the potential to achieve the same outcome as a sophisticated computer model, but in a much simpler manner.

The work using the electronic sensor (GreenSeeker™) was undertaken in parallel with the threshold validation work, previously discussed under objective 2. Measurements have now been taken over 2 seasons on 3 experiments but the results have not yet been analysed.

7. **Determine the effect of a range of herbicides including 2,4-D and glyphosate on the growth and yield of cotton plants exposed at varying growth stages.**

2006/7

A large experiment examining the effects of 2,4-D amine (Baton) and glyphosate (Roundup Ready Herbicide) on cotton growth and development had been undertaken in the previous project in 2005/6 (project DAN 174C). Each of these herbicides and the combination of the 2 herbicides were applied at 4, 8, 12 and 16 nodes of crop growth, at 10% and 1% (2,4-D) and 50% and 10% (glyphosate) of typical field rates) with 4 replicates, giving a total of 128 field plots. The effects of the herbicides were monitored in-crop every 2 weeks post-application and crop maturity and yield were recorded.

The lint samples from this experiment were ginned in 2006-2007 and the data were processed and analysed. Photos of typical damage from these herbicides were included in the **Herbicide Damage Symptoms** posters and the **Cotton Trade Show 2009 Research & Extension CD** (see **Appendix** pg. 117, 118), and on the CRC website in the **Herbicide Damage Symptoms Guide** in **WEEDpak** (see **Appendix** pg. 301-308, 317-331). Full herbicide damage information sets for these herbicides were produced and made available on the CRC website under **Crop Impacts and Herbicide Damage Images** (see **Appendix** pg. 191-300).

The distorted growth which is an obvious symptom of phenoxy damage emerges a few weeks after the crop is exposed to the herbicide.

The crop will continue to produce damaged (distorted) growth for 4 – 6 weeks after damage occurs. The damage is worst when the crop is exposed at about 8 nodes.

2007/8

An experiment explored the effects of Spray.Seed (paraquat & diquat), glufosinate ammonium, MCPA, dicamba and fluroxypyr on cotton growth and development. These herbicides were applied at 2 rates (50% and 10% of a typical field rate), at 3 growth stages (4 nodes, 8 nodes and 16 nodes), with 4 replicates, giving a total of 168 field plots. The effects of the herbicides were monitored in-crop every 2 weeks post-application and crop maturity and yield were also recorded.

The experiment was successfully completed and has been processed and analysed. Photos of typical damage from these herbicides were included in the **Herbicide Damage Symptoms** posters and the **Cotton Trade Show 2009 Research & Extension CD** (see **Appendix** pg. 117, 118), and on the CRC website in the **Herbicide Damage Symptoms Guide** in **WEEDpak** (see **Appendix** pg. 301-308, 317-331). Full herbicide damage information sets for these herbicides were produced and made available on the CRC website under **Crop Impacts and Herbicide Damage Images** (see **Appendix** pg. 191-300).

Symptoms of other phenoxy herbicides can be very difficult to distinguish from 2,4-D damage. Plants in this photo were damaged by MCPA .

These plants, damaged by fluroxypyr, are showing symptoms which would normally be attributed to 2,4-D damage.

2008/9

Three experiments were conducted in this season. The first examined the effects of 2,4-D amine (Baton) and glyphosate (Roundup Ready Herbicide) on cotton growth and development. Each of these herbicides and the combination of the 2 herbicides were applied at 4, 8, 12 and 16 nodes of crop growth, at 10% and 1% (2,4-D) and 50% and 10% (glyphosate) of typical field rates, with 4 replicates, giving a total of 128 field plots. The effects of the herbicides were monitored in-crop every 2 weeks post-application and crop maturity and yield were also recorded.

The experiment was successfully completed but some samples are still to be ginned. The data have not been processed or analysed as yet.

The 2nd experiment explored the effects of atrazine, simazine, Tordon 242 (picloram & MCPA), Tordon 75D (picloram & 2,4-D) and Grazon (picloram & triclopyr) on cotton growth and development. These herbicides were applied at 2 rates (50% and 10% of a typical field rate), at 4 growth stages (at-planting, 4 nodes, 8 nodes and 16 nodes), with 4 replicates, giving a total of 168 field plots. The effects of the herbicides were monitored in-crop every 2 weeks post-application and crop maturity and yield were also recorded.

The experiment was successfully completed but some samples are still to be ginned. The data have not been processed or analysed as yet. Photos of typical damage from these herbicides were included in the **Herbicide Damage Symptoms** posters (see **Appendix** pg. 117, 118), and on the CRC website in the **Herbicide Damage Symptoms Guide** in **WEEDpak** (see **Appendix** pg. 301-308).

A 3rd, small experiment, monitored the responses of 2 cotton varieties affected by phenoxy drift in a commercial cotton block at Jeff Hamblin's property "Riverway", near Pilliga. Plants appeared to have been affected by at least 7 separate phenoxy drift events over the season.

The varieties showed large differences in their visual response to the phenoxy drift, with a mass of distorted growth obvious on the Sicot 71BRF, typical of phenoxy damage symptoms. Few symptoms of phenoxy damage were apparent on the DP 210BRF, which had been planted a month after the Sicot 71 due to problems with establishment of the original crop. The 2 varieties were similar in height, node number etc. at the time the monitoring started. Plant monitoring over the remainder of the season found only small differences between the 2 varieties in their responses, except for the excessive production of leaves on the Sicot 71 (50% higher leaf number and some increase in leaf area). Clearly, plants can recover from phenoxy damage, even with multiple damage events as occurred in this case, but there is a big penalty in delayed maturity.

Plant growth and development was followed throughout the season until the crop was picked in early June 2009. This long season required an additional 2 irrigation inputs and 2 white fly sprays. The late picking has also had a large opportunity cost, with the late-planted chick pea crop which followed failing. Nevetheless, the crop produced around 9 bales/ha, a very good result considering the amount of phenoxy damage which had occurred, with similar yields on both the Sicot 71 and the DP 210.

Cotton, Sicot 71BRF, at Jeff Hamblin's on 19th Jan 2009, showing symptoms of severe phenoxy damage. The symptoms suggested plants had been hit by 5 separate drift events. Another 2 drift events were detected later in the season.

The Sicot 71BRF on the right initially appeared to have been much more damaged by the phenoxy drift than the DP 210BRF on the left, but the varieties gave the same yield at the end of a long season.

The evidence from this 'trial' was confounded by the difference in the sowing dates between the varieties, but does suggest there is a poor correlation between the varietal expression of phenoxy damage and the effect of phenoxy damage on crop development. Some varieties, such as Sicot 71, appear to show more visual symptoms of damage, producing a lot of distorted leaf growth, but this difference in visual symptoms did not appear to correlate with differences in plant development in this trial.

8. **Explore best-bet management options for herbicide damaged cotton in research and commercial fields.**

2006/7

An experiment was established to examine whether additional water and/or fertilizer could assist the recovery of herbicide damaged cotton, as this has been a post-damage management strategy used by some cotton growers, but with uncertain results. Roundup Ready Herbicide was applied at 2 and 12 nodes of crop growth, at 25% and 5% of a typical field rate (1 kg of Roundup Ready Herbicide/ha). Plots received either additional foliar fertilizer weekly for 6 weeks, starting when the first symptoms appeared 2 weeks post-damage, or additional water 4 and 8 weeks post-damage. The experiment was replicated 4 times, giving 72 plots.

Only the first additional water was applied to the plants damaged at 2 nodes, as there had been good rainfall prior to this event, and additional water would only have waterlogged this crop. The plants damaged at 12 nodes only received the additional foliar fertilizer, as the crop was being irrigated every 14 days and additional water would have been counterproductive.

The crop was not damaged by either level of glyphosate and gave no positive response to any of the additional inputs. The only response was a slight reduction in yield caused by the additional water following the damage at 2 nodes.

It was concluded that the glyphosate rate used was too low to adequately test the water and fertilizer effects. The experiment will be repeated, using a higher dose rate.

The rate of glyphosate applied caused no damage to the crop, nor was there any positive response from additional water or foliar fertilizer.

2007/8

The experiment was repeated, again using Roundup Ready Herbicide applied at 2 and 12 nodes of crop growth, at 50% and 10% of a higher field rate (1.5 kg of Roundup Ready Herbicide/ha), effectively 3 times the rate used in the previous experiment. Plots received either additional foliar fertilizer weekly for 6 weeks, starting when the first symptoms appeared 2 weeks post-damage, or additional water 4 and 8 weeks post-damage. In addition, glufosinate ammonium (Liberty Link herbicide) was also applied at a 50% rate (1.88 L/ha) and included in the experiment. The experiment was replicated 4 times, giving 96 plots.

The experiment did not run according to plan, with poor establishment on all treatments due to seedling diseases. Consequently, the experiment was replanted. Also, contrary to the plan, no additional water was applied to the plants in this experiment, as there had again been good rainfall prior to the 2 node damage event and additional water would only have waterlogged this crop. The plants damaged at 12 nodes only received the additional foliar fertilizer, as the crop was being irrigated every 14 days and additional water would have been counterproductive.

The crop was visually damaged and stunted by these levels of glyphosate and glufosinate, and did appear to respond to the foliar fertilizer, but the results have not been processed or analysed as yet. Analysing this data set must be a priority.

This level of glufosinate visually damaged and stunted the cotton plants.

The plants which received foliar fertilizer appeared to be much larger and more robust than those damaged by herbicide.

The low level of glyphosate caused less damage than the glufosinate, but plants appeared to be much smaller than the plants which received foliar fertilizer and were not damaged by the herbicides

2008/9

The experiment explored the effect of defoliation and the removal of damaged nodes on the recovery of cotton damaged by 2,4-D, as this again has been a post-damage management strategy used by some cotton growers, but with uncertain results. 2,4-D amine was applied at 4, 8 and 16 nodes of crop growth, at 10% and 1% of a typical field rate (1.6 L of Amicide 500/ha). This was followed up 14 days later by either applying Spray.Seed at 1.2 L/ha to defoliate the plants, or slashing the plants, removing the damaged growth. The experiment was replicated 4 times, giving a total of 108 plots.

The experiment was successfully completed but some samples are still to be ginned. The data have not been processed or analysed as yet.

Plants in this plot were severely damaged by 2,4-D amine applied at 10% of a typical field rate at 4 nodes of crop growth.

Summary

This project was created from the combination of 2 project proposals. The 1st designed around the objective of developing the weed control threshold concept, and the 2nd aiming to provide information on herbicide damage.

The project has been highly successful in:

- Compiling and analysing the data from 3 previous seasons work on the weed control threshold,
- Developing the weed control threshold concept through to a threshold which can be applied by cotton growers, and
- Developing a comprehensive set of herbicide damage data for a number of key herbicides,

The project has, in its 3 year life, undertaken a large amount of field research and succeeded in developing much of the data developed in the project, as well as data which had previously been collected.

However, there remains a lot of work still to be done, especially with the final year's experiments. It is essential that this data is not 'lost', but is fully developed over the next couple of years. With this in mind, a new project, Project 1.01.64 'Managing weeds and herbicides in a genetically modified cotton farming system' has been developed and accepted by the funding bodies. This new project builds on both aspects of the old project, but also allows additional resources to ensure that the work yet to be developed from the project in this report can be progressed.

Outcomes

1. **Describe how the project's outputs will contribute to the planned outcomes identified in the project application. Describe the planned outcomes achieved to date.**

Planned outcomes for science:

a) Greater understanding of the competitive effect of weeds on cotton growth and yield in relation to crop growth stage;

b) Improved understanding of the relationship between weed leaf area, biomass and weed competitiveness and how this can be exploited to develop better weed management programs for herbicide tolerant cotton;

c) An understanding of different management tools on weed management decisions;

d) New work, giving much better understanding of the impact of these herbicides on cotton growth and development; and

e) New work, giving better understanding of the management of damaged crops.

Planned outcomes for industry:

f) Improved weed management and decreased control costs through the timely application of post-emergent herbicides;

g) An improved IWM system that will enable growers and managers to determine when in the growth stage of a weed in relation to the cotton crop should post-emergent herbicides be applied;

h) Ability for growers to select the most effective weed management treatments for their weeds and to calculate when those treatments need to be applied to cotton crops;

i) Will enable us to develop better guidelines for growers to assess herbicide damage and determine the most appropriate management options; and

j) Will give growers guidance for managing herbicide damaged crops.

These outcomes fall into 2 groups. These are:

I. The weed control threshold, its development and application, and

II. Herbicide damage and the consequences of damage for the crop.

Actual outputs against planned outcomes:

A total of 20 publications have arisen from this work over the last 3 years, and the web resources of **WEEDpak** have been enriched with an additional 12 inputs. A further 14 weeds have been added to the **WEEDpak Weed Identification Guide**, and the **Herbicide Damage Identification & Information Guide** and **Weeds Growth & Development Guide** have been created and added to **WEEDpak**.

The project's outputs fell into 3 broad groups. These were:

I. Scientific papers on weed competition and 2,4-D tolerant cotton,

II. A series of articles and presentations on the weed control threshold, its development and application, and

III. A series of articles and presentations on the identification of herbicide damage, and the consequences of damage for the crop.

These outputs fully realise the planned outcomes of these projects, providing readily accessible and readily usable information to the cotton industry on these subjects.

At first glance it may appear that the project has not been effective in fully analysing the data collected in the project. However, this observation fails to recognise that an unanticipated part of the project was to tabulate, analyse and develop 3 years of earlier work undertaken on the weed control threshold which was inherited with this project (I had thought most of the work on this data had already been done). Analysis of this work was very time consuming, but developed the framework for the weed control threshold and clarified a number of issues which needed to be further explored in this data, more accurately focusing much of the work over the past 3 seasons.

2. **Please describe any:-**

   a) **technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.);**

   No information of this type has been generated in this project.

   b) **other information developed from research (eg discoveries in methodology, equipment design, etc.); and**

   No information of this type has been generated in this project.

   c) **required changes to the Intellectual Property register.**

   No changes should be required. All information coming from this project has been published as scientific papers, articles in the Australian CottonGrower or other extension material with permission of the Cotton CRC, or on the Cotton CRC website.

Conclusion

3. **Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. What are the take home messages?**

Results & conclusions:

Adoption of the weed control threshold has the potential to lift the management of weeds in cotton from an art to a science, where management inputs are directly related to the damage done by the weeds. As with other pest thresholds, the weed control threshold has the potential to improve the management on properties which are already well managed, taking much of the guess work out of management decisions. As with other thresholds, it also gives managers an understanding of when weeds can be present without causing economic damage, and when weeds must be controlled to prevent yield loss or to prevent a build up in the seed bank. Optimizing of weed management inputs also has benefits for the management of species shift and herbicide resistance, and reduces the potential to overuse these pesticides. Adoption of the threshold will optimize pesticide inputs and support the push to higher crop yields.

An understanding of the herbicide damage information should have a large impact on those growers unfortunate enough to suffer herbicide damage. The data:

- Highlights the potential impact on cotton from exposure to a range of herbicides,
- Gives growers information to allow them to assess the type of damage they have suffered and the likely effect on the crop, and
- Enables growers to make informed decisions regarding the future management of damaged crops.

An understanding of this information should:

- Encourage growers to be extra vigilant with the use of some pesticides,
- Give growers independent information they can discuss with neighbours highlighting the importance of avoiding herbicide drift, and
- Ensure damaged crops are not unnecessarily terminated, or resources waisted on damaged crops which are unlikely to adequately respond.

Take home messages:

Species shift and herbicide resistant weeds, and herbicide damage are becoming increasingly important issues for the Australian cotton industry, although the importance of species shift and resistance may not yet be recognised by some cotton growers.

The information from this project is directly applicable to the cotton industry and will need to be applied if the industry is to achieve best management of weeds in cotton and make informed decisions regarding the management of herbicide damaged cotton.

The take home messages from this work are that:

- Herbicide resistance and species shift is no longer a threat, but a reality of the current farming system. This is not a cotton specific issue, but a symptoms of a breakdown in the whole farming system. That breakdown being the replacing of an integrated weed management system with a glyphosate centric system.

- A weed control threshold has been developed which enables glyphosate use to be optimized and is an essential step in the IWM system to deal with resistance and species shift. Adoption of a weed control threshold is a superior best-management practice, which optimizes inputs, reduces selection pressure on weeds and reduces the potential problems with herbicide drift and contamination by ensuring that pesticides are only used when they are economically justified.
- Herbicide damage is a serious issue for the cotton industry, but that crop response is not a simple story. The degree of crop damage depends on a range of factors, including crop growth stage, herbicide type and herbicide rate. Decisions on the management of herbicide damaged crops need to be based on an understanding of the likely scenario for each damage situation.

Extension Opportunities

4. Detail a plan for the activities or other steps that may be taken:
(a) to further develop or to exploit the project technology.

It is essential that the data collected in the project is processed and analysed to ensure the maximum benefit is achieved from this work. This is especially true of the validation and GreenSeeker data collected for the weed threshold work over the past 2 seasons. After discussion, it has been decided that Mr. Charles will spend much of his time in the early part of the new project (1.01.64) analysing and developing the data from the threshold component of the existing research, with the intention of publishing this work as a PhD and a series of scientific papers. This data will also be available to the industry. Consequently, project 1.01.64 has been structured with a reduced field work load and inclusion of a staff member to assist with the entry and analysis of the data from projects 1.01.09 and 1.01.49. This staff member will also ensure that data from the new project ware being processed as the project progresses.

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

The next step in dissemination of the project's technology is the uptake of the weed control threshold concept by the cotton extension team, leading to the uptake of this approach by the cotton industry. Probably the simplest approach for this would be to have the each member of the extension team agree to adopt the approach on 1 or 2 fields on key collaborating properties in each valley, showing the staff of these properties how to undertake the weed surveys and how the adoption of the threshold approach can optimize weed management decisions. However, this decision, on how best to extend this research, needs to be made in consultation with funding bodies and the extension team.

Further information has been added to **WEEDpak** on the CRC web in the last few months detailing:

- weed growth & development data for 18 key weeds,

- crop impacts and herbicide damage images for 5 additional herbicides, and
- herbicide damage symptoms for 12 additional herbicides.

Articles highlighting these additions to **WEEDpak** will be produced for the Australian CottonGrower in the next few weeks follow completion of this report and also for inclusion in Cotton Tales. Results from the project will also be promoted in articles and meetings as opportunities arise.

(c) for future research.

The future research needs and activities to build on this project have been outlined in Project 1.01.64, which was recently approved by CRDC and the Cotton CRC. These are:

- to expand and develop the herbicide damage data base, examining the effects of multiple low rates of 2,4-D on cotton growth and developing and extending the range of additional herbicides covered,
- to explore other management options for herbicide damaged cotton,
- to explore the apparent differences in varietal sensitivity to phenoxy herbicides, and
- to continue developing the weed control threshold model.

A component of research not planned at this time, is to expand the data set in the **Weed Growth & Development Guide** in **WEEDpak**. Currently, 18 weed are covered in the guide, but many of these have incomplete data sets, and most of the data are based on growth cabinet results which may not be an ideal guide to the growth of these weeds in the field. Improving and expanding this data set could form the basis of a new project commencing in 2012 after the completion of project 1.01.64.

Publications

9. A. List the publications arising from the research project and/or a publication plan.

- Charles G. W. and Taylor I. N. (2006). Positioning the second generation of herbicide tolerant cotton varieties – Roundup Ready Flex® and Liberty Link® cottons – into Australian cotton farming systems: opportunities and threats. 15th Australian Weeds Conference, Adelaide, p. 359-362. **Appendix** pages 33-36.
- Charles G. W. and Taylor I. N. (2006). Opportunities and threats with Roundup Ready Flex® and Liberty Link® cottons, the next generation of herbicide tolerant cotton varieties. 13th Australian Cotton Conference, Gold Coast, Qld, p. 411-416. **Appendix** pages 37-41.
- Charles, G. (2006). Managing weeds in vetch rotation crops. *The Australian Cottongrower* 27, (2): 22, 24. **Appendix** pages42-43.
- Charles, G. (2006). **WEEDpak** updated with new management tools. *The Australian Cottongrower* 27, (4): 20. **Appendix** page 44.
- Charles, G. (2006). The 3 ‘whats’ of managing herbicide damage. 2006 Lower Namoi Field Day Book, p. 65. **Appendix** page 45.

- Charles, G. (2006). Hands-on-research: 2,4-D & glyphosate damage to cotton. 13th Australian Cotton Conference, Broadbeach, pp. 8. **Appendix** pages 46-53.
- Charles G. W., Constable G. A., Llewellyn D. J. and Hickman M. (2007). Tolerance of cotton expressing a 2,4-D detoxification gene to 2,4-D applied in the field. *Australian Journal of Agricultural Research* **58**: 780-787. **Appendix** pages 54-61.
- Charles G. W. and Taylor I. N. (2007). Developing a threshold model for controlling weeds in glyphosate resistant cotton. Proceedings of the World Cotton Research Conference-4, Lubbock TX, Sept. 10-14, 2007. M. Stephens (Ed.), Lubbock, Texas. **Appendix** pages 62-83.
- Charles, G. (2007). Weed priorities. Cotton Catchment Communities Review, Narrabri, p. 10. **Appendix** page 84.
- Charles, G. (2007). Understanding the 'critical period for weed control' concept. *The Australian Cottongrower* **28, (4):** 48-50. **Appendix** pages 85-87.
- Charles, G. (2007). Applying the 'critical period for weed control' in the field. *The Australian Cottongrower* **28, 4):** 51-53. **Appendix** pages 88-90.
- Charles, G and Taylor, I. (2008). Using the critical period for weed control to manage weeds in Roundup Ready Flex® cotton in the 2007/8 season. Proceedings of the 14th Australian Cotton Conference, Broadbeach, Qld., 12-14 August 2008. **Appendix** pages 91-97.
- Charles, G. (2008). Managing herbicide resistance in cotton: why is the Crop Management Plan important. Proceedings of the 14th Australian Cotton Conference, Broadbeach, Qld., 12-14 August 2008. **Appendix** pages 98-104.
- Charles, G. (2008). Developing a weed control threshold and managing herbicide damage in cotton. Proceedings of the Cotton Catchment Communities Cooperative Research Centre 3rd Year Review, Narrabri, 15-16 October 2008. **Appendix** page 105.
- Charles, G., Taylor, I. and Farrell, T. (2008). Roundup ready Flex and the critical period for weed control. *The Australian Cottongrower* **29, (1):** 38-43. **Appendix** pages 106-110.
- Charles, G. and Taylor, I. (2008). How well does the critical period for weed control (CPWC) work? *The Australian Cottongrower* **29, (7):** 40-42. **Appendix** pages 111-113.
- Ceeney, S., Charles, G., Hickman, M., Thornby, D., Walker, S. and Werth, J. (2009). ACRI. Glyphosate resistance: know your risk. Cotton Trade Show, Moree, 27-28 May 2009. **Appendix** pages 114-116.
- Charles G. and Larsen, D. (2009). Herbicide damage symptoms. Cotton Trade Show, Moree, 27-28 May 2009. **Appendix** page 117.
- Charles G. and Larsen, D. (2009). Herbicide damage symptoms - phenoxy. Cotton Trade Show, Moree, 27-28 May 2009. **Appendix** page 118.

- Charles G. W. (2009). The 3 WHATS of managing herbicide damage. Lower Namoi 2009 Field Day book. p. 15. **Appendix** page 119.

B. Have you developed any online resources and what is the website address?

Yes – all material is on the Cotton CRC website, under **Industry/Publications/Weeds** and either **WEEDpak**, **Weed Identification Tools**, or **Herbicide Damage Identification and Information**.

- Charles G. (2008). Weed identification and information guide (update). In '**WEEDpak** – a guide for integrated management of weeds in cotton'. Available through the web & **COTTONpaks CD**. **Appendix** pages 120-147.
- Charles G. (2008). Integrated weed management (update). In '**WEEDpak** – a guide for integrated management of weeds in cotton'. Available through the web & **COTTONpaks CD**, pp. 4. **Appendix** pages 148-151.
- Charles G. (2008). The critical period for weed control sampling sheet. In '**WEEDpak** – a guide for integrated management of weeds in cotton'. Available through the web & **COTTONpaks CD**, pp. 2. **Appendix** pages 152-153.
- Charles G. (2008). Understanding the critical period for weed control concept. In '**WEEDpak** – a guide for integrated management of weeds in cotton'. Available through the web & **COTTONpaks CD**, pp. 4. **Appendix** pages 154-157.
- Charles G. (2008). Applying the critical period for weed control in the field. In '**WEEDpak** – a guide for integrated management of weeds in cotton'. Available through the web & **COTTONpaks CD**, pp. 4. **Appendix** pages 158-161.
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Cotton CRC Project Title (1.01.49): The development of weed control thresholds and management of herbicide damage in cotton

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Following the introduction of transgenic, herbicide tolerant varieties, the Australian cotton industry has developed glyphosate-centric weed management systems which are less reliant on residual herbicides and non-herbicide methods of weed control, such as cultivation and hand hoeing, than has been the case in the past. These systems have contributed to improved crop yields, while reducing the environmentally negative aspects of cotton production. However, farming systems which rely too heavily on a single weed management tool are not sustainable, with inevitable shifts to weed species that are tolerant of the management tool. Where the single management tool is a herbicide, such as glyphosate, selection of herbicide resistant weed species is also likely.

The primary aim of this project was to develop "intelligent" weed management systems for transgenic cotton to optimize herbicide use, achieving better yields, while maintaining the value of glyphosate to the farming system by minimizing the selection pressure for species shift and glyphosate resistant weeds. This was achieved using a series of field experiments to develop a weed control threshold based on the critical period for weed control concept.

Information on the weed control threshold and sampling techniques has been extended to the industry through articles in the Australian CottonGrower and in **WEEDpak** on the Cotton CRC website. Ongoing work is looking at developing a simplified sampling technique for the threshold using an electronic sensor to estimate weed biomass and hence weed competitiveness.

Information on weed growth, development and seed production has also been produced to provide guidance for the control of weed populations which are below threshold, ensuring that weeds are controlled before they set seed.

The 2nd aim of the project was to provide cotton growers with information to allow them to assess the likely effects of herbicide damage on a cotton crop in terms of final yield and maturity, and subsequently to make better informed management decisions for herbicide damaged crops.

A series of field experiments explored the effects of a range of phenoxy and other herbicides on post-damage crop growth and development, including leaf, square and boll production, crop maturity and final yield. Herbicides have been applied at varying rates and stages of crop development. This information has been published in **WEEDpak** on the Cotton CRC website, along with information assisting cotton growers to compare the post-damage symptoms for a range of herbicides.

Experiments have also explored post-damage crop management options, but to date have found no options which improve crop recovery.

These outcomes significantly progress the science of weed management in the Australian cotton industry, providing guidelines for best practices for weeds.

Positioning the 2nd generation of herbicide tolerant cotton varieties – Roundup Ready® Flex and Liberty Link® cottons – into Australia cotton farming systems: opportunities and threats

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Summary Roundup Ready® cotton has been commercially available to Australian cotton growers for five years and has been widely adopted by the industry with approximately 77% of the area planted to Roundup Ready cotton in the 2005/06 season. The next generation of herbicide tolerant cotton varieties Roundup Ready® Flex and Liberty Link® are likely to become commercially available over the next couple of years. These traits will allow the cotton industry to further develop in-crop weed management systems that may rely almost exclusively on the use of one or other of these technologies. This is likely to result in a further decrease in the use of residual herbicides, inter-row cultivation and hand-hoeing. Adoption of these new technologies should overcome some seedling establishment problems, allow better yields and reduce problems of environmental contamination currently occurring with residual herbicides. However, their use is also likely to further exacerbate problems with species shifts, herbicide spray drift and the control of volunteer crop plants, as well as increasing the risk of weeds developing herbicide resistance. This paper explores these issues and their potential implications for the northern farming system and offers options to minimise the possible risks associated with introducing these technologies.

Keywords GM cotton, resistance, species shifts, tolerance, Roundup Ready Flex®, Liberty Link®.

INTRODUCTION

Australian agriculture has rapidly embraced most new technologies, but for various reasons, has been slow to adopt genetically modified crops. The exception to this has been the Australian cotton industry, which has been using transgenic, insect tolerant cotton varieties for the last decade and transgenic herbicide tolerance for the last six seasons. Approximately 80% of the Australian cotton crop was transgenic insect tolerant Bollgard II® (a stack of two genes) and 77% was glyphosate tolerant, Roundup Ready® cotton in the 2005/06 season, with the combination of all three genes employed on 70% of the crop area (about 210,000 ha).

The rapid uptake of herbicide tolerant cotton can be attributed partly to the value of the technology for managing some of the more problematic weeds that are difficult to control in the traditional system, such as the nutgrasses (*Cyperus rotundus* and *C. bifax*) and the vines (*Ipomoea lonchophylla* and *I. plebia*).

However, Roundup Ready cotton is also being grown in many fields that do not have major weed problems, as additional benefits have been gained through using the technology to replace less favoured components of the system. The use of Roundup Ready cotton has lead to a large increase in the use of glyphosate in the crop, to a reduction in the use of pre-planting herbicides, and to small reductions in the use of inter-row cultivation and hand-hoeing (Werth *et al*. in press). There has also been an increase in the use of lay-by residual herbicides (applied just prior to crop canopy closure). Roundup Ready cotton allows more timely targeted management inputs, with the ability to control weeds that emerge with or soon after the crop. The crop safety of shielded glyphosate applications later in the season is greatly improved compared to conventional cotton (applications shielded to contain spray to the inter-row area, preventing contact with the crop), allowing this herbicide to be used to manage some of the more problematic weeds in cotton later in the season. These changes have contributed to improved productivity in the cotton system, with more timely weed management and reductions in crop damage from residual herbicides and cultivation.

The value of the Roundup Ready technology, however, has been limited by relatively poor expression of the gene in the reproductive parts of the cotton plant, effectively limiting the broadcast application window for glyphosate to the emergence to four node stage of plant growth, before the reproductive plant parts are initiated. This limitation has ensured that glyphosate has not replaced the other management tools in the integrated weed management system used in the cotton system, but has been a useful additional tool in the system.

The problem of poor gene expression has been overcome in Roundup Ready Flex® cotton, the second generation of herbicide tolerant cotton that is set to become commercially available in Australia in the 2006/7 season and beyond. Roundup Ready Flex cotton varieties have high levels of tolerance to glyphosate in both vegetative and reproductive phases, with potentially a season-long application window. However, in practice, broadcast applications will be limited to the emergence to 16 node stage of plant growth.

A second new technology, Liberty Link® cotton, with a high level of tolerance to glufosinate-ammonium may also become commercially available in the near future. This technology will bring a new herbicide into the cotton farming system, with good efficacy on some of the weeds that are difficult to control in conventional and Roundup Ready systems. However, the introduction of these technologies will challenge the integrity of the integrated weed management system now in use.

DISCUSSION

Managing weeds with Roundup Ready® cotton The development of a new weed management system was one of the challenges faced with the introduction of Roundup Ready cotton. Prior to the commercial release of Roundup Ready cotton it was anticipated that a weed management system relying heavily on glyphosate might develop, potentially leading to species shifts and herbicide resistance. To address this threat a crop management plan was developed that emphasised the continuing need for an integrated approach to weed management, and included assessment of the weed threat, scouting for weed escapes after a glyphosate application, and treatment of any escapes with an alternative weed management tool to prevent seed-set.

This management plan has proven to be effective, although a shift towards glyphosate tolerant weed species is already apparent in the cotton industry (Charles *et al*. 2004). This shift has not been primarily caused by the introduction of Roundup Ready cotton, but has been a response to a general change in the farming system to using glyphosate as the primary weed management tool in place of cultivation. The species shift is being managed with alternative management tools and has not caused major problems to date.

Problems with the management of volunteer Roundup Ready cotton plants were also anticipated, but were not expected to be a major issue. However, adoption of Roundup Ready cotton has led to significant problems with the management of volunteer plants, to increasing problems with herbicide (glyphosate) drift, and to problems with the management of weeds in the areas around cotton fields, particularly in irrigation structures.

Problems with the control of volunteer cotton plants have highlighted the heavy reliance on glyphosate for weed control in fallows over the summer period in the cotton farming system, particularly in zero-till systems where standing crop stubble is retained. Seedling volunteers can be controlled with alternative chemistry such as paraquat + diquat (Spray.Seed®) or carfentrazone-ethyl (Hammer®), but there are few options other than cultivation for the removal of these weedy plants once they are well established. Maintaining good fallow hygiene and controlling seedling volunteers with non-glyphosate options has become an important part of the transgenic farming system.

Problems with volunteer Roundup Ready cotton plants also occur in back-to-back cotton, where a Roundup Ready cotton crop follows a previous Roundup Ready crop and are much worse where reduced rates of residual herbicides are used at planting. Far higher numbers of volunteer cotton plants may establish than is normally the case where standard rates of residual herbicides are used. Three or four inter-row cultivation passes may be required to manage these volunteers, reducing the value of the technology, and potentially leaving an excessive population of cotton in the plant-line. This problem is most readily overcome by rotating cotton with a winter crop and ensuring that crop volunteers are managed in the summer fallow.

Far too many instances of herbicide drift from broadcast applications of glyphosate to Roundup Ready cotton have occurred, with damage reported on crops such as conventional cotton and sorghum. Problems with glyphosate drift from Roundup Ready cotton have been accentuated by the necessity of making a broadcast glyphosate application no later than the four node stage of crop development. This application is often delayed as late as possible to ensure maximum effectiveness is achieved with the spray. However, when wet and windy conditions then occur it has on some occasions become necessary to apply the herbicide under less than ideal conditions, increasing the risk of spray drift.

Where the adoption of Roundup Ready cotton has led to large reductions in the use of pre-emergent residual herbicides in fields, problems have developed with weeds in irrigation channels and surrounding areas. It has become apparent that many of these weeds were largely controlled in the traditional system by residual herbicides that moved out of the crop area in irrigation tail water. With a reduction in the use of these herbicides, volunteer cotton, weeds and particularly grass weeds, have become more problematic, potentially creating a seed source for re-infesting the fields. This problem has been exacerbated by the tendency to use glyphosate as the primary weed control tool in these areas and is necessitating the use of residual herbicides, cultivation and alternative herbicides such as amitrole + ammonium thiocyanate (Amitrole T®) and paraquat + diquat (Spray.Seed) to manage these areas.

Opportunities and threats with Flex® The introduction of Roundup Ready Flex will allow cotton growers to develop weed management systems that are much less reliant on traditional inputs, and to manage some problematic weeds with much better crop safety.

On cotton fields that have relatively low weed pressure, it is likely that systems will develop that rely almost solely on glyphosate, with no pre-emergence residual herbicide, little or no hand-hoeing, and no inter-row cultivation for weed control. Some inter-row cultivation may still be necessary to incorporate a lay-by residual herbicide and to facilitate the movement of irrigation water. Such a system will be conducive to optimal crop yields but will inevitably lead to problems with species shifts to glyphosate tolerant species and may lead to the development of herbicide resistance. Modelling has shown that resistance is unlikely to occur in the short-term in the irrigated cotton system (Werth *et al*. 2006), but is more likely in the rain-fed cotton system where cotton is a less significant component of the whole system. Nevertheless, Roundup Ready Flex cotton will give growers the opportunity to develop a weed management system, which is more environmentally friendly (with less cultivation and residual herbicide) and is consistent with good crop management. Regular cropping rotations with winter cereals (a common practice) will continue to give opportunities to manage weeds with other technologies and can decrease the selection pressure on weeds.

Where species shifts do lead to problematic levels of glyphosate tolerant weeds, cotton growers will have the opportunity to rotate to an alternative crop and use different chemistry, or to re-introduce some of the conventional weed management tools. In an extreme case, a cotton grower may choose to fully reintroduce a conventional weed management program to manage species shifts.

In high weed pressure fields and where problem weeds are common, glyphosate will continue to be a valuable tool in a Roundup Ready Flex system that continues to incorporate most of the more conventional weed management tools in an integrated weed management system.

Problems with glyphosate drift should decline with Roundup Ready Flex cotton due to the much extended window for broadcast applications with this technology allowing applications to be delayed until conditions are favourable.

Problems with the management of glyphosate tolerant weeds and crop volunteers are likely to be increased with Roundup Ready Flex cotton. While these problems can be addressed using an integrated approach with cultivation, residual and alternative herbicides, this will increase the cost of the overall system, reducing its value. Over time, cotton growers should be able to reduce the weed seed bank on most cotton fields, and may then have the opportunity to return to a more traditional weed management system using lower herbicide rates. This decision will be driven by the cost of the technology.

Opportunities and threats with Liberty Link® The introduction of Liberty Link cotton brings the opportunity to introduce a new herbicide to the cotton farming system, with very good crop safety. Liberty® (glufosinate-ammonium) is effective on a wide range of broad-leaf weeds, some of which are not well controlled by glyphosate, but has much poorer efficacy on the grasses. It is weakly translocated and has no efficacy on the nutgrasses, one of the strengths of glyphosate.

A cropping system for Liberty Link cotton could develop that is similar to the Roundup Ready Flex system, with reduced inputs of residual herbicides, inter-row cultivation and hand-hoeing, but it is likely that a Liberty system would need to retain a pre-emergence residual grass herbicide.

Such a system would have similar advantages to a Roundup Ready Flex system, but also have some of the same disadvantages. Liberty Link cotton plants will be no different to conventional plants in their tolerance to the herbicides normally used in fallows and rotation crops and will be controlled by glyphosate. Consequently, their management in fallows and rotation crops should raise no additional difficulties. However, back-to-back Liberty Link crops will see significant problems with crop volunteers. Problems with herbicide drift will also be similar to those with Roundup Ready Flex cotton, although the consequences of drift are likely to be less severe, as glufosinate-ammonium is only weakly translocated in the plant and will have a more transitory effect. Problems with weeds in irrigation structures and surrounding areas will be similar to the problems with Roundup Ready Flex cotton.

However, it may be that a cropping system with Liberty Link cotton may be more like the traditional cotton system. The relative costs of the Liberty Link cotton technology and Liberty herbicide will have a large influence on the use of this technology. Glufosinate-ammonium has traditionally been a relatively expensive herbicide and one possible scenario is a lower price for the technology license fee, combined with a higher product cost when compared to Roundup Ready Flex cotton. In this scenario, it is likely that Liberty Link cotton may be grown using a more traditional weed management system, with Liberty most frequently used as a directed spray to manage problem weeds. The Liberty Link cotton would be grown within an integrated weed management framework and should have few associated problems other than the control of crop volunteers in back-to-back Liberty Link crops.

A herbicide tolerant farming system The best value from herbicide tolerant cotton varieties will be achieved by continuing to use this technology in an integrated weed management system, where weeds are prevented from setting seed, reducing the size of the weed seed-bank over time. As the size of the weed seed-back declines, it may be desirable to return to a more traditional weed management approach using non-herbicide tolerant cotton varieties.

Where possible, these technologies should be used in a rotational cropping system, where problems with volunteer crop plants can be managed in a rotation crop or fallow. Alternatively, rotation of the two technologies may give the best outcome in a continuous cotton system.

CONCLUSIONS

Continuing adoption of a crop management plan based on the premise of preventing weed escapes setting seed should maintain the viability of the herbicide tolerant systems in the medium term. However, the management of herbicide drift, volunteer crop plants and weeds around cotton fields will continue to be important issues, with different issues faced in back-to-back cotton compared to systems that include a cropping rotation. It seems likely that the value of these technologies will decline over time as weed densities decline in-field, and species shifts reduces the effectiveness of herbicide applications.

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Opportunities and Threats with Roundup Ready® Flex and Liberty Link® cotton, the next generation of herbicide tolerant cotton varieties

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Summary

Roundup Ready® cotton has been commercially available to Australian cotton growers for five years and has been widely adopted by the industry with approximately 77% of the area planted to Roundup Ready cotton in the 2005/06 season. The next generation of herbicide tolerant cotton varieties; Roundup Ready® Flex and Liberty Link®, are likely to become commercially available over the next couple of years. These traits will allow the cotton industry to further develop in-crop weed management systems that may rely almost exclusively on the use of one or other of these technologies. The widespread adoption of these technologies is likely to result in a further decrease in the use of residual herbicides, inter-row cultivation and hand-hoeing in cotton fields. Adoption of these systems should reduce crop establishment problems, allow better yields and reduce problems of environmental contamination currently occurring with residual herbicides. However, their use is also likely to further exacerbate problems with species shift, herbicide spray drift and the control of volunteer crop plants, as well as increasing the risk of weeds developing herbicide resistance.

Introduction

Australian agriculture has rapidly embraced most new technologies, but for various reasons, has been slow to adopt genetically modified crops. The Australian cotton industry has been the exception to this rule, using transgenic, insect tolerant cotton varieties for the last decade and transgenic herbicide tolerance for the last six seasons. Approximately 80% of the Australian cotton crop was transgenic insect tolerant Bollgard II® (a stack of two genes) and 77% was glyphosate tolerant, Roundup Ready® cotton in the 2005/06 season, with the combination of all three genes employed on 70% of the crop area (about 210 000 ha).

The rapid uptake of herbicide tolerant cotton can be attributed partly to the value of the technology for managing some of the more problematic weeds that are difficult to control in the traditional system, such as nutgrass, cowvine (peachvine) and bellvine. However, Roundup Ready cotton is also being grown in many fields that do not have major weed problems, as additional benefits have been gained through using the technology. These benefits include broad-spectrum post-emergence weed control through the use of Roundup Ready Herbicide in crop, the ability to easily control weeds in cotton planted into standing crop stubble and narrow-row configurations, the ability to replace less favored components of the system, such as hand-hoeing and inter-row cultivation, a reduction in seedling establishment problems where the technology has replaced pre-planting and at-planting residual herbicide applications, and as drift protection against the possibility of glyphosate drift occurring. The use of Roundup Ready cotton has lead to a large increase in the use of glyphosate in the crop, to a reduction in the use of pre-planting herbicides, and to small reductions in the use of inter-row cultivation and hand-hoeing. There has also been an increase in the use of lay-by residual herbicides. Roundup Ready cotton allows more timely targeted management inputs, with the ability to control weeds that emerge with or soon after the crop. The crop safety of shielded glyphosate applications later in the season is greatly improved compared to conventional cotton, allowing this herbicide to be used to manage some of the more problematic weeds in cotton later in the season. These changes have contributed to improved productivity in the cotton system, with more timely weed management and reductions in crop damage from herbicides and cultivation.

The value of the Roundup Ready technology, however, has been limited by relatively poor expression of the gene in the reproductive parts of the cotton plant, effectively limiting the broadcast application window for glyphosate to the emergence to 4-node stage of plant growth, before the reproductive plant parts are initiated. This limitation has ensured that glyphosate has not replaced the other management tools in the integrated weed management system used in the cotton system, but has been a valuable additional tool in the system. The problem of poor gene expression has been overcome in Roundup Ready Flex® cotton, the second generation of herbicide tolerant cotton that is set to become commercially available in Australia in the 2006/7 season and beyond. Roundup Ready Flex cotton varieties have much high levels of tolerance to glyphosate in both vegetative and reproductive phases, with an extended over-the-top Roundup application window.

A second new technology, Liberty Link® cotton, with a high level of tolerance to glufosinate-ammonium may also become commercially available in the near future. This technology will bring a new herbicide into the cotton farming system, with good efficacy on some of the weeds that are difficult to control in conventional and Roundup Ready systems. However, the introduction of these technologies may challenge the integrity of the integrated weed management system now in use.

Managing weeds with Roundup Ready® cotton

The development of a new weed management system was one of the challenges faced with the introduction of Roundup Ready cotton. Prior to the commercial release of Roundup Ready cotton it was anticipated that a weed management system relying heavily on glyphosate might develop, potentially leading to species shifts and herbicide resistance developing. To address this threat a crop management plan was developed that emphasized the continuing need for an integrated approach to weed management, and included assessment of the weed threat, scouting for weed escapes after a glyphosate application, and treatment of any escapes with an alternative weed management tool to prevent seed-set. This management plan has proven to be effective, although a shift towards glyphosate tolerant weed species is already apparent in the cotton industry, as shown by results of a series of in-crop weed surveys. This shift has not been primarily caused by the introduction of Roundup Ready cotton, but has been a response to a general change in the farming system to using glyphosate as the primary weed management tool in place of cultivation, especially in fallow weed control. The species shift is being managed with a range of alternative weed management tools and has not caused major problems to date.

A number of other problems have, however, occurred subsequent to the introduction of Roundup Ready cotton. Problems with the management of volunteer Roundup Ready cotton plants were anticipated, but were not expected to be a major issue. However, adoption of Roundup Ready cotton has led to significant problems with the management of volunteer plants, to increasing problems with herbicide (glyphosate) drift, and to problems with the management of weeds in the areas around cotton fields, particularly in irrigation structures.

Problems with the control of volunteer cotton plants have highlighted the heavy reliance on glyphosate for weed control in fallows over the summer period in the cotton farming system, particularly in zero-till systems where standing crop stubble is retained. Seedling volunteers can be controlled with alternative chemistry such as Spray.Seed® (paraquat+diquat) or Hammer® (carfentrazone-ethyl), but there are few options other than cultivation for the removal of these weedy plants once they are well established. Maintaining good fallow hygiene and controlling seedling volunteers with non-glyphosate options has become an essential component of the transgenic farming system. Problems with volunteer Roundup Ready cotton plants also occur in back-to-back cotton and are much worse where reduced rates of residual herbicides are used at planting. Where no residual herbicides are used prior to or at planting far higher numbers of volunteer cotton plants may establish than is normally the case where standard rates of residual herbicides are used. Three or four inter-row cultivation passes may be required to manage these volunteers, reducing the value of the technology, and potentially still leaving an excessive population of cotton in the plant-line, particularly problematic when there has been a change in the cotton variety. This problem is most readily overcome by rotating cotton with a winter crop and ensuring that crop volunteers are managed in the summer fallow.

Far too many instances of herbicide drift from broadcast applications of glyphosate to Roundup Ready cotton have occurred, with damage reported on surrounding crops including conventional cotton and sorghum. Problems with glyphosate drift from Roundup Ready cotton have been accentuated by the necessity of making a broadcast glyphosate application no later than the 4-node stage of crop development. This application is often delayed as late as possible to ensure maximum effectiveness is achieved with the spray. However, when wet and windy conditions then occur it has on some occasions become necessary to apply the herbicide under less than ideal conditions, increasing the risk of spray drift.

Where the adoption of Roundup Ready cotton has led to large reductions in the use of pre-emergent residual herbicides in fields, problems have developed with weeds in irrigation channels and surrounding areas. It has become apparent that many of these weeds were largely controlled in the traditional system by residual herbicides that moved out of the crop area in irrigation tail water. With a reduction in the use of these herbicides, volunteer cotton, weeds and particularly grass weeds, have become more problematic, potentially creating a seed source for re-infesting the fields. This problem has been exacerbated by the tendency to use glyphosate as the primary weed control tool in these areas and is necessitating the use of residual herbicides, cultivation and alternative herbicides such as Amitrole T (amitrole+ammonium thiocyanate ®) and Spray.Seed to manage these areas.

Opportunities and threats with Roundup Ready Flex® cotton

The introduction of Roundup Ready Flex will allow cotton growers to develop weed management systems that are much less reliant on traditional inputs, and to manage some problematic weeds with improved crop safety. On cotton fields that have relatively low weed pressure, it is likely that Roundup Ready Flex systems will develop that rely almost solely on glyphosate, with no pre-emergence or at-planting residual herbicides, little or no hand-hoeing, and no inter-row cultivation for weed control. Some inter-row cultivation may still be necessary to incorporate a lay-by residual herbicide and to facilitate the movement of irrigation water. Such a system will be conducive to optimal crop yields but will inevitably lead to problems with species shifts to glyphosate tolerant species and may lead to the development of herbicide resistance. Modeling undertaken by Jeff Werth has shown that resistance is unlikely to occur in the short-term in the irrigated cotton system, but is more likely with rain-fed cotton where cotton is a less significant component of the whole system. Nevertheless, Roundup Ready Flex cotton will give growers the opportunity to develop a weed management system which is more environmentally friendly (with less cultivation and residual herbicide) and is consistent with good crop management. Regular cropping rotations will provide opportunities to manage weeds with other technologies and can decrease the selection pressure on weeds. Where species shift does lead to problematic levels of glyphosate tolerant weeds, cotton growers will have the opportunity to rotate to an alternate crop and use different herbicide chemistry, or to re-introduce some conventional weed management tools. In an extreme case, a cotton grower may opt to use a conventional weed management program to manage glyphosate tolerant weeds.

In high weed pressure fields and where problem weeds such as nutgrass are common, glyphosate will continue to be a valuable tool in a Roundup Ready Flex system that continues to incorporate many of the more conventional weed management tools in an integrated weed management system.

Problems with glyphosate drift should decline with Roundup Ready Flex cotton due to the much extended window for broadcast applications with this technology allowing applications to be delayed until conditions are favorable for ground-rig application.

Problems with the management of glyphosate tolerant weeds and crop volunteers are likely to be increased with Roundup Ready Flex cotton. While these problems can be addressed using an integrated approach with cultivation, residual and alternative herbicides, this will increase the cost of the overall system, reducing its value. Over time, cotton growers should be able to reduce weed pressure and the weed seed bank on most cotton fields, and may then have the opportunity to return to a more traditional weed management system using lower herbicide rates. This decision will be driven by a range of factors including the cost of the technology.

Opportunities and threats with Liberty Link® cotton

The introduction of Liberty Link cotton brings the opportunity to introduce a new herbicide to the cotton farming system, with very good crop safety. Liberty® (glufosinate-ammonium) is effective on a wide range of broad-leaf weeds, some of which are not well controlled by glyphosate, but has poorer efficacy on the grasses. It is weakly translocated and has no efficacy on the nutgrasses, one of the strengths of glyphosate.

A cropping system for Liberty Link cotton could develop that is similar to the Roundup Ready Flex system, with reduced inputs of residual herbicides, inter-row cultivation and hand-hoeing, but it is likely that a Liberty system would need to retain a pre-emergence residual grass herbicide due to the poor efficacy of this product on grasses.

Such a system would have similar advantages to a Roundup Ready Flex system, but also have many of the same disadvantages. Liberty Link cotton plants will be no different to conventional plants in their tolerance to the herbicides normally used in fallows and rotation crops and will be controlled by glyphosate. Consequently, their management in fallows and rotation crops should raise no additional difficulties over that of conventional cotton. However, back-to-back Liberty Link crops will see significant problems with crop volunteers. Problems with herbicide drift will also be similar to those with Roundup Ready Flex cotton, although the consequences of drift may be less severe, as glufosinate-ammonium is only weakly translocated in the plant and will have a more transitory effect. Problems with weeds in irrigation structures and surrounding areas will be similar to the problems with Roundup Ready Flex cotton where weed problems are accentuated by a reduction in the use of residual herbicides in crop.

However, it may be that a cropping system with Liberty Link cotton may be more like the traditional cotton system. The relative costs of the Liberty Link cotton technology and Liberty herbicide will have a large influence on the use of this technology. Glufosinate-ammonium has traditionally been a relatively expensive herbicide and one possible scenario is a lower price for the technology license fee, combined with a higher product cost when compared to Roundup Ready Flex cotton. In this scenario, it is likely that Liberty Link cotton may be grown using a more traditional weed management system, with most weeds controlled by conventional means and Liberty used as a directed spray to manage problem weeds. In this scenario Liberty Link cotton would be grown within an integrated weed management framework and would have few associated problems other than the control of crop volunteers in back-to-back Liberty Link crops.

A herbicide tolerant farming system

The best outcome from herbicide tolerant cotton varieties will be achieved by continuing to use these technologies in an integrated weed management system, where weeds are prevented from setting seed, reducing the size of the weed seed-bank and weed pressure over time. As the weed seed-back declines, it may be economically desirable to return to a more traditional weed management approach using non-herbicide tolerant cotton varieties.

Where possible, these technologies should be used in a rotational cropping system, where problems with volunteer crop plants can be managed in a rotation crop or fallow. Alternatively, rotation of the two technologies may give the best outcome in a continuous cotton system.

Conclusions

- Continuing adoption of a crop management plan based on the premise of preventing weed escapes setting seed should maintain the viability of the herbicide tolerant systems.
- The management of herbicide drift, volunteer crop plants and weeds around cotton fields will continue to be important issues, with different issues faced in back-to-back cotton compared to systems that include a cropping rotation.
- It seems likely that the value of these technologies will decline over time as weed densities decline in-field, and species shifts reduces the effectiveness of herbicide applications.

Acknowledgments

We greatly acknowledge the ongoing support of the Cotton Research and Development Corporation and the Cotton Catchment Communities Cooperative Research Centre.

Managing weeds in vetch rotation crops

By Graham Charles, NSW DPI and Cotton Catchment Communities CRC

Vetch is being increasingly grown as an alternative rotation crop for cotton. It is a useful green manure crop, and is capable of adding large amounts of nitrogen to the soil.

Vetch crops can be sown in autumn into a fallow or crop stubble. They are commonly sown into cotton stubble soon after picking. Vetch grows over winter, and is normally removed in early spring, prior to cotton planting and before the vetch has started to set seed.

Removing the crop prior to seed-set is important as vetch is hard seeded and can produce large quantities of viable seed. If it is allowed to seed, vetch will be a nuisance weed in later cotton crops.

Weed management in vetch is problematic, with few herbicides registered for in-crop weed control and none registered for controlling the vetch to allow replanting back to cotton, where this option is desired.

It is a legal requirement that pesticide users follow the directions on the product label. Growers who wish to make an off-label pesticide application must first obtain a minor-use permit from the APVMA for the proposed use.

Many of the herbicide options discussed in this article are off-label and must be covered by a minor-use permit.

Pre-planting herbicides

Vetch should be sown into a clean seedbed, with weeds controlled prior to planting with cultivation and/or herbicides. A wide range of products are registered for controlling weeds in fallows.

Spray.Seed (a range of trade names) and Surpass plus glyphosate (a range of trade names for both products) are registered for controlling weeds prior to planting vetch. There is a 7–10 day plant-back period constraint before planting vetch following a Surpass application.

Growers should be aware that vetch emergence and establishment may be adversely affected by residual herbicides previously applied to cotton when vetch is planted immediately following a cotton crop.

There are no pre-planting residual herbicides registered for use with vetch crops in NSW and Queensland.

A range of residual pre-planting herbicides was screened in an experiment at the ACRI in 2005. Herbicides were applied and incorporated prior to planting the vetch and the crop was watered up.

No establishment problems were observed with any of the herbicides used, with satisfactory establishment levels on all treatments.

Vetch growth was monitored following establishment. All treatments grew satisfactorily, but some stunting was observed on treatments containing simazine and fluometuron, indicating that vetch had less tolerance to these herbicides.

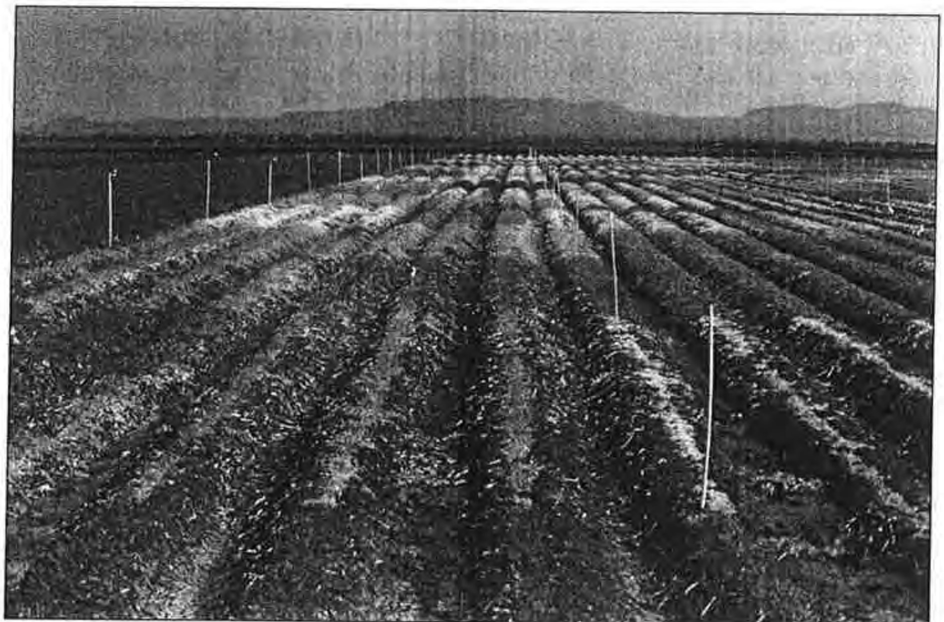
The results indicated that pendimethalin, trifluralin, diuron and prometryn might all be satisfactorily used as pre-planting residual herbicides for vetch crops.

Post-emergence weed control

A number of herbicides are registered for controlling grass weeds in vetch. These include Aramo, Correct, Fusilade Forte, FusionSuper, Targa and Verdict.

24 ▷

Vetch crops may be sown into cotton trash after picking. They can fix large amounts of nitrogen and may be plowed in as green manure, or killed by herbicides and left as a surface mulch.



Herbicide combinations for early removal of a vetch crop seven weeks after planting.

◁ 22 ... WEEDS IN VETCH

No herbicides are registered for broad-leaf weed control in vetch crops.

A range of herbicides were screened for broad-leaf weed control in vetch, not all of which could be safely used if a cotton crop was to be planted in the same season. Basagran and simazine had no negative affect on the vetch, but simazine has a long soil half-life and a nine month plant-back to cotton.

Fluometuron, prometryn and diuron all caused some initial leaf damage to the vetch, but caused no long-term damage. These products could be used with some caution, with lower rates used where possible. These products would ideally be applied as shielded or directed sprays in young vetch.

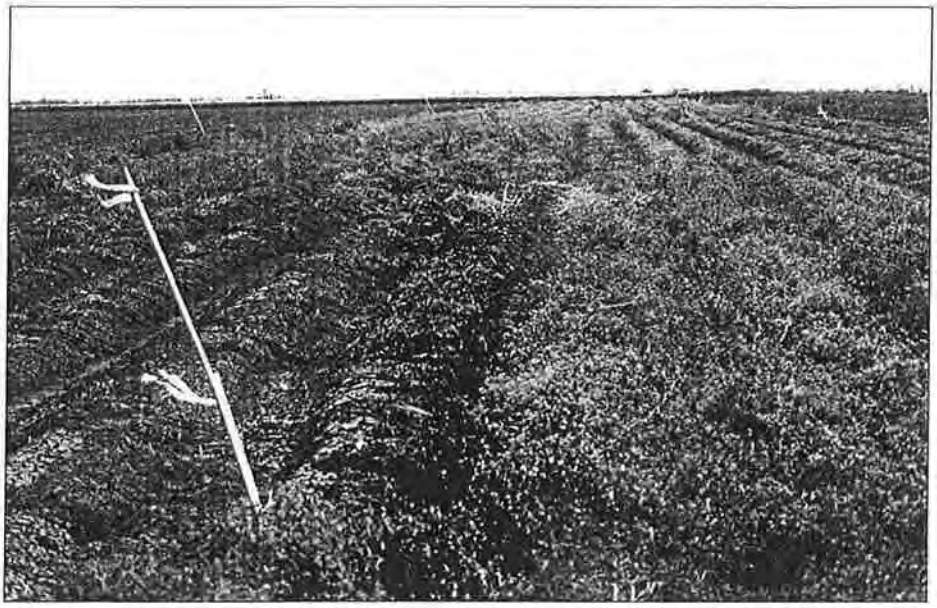
Removing vetch crops with herbicides

Vetch crops are normally planted in the autumn/winter before a cotton crop and must be killed prior to cotton planting.

Slashing and incorporating the vetch crop is the best option for removal, as this method returns the maximum amount of available nitrogen to the following cotton crop, while minimising any potential problems with insects and diseases.

There are no herbicides registered for killing a vetch crop.

A range of herbicides and herbicide combinations with Roundup PowerMAX were screened for removing young vetch in late winter, and an older crop at the flowering stage in spring.



Herbicides for late removal of a vetch crop in late September, 16 weeks after planting, when vetch was at the flowering stage.

MCPA 500 at four litres per hectare and Starane at one and two litres per hectare gave the best control of young vetch, with better than 95 per cent control observed.

Roundup PowerMAX at four litres per hectare gave a reasonable result, also controlling all other weeds present on the plots.

A range of combinations using lower rates of Roundup PowerMAX in combination with lower rates of some of the other herbicides was also screened.

The Roundup PowerMAX at one litre per hectare plus Envoke at 10 grams per hectare and Roundup PowerMAX at two litres per hectare plus Starane at one litre per hectare combinations both gave good results, although the result for the Starane combination was no improvement over Starane alone at one litre per hectare.

Cotton was planted into all treatments in early October and no phytotoxicity was observed with any of the treatments. But the Envoke label specifies a nine month plant-back period to cotton and so Envoke cannot be used to remove vetch this close to a cotton crop.

A later application was made to much larger vetch on September 30, 16 weeks after planting.

Envoke at 20 grams per hectare, Starane at one and two litres per hectare and MCPA 500 at four litres per hectare all gave very good control of large vetch plants. The combination of Roundup PowerMAX plus Envoke at 10 grams per hectare also gave good control and controlled all other weeds present on the plots.

The combination gave much better control than Envoke alone at 10 grams per hectare. But Envoke, with a nine month plant-back period to cotton, cannot be used to remove vetch immediately prior to a cotton crop. Starane has a much shorter plant-back to cotton of 14 to 28 days (depending on the application rate). The plant-back to MCPA should be similar, at around 14 days, although no plant-back period for cotton was specified on the product label.

Both Roundup and Envoke may be valuable for controlling volunteer vetch plants in a cotton crop, should these become a problem.

The Roundup PowerMAX at two litres per hectare plus MCPA 500 at four litres per hectare combination also gave a good result and controlled all other weeds, but gave a slightly inferior result to MCPA 500 at four litres per hectare alone. Growers electing to use this combination would have to weigh up the advantage of an increased weed control spectrum with the disadvantage of possibly poorer control of vetch.

For more detail on herbicides for vetch crops, refer to the full article in WEEDpak on the internet at www.cotton.crc.org.au. Follow the links through Information Resources and Weeds, or contact the author.

This work was made possible through the financial support of the Cotton Research & Development Corporation and the hard work of my support staff.

WEEDpak updated with new management tools

WEEDpak, the industry guide for integrated management of weeds in cotton released in 2002, has been updated to include new management tools for important weeds including cowvine and bellvine, and for handling weeds in cover and rotational crops such as pigeon pea and vetch.

Graham Charles, a weed expert with NSW DPI and the Cotton CRC, said weeds directly impact on cotton production by competing for water, nutrients and light, and can contaminate fibre and seed production.

They also act as hosts for both insects and pathogenic organisms that have adverse impacts on cotton production, and they reduce the efficiency of various operations such as picking.

The management of weeds imposes a significant cost burden on growers particularly as they aim for environmental sensitivity while reducing the risk of weeds developing herbicide resistance.

He said the weed identification section of WEEDpak has also been progressively updated with improved images of many of the original weeds, and a doubling of the number of weeds covered.

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 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:

Bellvine in cotton field.

- Strong seed dormancy;
- Long seed life in the seedbank;
- Ability to germinate rapidly after rain, all year round;
- Rapid seedling growth;
- A short generation; and,
- A twining growth habit, making larger plants difficult to control with inter-row cultivation.

An effective cowvine management system will use all the available control options (cultivation, chipping and herbicides) in combination.

Bellvine is an aggressive, highly competitive annual weed that can grow through and over a cotton crop and can tangle inter-row and harvesting equipment.

Very high densities of bellvine seedlings can emerge with the cotton crop, and successive germinations may occur throughout the season. Bellvine plants do not flower and set seed until late summer and autumn, but are capable of producing very large numbers of seeds.

Vetch is being increasingly grown as an alternative rotation crop for cotton.

A bellvine problem can be greatly reduced by good management over a couple of seasons, provided no plants are allowed to set seed.

Summer fallows and rotation crops such as sorghum may give the best opportunity to manage bellvine, which is readily controlled by cultivation and herbicides in fallows, but is very difficult to control in cotton.

Pigeon pea is useful as a trap crop and refuge for beneficial insects. A range of herbicides are now available for use with pigeon peas, but may only be used on pigeon peas that are not used for human or livestock consumption.

Weeds in pigeon peas can be best managed using a pre-planting application of prometryn or Sencor and either trifluralin or pendimethalin, and postemergence applications of prometryn as a directed spray or Sencor, or one of the selective grass herbicides listed.

Vetch is being increasingly grown as an alternative rotation crop for cotton, capable of adding large amounts of nitrogen to the soil. Weed management in vetch is problematic, with few registered herbicides for pre-planting applications, and no herbicides registered for controlling broad-leaf weeds in vetch, or for controlling vetch prior to planting cotton.

Vetch should be sown into a clean seedbed, with weeds controlled prior to planting with cultivation and/or herbicides. A wide range of products are registered for controlling weeds in fallows and for controlling grass weeds in vetch.

Further information: Graham Charles NSW DPI Ph: 02 6799 1524.

The 3 'whats' of managing herbicide damage

Graham Charles

Generally the second response after discovering herbicide damage in a cotton crop is to ask the 3 'whats'. The first response of course involves the expression of some frustration and disappointment!

The 3 whats are:

- What caused the damage?
  - which herbicide, and
  - at what rate?
- What will it do to the crop?
- What do I do now?

The best solution to herbicide damage is to avoid it, but this is not always possible. Herbicide damage is becoming increasingly common in cotton crops, with 2,4-D® and glyphosate two of the more common culprits.

Damage may have come from a wide range of sources, with drift from an application to another target a far too common problem. Damage can also result from poorly set-up or contaminated equipment, operator error, operating in unsuitable conditions, or residues from a previous spray. So, after damage occurs, what next?

A cotton crop starting to show symptoms of 2,4-D® damage. Note the distortion on the new leaf growth. (Photo:Graham Charles)

What caused the damage?

Determining the cause of the damage may be a difficult challenge, with a range of herbicides causing similar symptoms. Generally the hormone type herbicides (2,4-D®, dicamba®, bromoxynil®, MCPA® and Starane®) cause leaf distortion, but it can be difficult to positively identify which of these herbicides was the culprit.

Glyphosate (Roundup® and various other trade names) damage is more difficult to identify on cotton, with no obvious symptoms being induced by low rates. In some cases, damage may be most readily determined by comparing growth rates on neighboring Roundup Ready® and non-Roundup Ready® crops.

A damage symptoms guide is currently being compiled by the Cotton CRC. It will help in identification of plant symptoms brought about by environmental, disease and herbicide effects. A full range of herbicide damage symptoms will be included in the guide, over a range of herbicide rates and plant growth stages.

What will it do to the crop?

Surprisingly little information based on research is available to answer this question in terms of yield. There is a lack of detailed understanding of the effects on the plant in terms of fruit initiation, shedding of flowers, squares, bolls etc.

A CRDC-funded project has commenced this season at ACRI to identify this detail. This season the effects of glyphosate, 2,4-D® and a combination of glyphosate and 2,4-D® are being investigated using 2 different herbicide rates and 4 damage events (4, 8, 12 and 16 nodes). This work will expand over the next couple of seasons to provide more detailed answers. Assistance from growers with crops suffering herbicide damage will be sought over the next couple of seasons.

Reporting phenoxy herbicide damage

Only 12 cases of herbicide damge have been reported in the Lower Namoi for the 05/06 summer season, until 31/01. This is thought to be well below the actual number of damage cases. It is import to report all instances of damage to Cotton Australia. The data is used to make recomendations to the APVMA on product registrations and label directions. Small or large areas, severe or mild damage, cotton or other crops, it is important that all damage is reported. Contact Gus Macrae: 0407 956 586

What do I do now?

No information is available to guide growers as to their best options in terms of deciding to terminate or salvage the crop, or what additional inputs may be of value to assist a crop to recover. Research over the next 3 seasons will go a long way to answering these questions.

Graham Charles
NSW DPI and CRDC

Hands-on-Research

2,4-D & Glyphosate Damage to Cotton

Graham Charles
NSW Dept Primary Industries
Cotton Catchment Communities CRC

Baton @ 100 g/ha applied on 4 Jan 06 at 12 nodes. Photos taken on 8 Mar 06.

Baton + Roundup Ready Herbicide @ 100 g + 250 g/ha applied at 12 nodes.

Research conducted in the 2005/06 season
Experiment at the ACRI Narrabri

Aim: to identify the specifics of 2,4-D and glyphosate damage and the combination of the two on the physiology of the cotton crop. That is, to measure the impact of known amounts of herbicide and determine whether the herbicides effects are primarily on plant growth, flowering, square retention, boll retention or development.

Cotton replanted on 5 Nov 05

<u>Treatments:</u>

- Baton (2,4-D amine 800 g/kg) @ 10% (100 g/ha)
- @ 1% (10 g/ha)
- Roundup Ready Herbicide @ 17% (250 g/ha)
- (glyphosate 690 g/ha) @ 6% (50 g/kg)
- Combination of 2,4-D + RRH @ 10% + 17% (0.16 L + 250 g/ha)
- @ 1% + 6% (16 mL + 50 g/ha)

Applied over-the-top of cotton at:

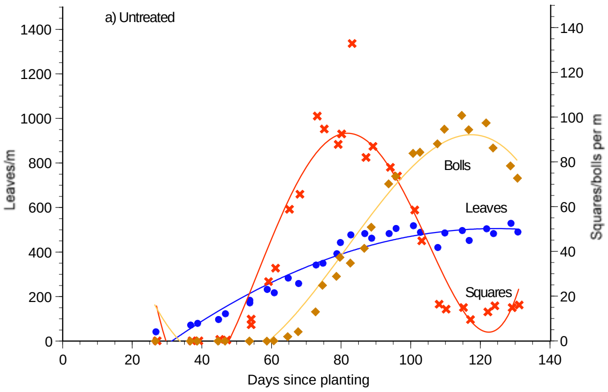
- 6-nodes - 12 Dec 05 5 weeks after planting
- 8-nodes - 20 Dec 05 6½ weeks after planting
- 12-nodes - 4 Jan 06 8½ weeks after planting
- 16-nodes - 24 Jan 06 11½ weeks after planting

<u>Measurements:</u>

- complete plant-map every 2 weeks after the herbicides were applied
- maturity picks
- final plant map, and
- yields - harvested on 21 May 06

Results.
Baton @ 100 g/ha

The herbicide application is indicated by an arrow



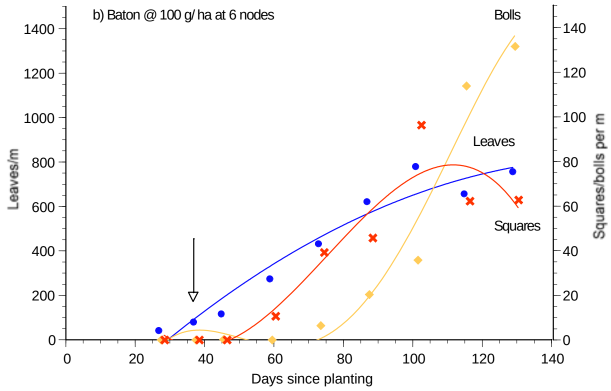


Photo 1. Baton @ 100 g/ha applied on 12 Dec 05 at 4 nodes. Photo taken on 5 Jan 06, 24 days after exposure

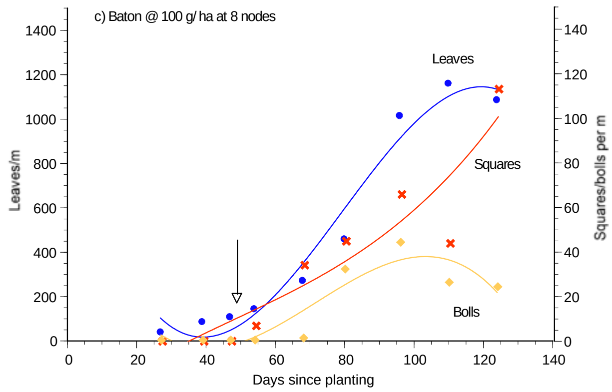
Photo 2. 2 Baton @ 100 g/ha applied on 12 Dec 05 at 4 nodes. Photo taken on 8 Mar 06, 86 days after exposure.

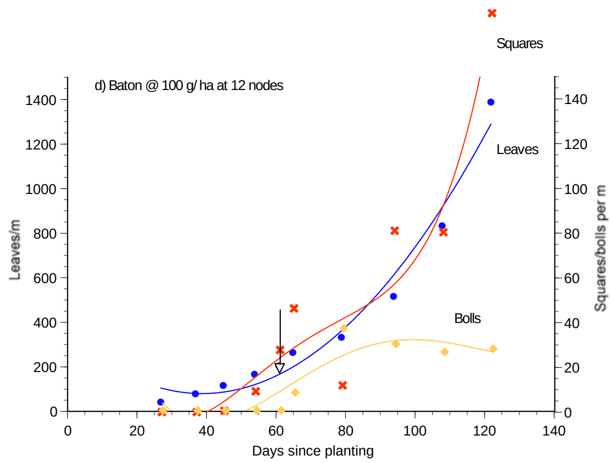
Photo 3. Baton @ 100 g/ha applied on 12 Dec 05 at 4 nodes. Photo taken on 8 Mar 06, 86 days after exposure.

Note the extensive distortion of the main stem in Photo 1, 24 days after exposure.

The main stem continued to produce distorted leaves throughout the season (Photo 2), but the lateral branches were undamaged and developed normally resulting in a plant that developed normally, except for the main stem (Photo 3).

Photo 2 is a close-up view of the top of the plant central to Photo 3.





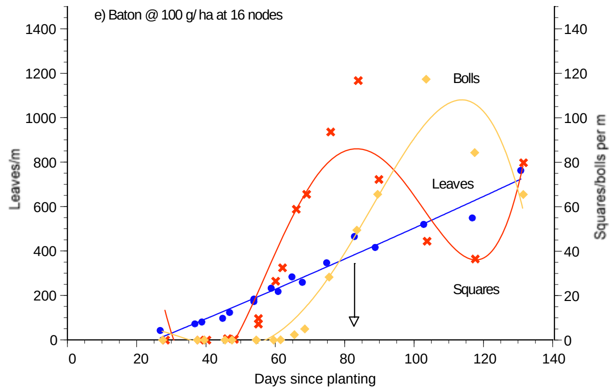


Photo 4. Baton @ 100 g/ha applied on 4 Jan 06 at 12 nodes. Photo taken on 6 Jan 06, 2 days after exposure.

Photo 5. Baton @ 100 g/ha applied on 4 Jan 06 at 12 nodes. Photo taken on 19 Jan 06, 15 days after exposure.

Photo 6. Baton @ 100 g/ha applied on 4 Jan 06 at 12 nodes. Photo taken on 8 Mar 06, 63 days after exposure.

Cotton plants exposed to a 10% drift of 2,4-D showed immediate damage symptoms, with petiole twisting apparent within a few hours (Photo 4).

Leaf distortion became apparent later as new leaves developed (Photo 5).

The laterals of plants exposed at 8 nodes and later had already been initiated at the time of exposure. Consequently, 2,4-D damage was apparent on both the main branch and most of the laterals of these plants season long (Photo 6).

These plants produced large numbers of late squares but retained few bolls.

Baton broadcast @ 100 g/ha

	Final plant count data				
	Untreated	**6 nodes**	**8 nodes**	**12 nodes**	**16 nodes**
Nodes/plant	21.5	23.9	24.6	24.0	25.1
Leaves/m	498	753	1084	1386	759
Light interception	86%	90%	79%	72%	80%
Leaf area	21930	19737	14693	14376	23203
Bolls/m	100	132	24	28	65
Boll weight (g/boll)	4.4	2.6	0.4	0.4	4.3
Days to 50% open*	154	-	-	152	155
Lint yield/ha	1649	1471	277	192	1148

Note*. Fewer than 50% of bolls opened on the 6 node and 8 node treatments

Observations:

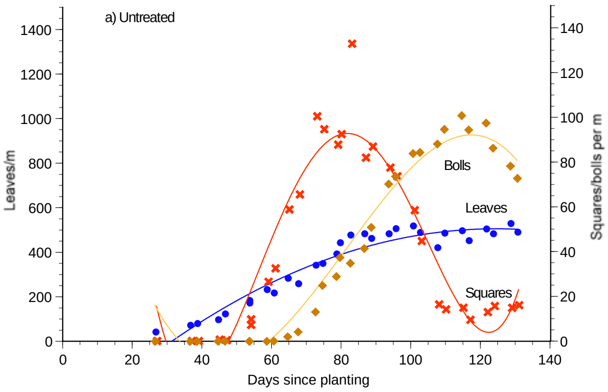
- 2,4-D caused vegetative regrowth and extensive leaf distortion with increased leaf and node number
- Distorted leaves had reduced surface area and poor orientation resulting in much reduced light interception per leaf
    - Total leaf area generally declined even though leaf number increased
    - Total light interception was also generally reduced
- New lateral branches that were initiated and developed after the herbicide exposure grew normally, producing normal squares and bolls
- Plants exposed early-season (6 nodes) largely grew away from the damage, with fruit developing on undamaged laterals
    - Square production was delayed
    - Boll production was delayed, with a large number of late season bolls
    - Average boll weight was reduced
    - Less than 50% of boll opened (a large percentage of late season bolls)
    - Lint yield was reduced by only 11%
- Mid-season (8 & 12 node) exposure to 2,4-D had the most impact
    - Leaf number greatly increased
    - Square production was delayed, with a mass of late-season squares
    - Most bolls were shed, few reached maturity
    - The retained bolls were small and had low weight
    - Lint yield was reduced by 83 & 88% following 8 & 12 node exposure
- Exposed branched continued to produce distorted growth throughout the season and retained few if any bolls
- Late season exposure (16 nodes) had less impact on the plant
    - New growth was distorted
    - A flush of late-season squares was initiated
    - Some bolls were shed
    - Most developing bolls were retained
    - Lint yield was reduced by 30%

Photo 7. Baton @ 100 g/ha applied on 24 Jan 06 at 16 nodes. Photo taken on 8 Mar 06, 43 days after exposure.

Photo 8. 2 Baton @ 100 g/ha applied on 24 Jan 06 at 16 nodes. Photo taken on 8 Mar 06, 43 days after exposure.

Results.
Roundup Ready Herbicide @ 250 g/ha

The herbicide application is indicated by an arrow



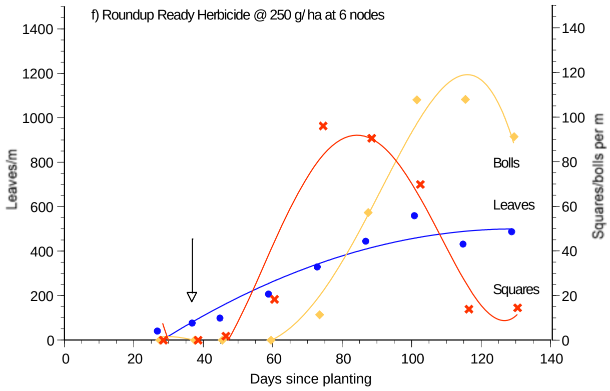


Photo 9. Roundup Ready Herbicide @ 250 g/ha applied on 12 Dec 05 at 4 nodes. Photo taken on 5 Jan 06, 24 days after exposure.

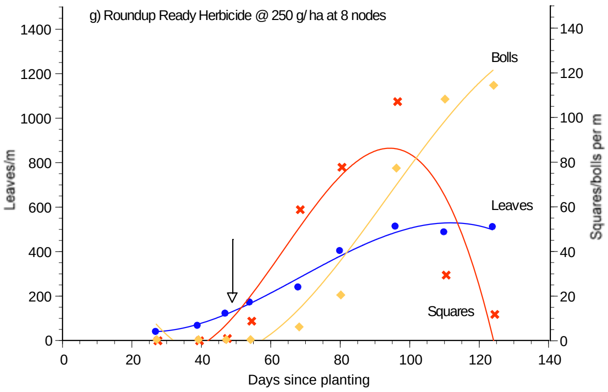
Photo 10. Roundup Ready Herbicide @ 250 g/ha applied on 12 Dec 05 at 4 nodes. Photo taken on 8 Mar 06, 86 days after exposure. Plants showed no symptoms of damage

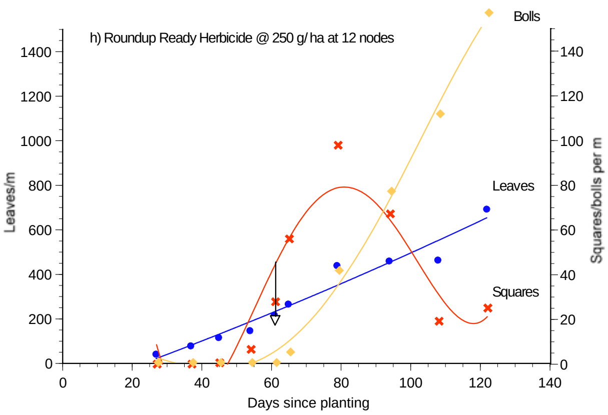
Photo 11. Roundup Ready Herbicide @ 250 g/ha applied on 4 Jan 06 at 12 nodes. Photo taken on 8 Mar 06, 63 days after exposure.

Note the leaf cupping which was apparent within 2 days of exposure (Photo 9). This effect was transitory.

New growth displayed no damage symptoms (Photo 10).

Some parrot beaking occurred in plants exposed to glyphosate. It was most common in plants exposed at the 12 node stage (Photo 11).





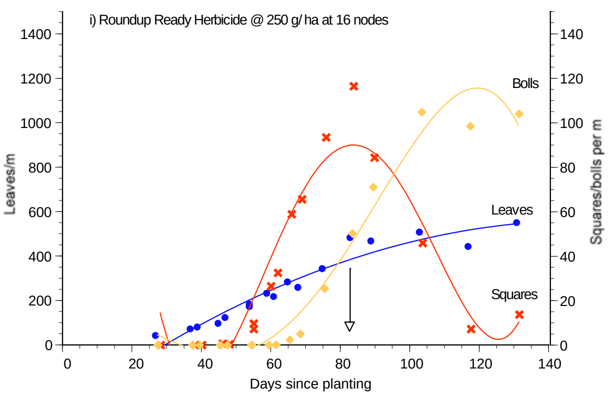


Photo 12. Roundup Ready Herbicide @ 250 g/ha applied on 24 Jan 06 at 16 nodes. Photo taken on 8 Mar 06, 43 days after exposure.

Photo 13. The combination of Baton + Roundup Ready Herbicide @ 100 + 250 g/ha applied on 4 Jan 06 at 12 nodes. Photo taken on 6 Jan 06, 2 days after exposure.

Roundup Ready Herbicide broadcast @ 250 g/ha

	Final plant count data				
	Untreated	**6 nodes**	**8 nodes**	**12 nodes**	**16 nodes**
Nodes/plant	21.5	21.8	20.7	22.6	22.4
Leaves/m	498	484	509	690	547
Light interception	86%	85%	86%	80%	84%
Leaf area	21930	19179	21731	28893	17681
Bolls/m	100	91	93	90	87
Boll weight (g/boll)	4.4	4.4	3.0	3.4	4.2
Days to 50% open	154	157	162	179	180
Lint yield/ha	1649	1684	1393	1427	1606

Observations:

- Exposure to glyphosate caused cupping of the upper leaves
    - This effect was transitory and not apparent 2 weeks after exposure
- No other visual symptoms were apparent
- Plants exposed early-season (6 nodes) were largely unaffected
    - Crop maturity was delayed by 3 days
- Mid-season (8 & 12 node) exposure to glyphosate had the most impact
    - Leaf number and area was increased by the 12 node application
    - Boll number was slightly reduced
    - Boll development was affected, with reduced boll size
    - **Crop maturity was delayed by** 8 days following the 8 node application and **25 days following the 12 node exposure**
    - Lint yield was reduced 16 & 13% after 8 & 12 node exposures
- Late season exposure (16 nodes) had little visual impact on the plant
    - Boll number was slightly reduced
    - **Crop maturity was delayed by 26 days**

Baton + Roundup Ready Herbicide broadcast @ 100 + 250 g/ha

	Final plant count data				
	Untreated	**6 nodes**	**8 nodes**	**12 nodes**	**16 nodes**
Nodes/plant	21.5	23.2	23.9	25.0	25.3
Leaves/m	498	683	895	1239	956
Light interception	86%	87%	73%	67%	74%
Leaf area	21930	11741	13132	13609	20155
Bolls/m	100	59	26	13	35
Boll weight (g/boll)	4.4	1.3	0.6	0.7	1.0
Days to 50% open	154	-	-	-	146
Lint yield/ha	1649	747	453	190	780

Note*. Fewer than 50% of bolls opened on the 6, 8 and 12 node treatments

Observations:

- Generally the combination of 2,4-D amine and glyphosate caused similar damage to 2,4-D alone
    - Visual symptoms of damage were the same as for 2,4-D alone
    - Leaf area reduction was greater than for 2,4-D alone
    - Boll reduction was generally greater than for 2,4-D alone
    - Boll weight and yield reductions for early and late-season exposures (6 & 16 nodes) were greater than for 2,4-D alone


Damage to sorghum from glyphosate drift.


Damage from Arsenal applied to control a problem weed in a previous crop.


Damage to sorghum from glyphosate drift


Damage from Ally applied to a previous crop.


Damage to conventional cotton from glyphosate drift from a 4-leaf application


Damage from Ally applied to a previous crop. The cotton emerged and grew normally in untreated soil in the background.


Seedling damage from fluometuron applied at planting.


Seedling damage from Starane applied prior to planting.

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Tolerance of cotton expressing a 2,4-D detoxification gene to 2,4-D applied in the field

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Abstract. The tolerance to 2,4-dichlorophenoxy acetic acid (2,4-D) of a genetically modified (transgenic) cotton (*Gossypium hirsutum*) expressing a 2,4-D detoxification gene was compared with conventional (non-transgenic) cotton over 2 seasons. The 2,4-D was applied over-the-top of cotton in the field at 7–17 nodes of crop growth at rates of 0.004–1.12 kg a.i./ha. The transgenic cotton displayed better tolerance to 2,4-D than conventional cotton at all growth stages and herbicide rates. Some damage was apparent on both types of cotton at 2,4-D rates of 0.07 kg/ha and above, with damage most pronounced when the plants were exposed at 7 nodes. The transgenic cotton also had some tolerance to MCPA. Commercial use of transgenic, 2,4-D-tolerant cotton has the potential to greatly reduce problems of 2,4-D damage in cotton from accidental spray drift and herbicide residues in spraying equipment, where plants are predominantly exposed to low rates of 2,4-D.

Additional keywords: genetically modified organism, herbicide resistance, MCPA, transgenic.

Introduction

Cotton (*Gossypium hirsutum*) is grown over a broad geographical region of Australia, from intensive mixed-cropping areas through to areas that previously had only extensive grazing enterprises. Historically, 2,4-dichlorophenoxy acetic acid (2,4-D) has been used through many of these areas to control broadleaf weeds in winter cereal crops such as wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*) and summer crops such as sorghum (*Sorghum bicolour*) (Martin *et al.* 1988). The 2,4-D has also been widely used to control weeds in fallows (Storrie *et al.* 1998) and for controlling the noogoora burr complex (*Xanthium* spp.) and Bathurst burr (*X. spinosum*) in grazing areas (Medd and McMillan 1992).

Cotton is very sensitive to 2,4-D and is readily damaged by 2,4-D drift and residues. The problem of accidental 2,4-D damage to cotton was recognised as early as 1946 (Staten 1946) and remains a problem nearly 60 years later in Australia, the USA, China, and elsewhere. Damage symptoms have been observed from 2,4-D rates as low as 77 μg a.i./ha (Birch 2004), and rates as low as 10 mL/ha can reduce yields when applied to young cotton (Horowitz *et al.* 1976). Field rates, however, are typically much higher (0.5–1.0 kg a.i./ha), increasing the risk of damage from herbicide drift.

Continuing use of 2,4-D in cotton-growing areas has resulted in many instances of 2,4-D damage to cotton crops in Australia (Birch 2004). The use of 2,4-D during the warmer months while cotton is growing (especially the use of the ester formulation of 2,4-D) is actively discouraged in and around the cotton areas, but there have still been many instances where 2,4-D has been inappropriately applied too near to cotton fields, resulting in herbicide damage (Storrie *et al.* 1998). The 2,4-D has also been routinely used during autumn and winter on some fields to be planted to cotton. In some instances, 2,4-D residues remaining in the soil (Hammond 1992; Baker 1993) or in spraying equipment have damaged a subsequent cotton crop.

The development of genetically modified cotton tolerant to 2,4-D has the potential to protect cotton from accidental exposure to 2,4-D, greatly reducing what is an industry-wide problem in many cotton-producing countries, including Australia. The 2,4-D-tolerant cotton expressing a bacterial enzyme (2,4-D dioxygenase) that detoxifies this herbicide was developed in several laboratories (Bayley *et al.* 1992; Lyon *et al.* 1993; Chen *et al.* 1994; Zhang *et al.* 2001) and all have shown good tolerance to 2,4-D under greenhouse conditions.

The objective of this work was to assess the tolerance of the transgenic event produced by Lyon *et al.* (1993) to 2,4-D applied under field conditions. Although cotton is normally exposed to low levels of 2,4-D, exposure to higher levels was also examined in these experiments to better determine the potential of this material to tolerate 2,4-D. The tolerance of the transgenic, 2,4-D-tolerant cotton was compared with conventional cotton of the same genetic background, but without the tolerance gene.

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MCPA (4-chloro-2-methylphenoxy acetic acid) was also included in the second season, as later laboratory studies showed that the transgenic cotton had some tolerance to this herbicide that is structurally similar to 2,4-D.

Materials and methods

These experiments were undertaken using cotton cv. Coker 315, which had been transformed using *Agrobacterium*-mediated transformation to introduce a gene encoding a 2,4-D dioxygenase from *Ralstonia* (formerly *Alcaligenes*) *eutrophus*, which is expressed throughout the plant and breaks down 2,4-D to the considerably less toxic 2,4 dichlorophenol (Lyon *et al.* 1993). Plants were selected that contained a single copy of the gene in a homozygous state and seed was increased under greenhouse conditions. The transformed material was compared with conventional (non-transgenic) cotton cv. Coker 315. All experiments were carried out under contained conditions under permit from the Australian Genetic Manipulation Advisory Committee (GMAC) that at the time administered all research with genetically modified organisms in Australia.

The experiments were situated near Premer, NSW (31°26′S, 149°55′E). The location was selected to be remote from other cotton production, enabling 2,4-D to be used in-crop with safety. The soil was a self-mulching grey clay, pH 7.3, that had been fallowed for more than 12 months before the experiments and contained a full moisture profile at planting. Cotton was sown in November of each year, on raised beds 1.8-m wide, with rows 1-m apart and 2 rows per bed. Regular rain through most of the 1996–97 season ensured good soil moisture and plots were not irrigated in that season. Plots were furrow-irrigated on 3 occasions during the 1997–98 season.

The experiments were surrounded by a 20-m buffer of conventional cotton to act as a pollen sink (Llewellyn and Fitt 1996; Llewellyn *et al.* 2007) and were physically isolated from other cotton by many kilometers to ensure containment of the transgenic trait as required by Australia's guidelines for such experiments. The site was fallowed following the experiments and has not since been replanted to cotton.

The experiment was designed as a stratified, randomised complete block, with transgenic and conventional cotton sown in paired subplots within each herbicide and growth-stage main-plot treatment. Treatments were stratified to ensure that plots with the highest herbicide rates did not occur immediately adjacent to plots with low rates. Main plots were 4 rows wide by 10 m long, with subplots 2 rows by 10 m. Treatments were replicated 3 times. Four buffer rows were sown between each set of main plots in 1996 and 8 buffer rows between plots in 1997. An additional buffer plot was placed between each pair of main plots in 1997 to minimise within-crop spray drift.

Herbicide rates and application times are shown in Table 1. Herbicides were applied through a 4-m-wide hand-held boom, using 8001 flat-fan nozzles operated at 200 kPa with 100 L water/ha. Herbicides were applied in calm conditions, with the lowest rates applied first. The boom was cleaned between each herbicide and application time.

In 1997 the cotton was cut by an early heavy frost 149 days after planting (DAP), before reaching full maturity, and the crop was subsequently terminated. Plant-mapping measurements where taken from 2 randomly selected 1-m sections of row within each subplot. Plant node number, height, boll number, boll retention, and dry weight were recorded. The 1998 crop reached maturity and was machine-harvested 214 DAP. Node number and plant height were also recorded for 2 randomly selected 1-m sections of row within each subplot. Lint yields and ginning percentage were estimated from seed-cotton subsamples using a 20-saw gin.

Data were analysed using the REML routine in GENSTAT 6. Only statistically significant ($P < 0.05$) results are discussed. Plant mapping data were smoothed using moving averages.

Table 1. Summary of treatment combinations used in each season
Both the crop growth stage and corresponding average development stage are indicated. Herbicides were present as dimethylamine salts. The cotton was cut by frosts 149 and 167 days after planting (DAP) and harvested 155 and 214 DAP in 1997 and 1998, respectively

Herbicide rate (kg a.i./ha)		Application time		
2,4-D	MCPA	Nominal growth stage	(nodes)[A]	DAP
		1996–97		
Nil		Vegetative	7	76
0.07		Flowering	14	113
0.28		Boll-fill	17	133
1.12				
		1997–98		
Nil	Nil	Vegetative	7	58
0.004	0.08	Square initiation	11	81
0.022	0.4	Flowering	15	109
0.11	2.0	Boll-fill	17	127
0.56				

[A] All herbicide rate × growth stage combinations were included in the experiment.

Results

2,4-D 1996–97 season

Visual observation indicated that the transgenic cotton plants were more tolerant of 2,4-D than were conventional plants at all growth stages and herbicide rates, with rates up to twice a typical field rate of 2,4-D (Table 2). Visual symptoms of 2,4-D damage to conventional plants included leaf reddening, petiole twisting, and leaf death. Plant death occurred following the highest 2,4-D rate applied to conventional plants at 7 nodes.

Herbicide damage symptoms were apparent on both conventional and transgenic cotton 1–2 weeks after application, although symptoms were far more severe on conventional cotton when compared at the same herbicide rate and application time. All new growth on the conventional cotton following 2,4-D applications was distorted, but no distorted growth was observed on transgenic plants. Growth of the transgenic cotton did appear to be delayed for up to 2 weeks after 2,4-D application, but new growth was free of visual symptoms of herbicide damage, regardless of herbicide rate or application time.

The 2,4-D applied to conventional plants at 7 nodes caused a reduction in most plant parameters at all herbicide rates (Table 3). Plants were severely stunted, produced few flowers, retained few bolls, and were unlikely to yield a harvestable amount of cotton, consistent with 2,4-D-induced death of most meristematic tissues. The effect at later growth stages was less

Table 2. Visual observations of plant damage 7 and 21 days after topical applications (DAA) of 2,4-D to conventional and transgenic 2,4-D-tolerant cotton plants during 1996–97

Growth stage at application	Herbicide rate (kg a.i./ha)	Conventional 7 DAA	Conventional 21 DAA	Transgenic 7 DAA	Transgenic 21 DAA
7	0.07	Reddening & leaf curling	Severe damage, plant stunting	No effect	No effect
	0.28	Reddening & twisting, leaf curling	Severe damage, leaf curling	No effect	Slight damage
	1.12	Severe reddening & twisting, leaf death	Severe reddening & twisting, leaf death	Reddening & leaf curling	Slight damage
14	0.07	Slight reddening & twisting	Slight reddening & twisting	No effect	No effect
	0.28	Reddening & twisting	Reddening & twisting	Slight reddening & twisting	Slight reddening
	1.12	Severe reddening & twisting, leaf death	Severe reddening & twisting, leaf death	Severe reddening & twisting	Moderate reddening & twisting
17	0.07	Mild reddening	Mild reddening	Slight reddening	Slight reddening
	0.28	Reddening	Reddening	Slight reddening	Slight reddening
	1.12	Heavy reddening	Heavy reddening	Mild reddening	Slight reddening

Table 3. Plant parameters at season end following topical applications of 2,4-D to conventional and transgenic 2,4-D-tolerant cotton plants during 1996–97

The herbicide was applied at 7, 14, and 17 nodes of plant growth. Parameters were: average node number, height and dry weight per plant, and average % boll retention in the first 3 fruiting positions. The maximum standard error is shown for each parameter

Growth stage at application	Herbicide rate (kg a.i./ha)	Node number Conven.	Node number Trans.	Height (m) Conven.	Height (m) Trans.	Dry weight (g) Conven.	Dry weight (g) Trans.	Boll retention (%) Conven.	Boll retention (%) Trans.
	Nil	18.1	17.4	0.75	0.70	593	512	23.6	21.4
7	0.07	16.7	16.8	0.48	0.65	313	518	1.1	28.2
	0.28	13.1	16.7	0.39	0.79	203	636	1.9	32.2
	1.12	10.3	15.1	0.29	0.73	69	707	0.3	45.4
14	0.07	15.9	16.8	0.49	0.55	377	450	7	27.5
	0.28	17.3	15.2	0.69	0.66	333	466	8.5	25.0
	1.12	15.6	15.7	0.55	0.67	198	363	3.3	18.6
17	0.07	16.8	16.2	0.61	0.58	457	391	25.3	20.0
	0.28	15.1	15.1	0.70	0.70	477	468	21.3	18.4
	1.12	18.0	15.1	0.85	0.75	531	386	21.4	19.7
	Max. s.e.	1.6		0.08		71		3.5	

severe and may have been masked by the production of distorted vegetative growth following the herbicide application.

The final number of nodes of conventional plants was reduced by the higher herbicide rates applied at 7 nodes. The 2,4-D had a much smaller effect on node number when applied to older plants, partly due to the production of vegetative growth following the herbicide application. The 2,4-D had little effect on node number of the transgenic plants.

The 2,4-D applications affected the internode lengths of both conventional and transgenic plants, with the largest effects following the herbicide application at 7 nodes (Fig. 1). There was a significant ($P < 0.05$) 4-way interaction between node, herbicide rate, growth stage, and gene. The 2,4-D applied at 7 nodes reduced the internode lengths of later nodes of the conventional plants at all rates, although there was a stimulation of growth at nodes 18 and 19 at the highest rate. In contrast, internode length was stimulated in transgenic plants sprayed at 7 nodes, with increases in length from nodes 2 to 11 at the highest rate. The 2,4-D had less effect on the internode lengths of plants sprayed at the later growth stages (applied at nodes 14 and 17), where most nodes had developed before the herbicide application. Some stimulation of growth of the lower inter-nodes was apparent in both conventional and transgenic plants sprayed at nodes 14 and 17 at the higher herbicide rates.

The reduction in node number and node length following the 2,4-D application at 7 nodes combined to give a large reduction in the height of conventional plants sprayed at all herbicide rates (Table 3). The height of conventional plants was also lower at the 0.07 and 1.12 kg/ha rates sprayed at 14 nodes and the low rate applied at 17 nodes. The 2,4-D did not reduce the height of the transgenic cotton, except at the low rate applied at 14 and 17 nodes. Reductions in node number at other rates and stages were compensated for by increases in internode length.

Dry-matter production of the conventional cotton was reduced by all 2,4-D applications except the 1.12 kg/ha rate applied at 17 nodes. Reductions were greater with increasing

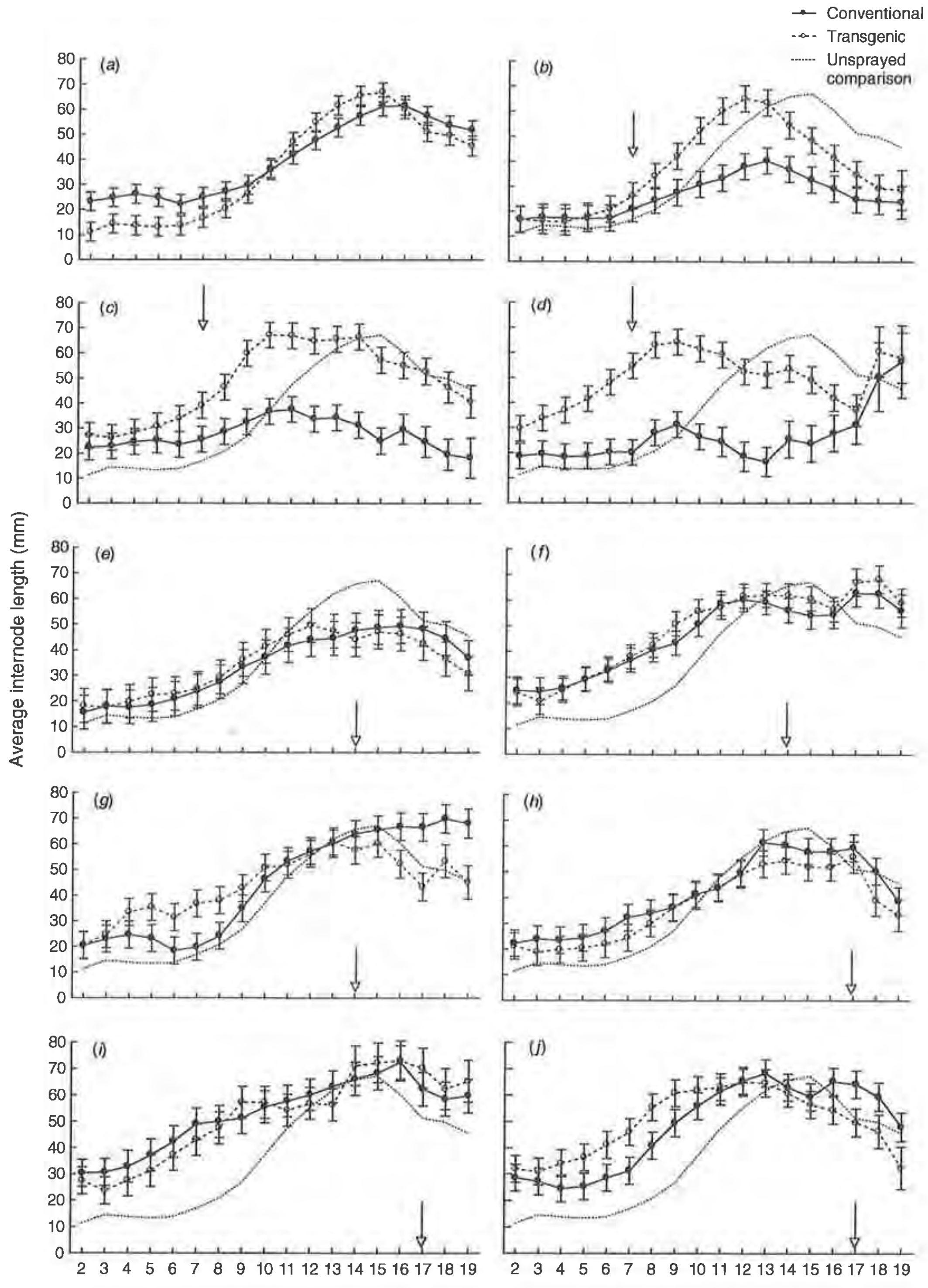

Fig. 1. Average internode length of conventional and transgenic cotton in the 1996–97 season starting at node 2, exposed to 2,4-D at 7, 14, and 17 nodes of plant growth, as indicated by arrows. Treatments were (*a*) untreated, (*b*) 0.07 kg a.i./ha at 7 nodes, (*c*) 0.28 kg a.i./ha at 7 nodes, (*d*) 1.12 kg a.i./ha at 7 nodes, (*e*) 0.07 kg a.i./ha at 14 nodes, (*f*) 0.28 kg a.i./ha at 14 nodes, (*g*) 1.12 kg a.i./ha at 14 nodes, (*h*) 0.07 kg a.i./ha at 17 nodes, (*i*) 0.28 kg a.i./ha at 17 nodes, and (*j*) 1.12 kg a.i./ha at 17 nodes. The internode length curve from the unsprayed transgenic treatment has been included in all sprayed treatments for ease of comparison. Curves were smoothed using moving averages. Standard error bars are shown.

herbicide rates at 7 and 14 nodes (Table 3). The transgenic cotton was less affected by the herbicide, although there were reductions in dry weight at the 1.12 kg/ha 2,4-D rate applied at 14 nodes and the 0.07 and 1.12 kg/ha rates applied at 17 nodes.

Percentage boll retention on the first 3 fruiting positions of the conventional cotton was substantially reduced by all 2,4-D applications at 7 and 14 nodes because of high levels of floral abortion (Table 3). Average percentage boll retention was not reduced by any of the applications to the transgenic cotton, although there were effects on total boll number at different nodes (Fig. 2). The large increase in boll retention of the transgenic plants sprayed with the highest 2,4-D rate at 7 nodes is probably an artefact of the design, where transgenic plants were able to gain a soil moisture advantage as they were paired with much smaller conventional plants damaged by the herbicide. The design used, with gene as a subplot treatment, was partly confounded by this effect, but this was the most satisfactory way to ensure that conventional and transgenic plants were equally exposed to the herbicide.

The final distribution and number of retained bolls on conventional and, to a lesser extent, transgenic plants were affected by all 2,4-D rates applied at all growth stages, most often with a reduction in the retention of early bolls (Fig. 2). The number of retained bolls on conventional cotton was reduced at nodes 10–16 by all 2,4-D applications at the 7 and 14 node stages, with most squares and flowers aborting following the herbicide applications. The 2,4-D applied at 17 nodes had less effect on boll number, but still caused some boll loss on conventional plants. Transgenic plants were much less affected, with some loss of bolls at nodes 10–12 following most applications and increased boll production on later nodes.

In the untreated plots, boll number at nodes 10–12 was lower on the conventional than on the transgenic plots, probably due to a small amount of spray drift. Evidence of this was also apparent in the internode length data, with increased internode lengths on nodes 2–6 of the conventional cotton (Fig. 2). The spray drift could have been from some of the higher application rates, but may have been from a more distant source.

2,4-D 1997–98 season

Visual observation again indicated that transgenic cotton plants were more tolerant of 2,4-D than were conventional plants at all growth stages and herbicide rates used. Damage symptoms were less apparent with the lower herbicide rates used in this season.

Complete plant mapping was not undertaken in this season as plants were able to grow through to maturity and lint yields were recorded. Plant height and node number were recorded.

Only the highest 2,4-D rate reduced the number of nodes per plant on conventional plants sprayed at 7 nodes (Table 4). Node number of the conventional plants was also reduced by the 0.11 kg/ha rate applied at 11 nodes and 0.022 and 0.11 kg/ha rates applied at 17 nodes. Node number was only reduced on the transgenic plants sprayed with the 0.004 kg/ha rate at 15 nodes and the 0.11 kg/ha rate at 17 nodes.

The height of conventional cotton was reduced by all 2,4-D rates applied at 7 nodes and by the higher rates sprayed at 11 nodes (Table 4).

The ginning percentage of conventional cotton was reduced by 2,4-D applications at the higher rates sprayed at 7 and 11 nodes (data not presented). The reductions were associated with very low yields and high trash content on these plots. The herbicide had no effect on the ginning percentage of the transgenic cotton.

Lint yields of the conventional plants were reduced by nearly all herbicide applications, regardless of growth stage, with large yield reductions from applications at 7 and 11 nodes (Table 4). Yield reductions generally increased as herbicide rate increased. Lint yield of transgenic cotton was not reduced by 2,4-D applied at 7 or 17 nodes, but was reduced by the heavier rates of 2,4-D applied at 11 nodes and the heaviest rate applied at 15 nodes, suggesting that developing flowers were the most susceptible to 2,4-D damage.

MCPA

Visual observations indicated that transgenic cotton was more tolerant of MCPA than was conventional cotton, although both cotton types were heavily damaged by MCPA applied at the highest rate, equivalent to a typical field rate of MCPA. Visual symptoms of MCPA damage were similar to symptoms of 2,4-D damage, with severe reddening, petiole twisting, and some leaf death.

The higher rates of MCPA reduced the number of nodes of conventional plants sprayed at 7 and 11 nodes (Table 5). There was also some reduction from the 15 and 17 node applications. There was a reduction in node number on the transgenic plants sprayed at the highest rate at 7 and 15 nodes.

MCPA reduced the height of conventional cotton sprayed at the higher rates at 7 and 11 nodes, but did not affect the plant height of transgenic cotton (Table 5).

The yield of conventional cotton plants was reduced by all MCPA rates (Table 6). The transgenic cotton was more tolerant of MCPA than was conventional cotton. Lint yield of the transgenic cotton was nearly double that of the conventional cotton at the higher MCPA rates. Time of application had no significant effect on lint yield.

Discussion

The topical 2,4-D applications damaged conventional cotton, regardless of application rate or crop growth stage, with rates as low as 4 g a.i./ha reducing the yield of young cotton. These results were consistent with previous observations (Porter *et al.* 1959; Horowitz *et al.* 1976; Banks and Schroeder 2002).

Overall, the transgenic cotton showed good tolerance to 2,4-D in the field at all growth stages, even at rates well above those expected from spray drift of ~10–30% of field rates (Al-Khatib *et al.* 1993). Where damage was observed, the transgenic plants were generally able to recover and reductions in yield were relatively small by comparison with the effects of comparable exposure to conventional cotton. Nevertheless, the transgenic cotton was damaged by the higher herbicide rates, with reductions evident in all plant parameters recorded. The degree of herbicide tolerance observed in the field was clearly less than was expected from greenhouse observations (Lyon *et al.* 1993). Consequently, the direct use of 2,4-D on this cotton for weed control could not be recommended even if this

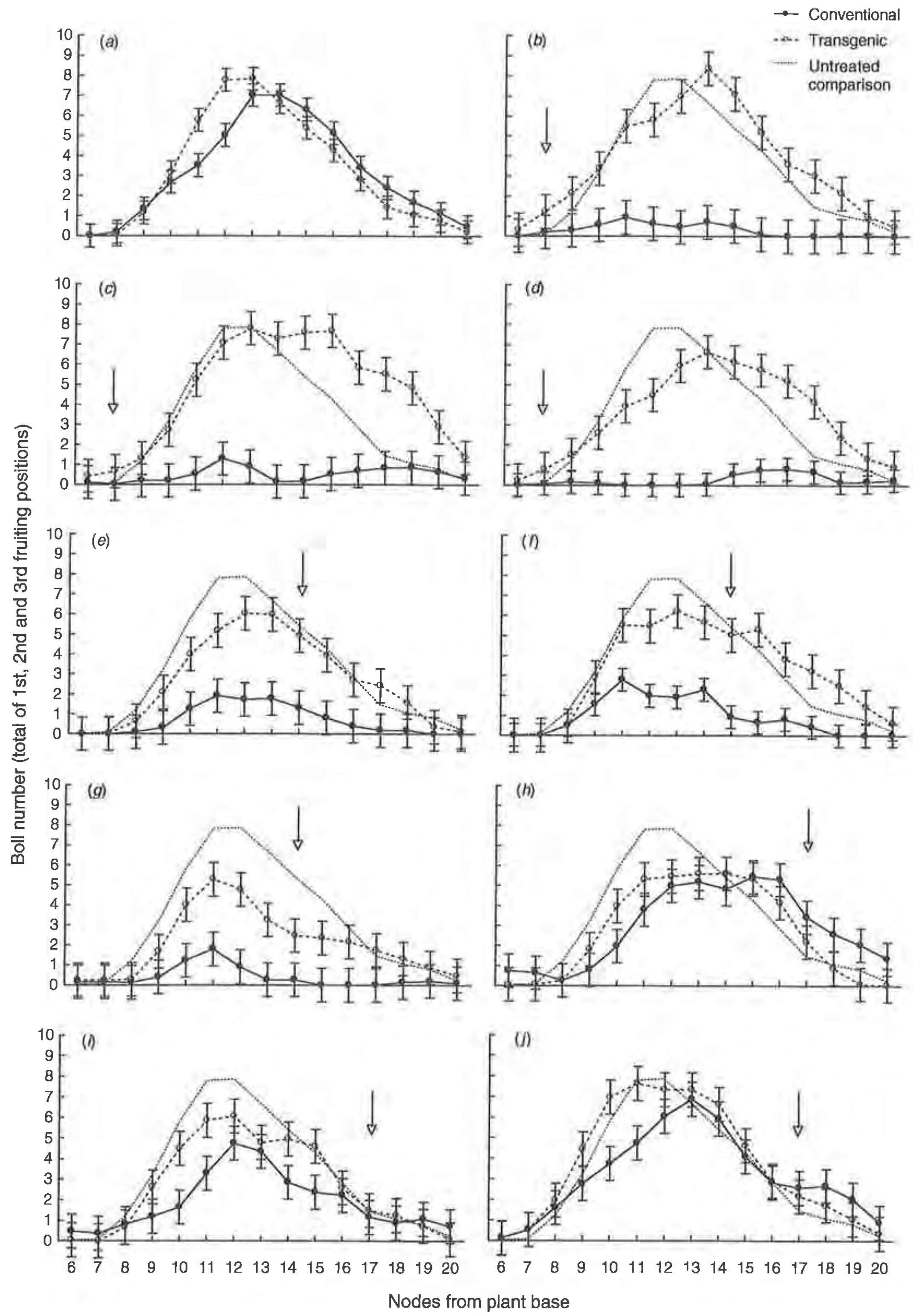

Fig. 2. Total boll number of the first 3 fruiting positions of conventional and transgenic cotton in the 1996–97 season, exposed to 2,4-D at 7, 14, and 17 nodes of plant growth, as indicated by arrows. Treatments were (*a*) untreated, (*b*) 0.07 kg a.i./ha at 7 nodes, (*c*) 0.28 kg a.i./ha at 7 nodes, (*d*) 1.12 kg a.i./ha at 7 nodes, (*e*) 0.07 kg a.i./ha at 14 nodes, (*f*) 0.28 kg a.i./ha at 14 nodes, (*g*) 1.12 kg a.i./ha at 14 nodes, (*h*) 0.07 kg a.i./ha at 17 nodes, (*i*) 0.28 kg a.i./ha at 17 nodes, and (*j*) 1.12 kg a.i./ha at 17 nodes. The boll production curve from the unsprayed transgenic treatment has been included in all sprayed treatments for ease of comparison. Curves were smoothed using moving averages. Standard error bars are shown.

Table 4. Plant parameters at maturity following topical applications of 2,4-D to conventional and transgenic 2,4-D-tolerant cotton plants during 1997–98

The herbicide was applied at 7, 11, 15, and 17 nodes of plant growth. Parameters were: average node number and height per plant and lint yield. The maximum standard error is shown for each parameter

Growth stage at application	Herbicide rate (kg a.i./ha)	Nodes		Height (m)		Lint yield (kg/ha)	
		Conven.	Trans.	Conven.	Trans.	Conven.	Trans.
	Nil	20.0	19.1	0.90	0.81	468	402
7	0.004	19.8	19.0	0.80	0.78	88	362
	0.022	20.7	20.3	0.73	0.85	97	403
	0.11	18.2	23.2	0.69	0.92	0	343
	0.56	11.5	20.5	0.32	0.99	0	377
11	0.004	22.8	18.3	1.04	0.89	190	386
	0.022	18.3	20.5	0.78	0.85	33	382
	0.11	17.2	23.2	0.65	0.92	6	243
	0.56	18.0	20.5	0.61	0.91	0	257
15	0.004	19.0	16.7	0.82	0.74	350	365
	0.022	22.5	20.8	0.95	0.86	402	417
	0.11	19.8	18.2	0.90	0.76	213	401
	0.56	18.8	19.5	0.79	0.82	24	280
17	0.004	20.5	20.3	0.94	0.81	295	417
	0.022	16.8	20.5	0.87	0.86	389	383
	0.11	15.0	15.2	0.84	0.72	313	317
	0.56	19.8	19.2	0.87	0.87	274	389
	Max. s.e.	1.3		0.05		74	

Table 5. Average node number and height per plant at maturity following topical applications of MCPA to conventional and transgenic 2,4-D-tolerant cotton plants during 1997–98

The herbicide was applied at 7, 11, 15, and 17 nodes of plant growth. The maximum standard error is shown for each parameter

Growth stage at application	Herbicide rate (kg a.i./ha)	Nodes		Height (m)	
		Conven.	Trans.	Convent.	Trans.
	Nil	21.1	19.8	0.91	0.84
7	0.08	20.8	18.7	0.84	0.93
	0.4	16.8	20.8	0.66	0.81
	2.0	13.7	15.2	0.41	0.76
11	0.08	20.0	16.3	0.80	0.73
	0.4	17.5	18.7	0.73	0.76
	2.0	12.3	19.2	0.63	0.87
15	0.08	19.2	18.7	0.99	0.82
	0.4	18.2	21.2	0.84	0.85
	2.0	21.2	17.3	0.86	0.87
17	0.08	17.7	20.3	0.93	0.93
	0.4	20.8	21.0	0.86	0.86
	2.0	17.7	19.2	0.83	0.76
	Max. s.e.	1.2		0.05	

Table 6. Cotton lint yield following topical applications of MCPA to conventional and transgenic 2,4-D-tolerant cotton plants during 1997–98

The time of herbicide application had no effect on lint yields. The maximum standard error is shown

Herbicide rate (kg a.i./ha)	Lint yield (kg/ha)	
	Conven.	Trans.
Nil	406	340
0.08	281	296
0.4	125	241
2.0	92	173
Max. s.e.	39	

transgenic material became commercially available in an elite cotton variety.

Even larger reductions in lint yield and other plant parameters of both transgenic and conventional cotton may have been observed in these experiments if lower water rates had been used and spray concentration rather than spray volume had been maintained at a constant across treatments (Banks and Schroeder 2002; Ellis *et al.* 2002). It is likely that our results underestimate the impact of spray drift from aerial and ground-rig applications where water rates are typically in the order of 25–60 L/ha at the point of application. Spray concentration at the point of deposition may be an order of magnitude higher again, with much of the carrier volume evaporating before deposition in hot conditions (typically 20–35°C). However, accurate application of very low spray volumes in these conditions in the field (down to 0.8 mL/ha if spray concentration was maintained) was not possible with the available equipment and would not have been conducive to accurate spray placement.

The lint yields obtained in these experiments were also lower than is normal in commercial Australian cotton production, due to the use of a poorly adapted variety (Coker 315) and the location of the experiments in a suboptimal growing area. Consequently, the experimental results cannot be directly extrapolated to the commercial cotton industry in Australia where water rates for herbicide applications are typically in the range of 25–60 L/ha and crop yields in the range of 1500–2500 kg lint/ha. However, it seems likely that this gene event would protect commercial cotton from most 2,4-D spray drift occurrences.

We were not able to compare this transgenic event with others developed elsewhere in the world (Bayley *et al.* 1992; Chen *et al.* 1994; Zhang *et al.* 2001), but it is possible that the field performance of one of these other gene events may give superior results to those reported here. The field expression of this tolerance may also be improved with another gene promoter.

Nevertheless, the transgenic plants displayed a high level of tolerance to 2,4-D and the commercial use of this material should greatly reduce problems of 2,4-D damage to cotton from spray drift and herbicide residues in spraying equipment.

While transgenic cotton displayed better tolerance to MCPA than did conventional plants, the tolerance was less robust than was the case for 2,4-D. This is consistent with the known differences in the ability of the 2,4-D dioxygenase enzyme encoded by the transgene to degrade phenoxyacetic acid herbicides. The additional tolerance afforded to MCPA is likely to be a bonus, but not a marketable attribute of the 2,4-D-tolerant transgenic cotton.

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TITLE: Developing a Threshold Model for Controlling Weeds in Glyphosate Resistant Cotton

DISCIPLINE: Weed Management

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ABBREVIATIONS: CPWC, critical period for weed control; LAI_C, leaf area index of the crop; LAI_W, leaf area index of the weed, LW, relative leaf area of weed; *q*, the relative damage coefficient; $RGRL_C$, the relative growth rate of the crop leaf area; $RGRL_W$, the relative growth rate of the weed leaf area.

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2

Developing a Threshold Model for Controlling Weeds in Glyphosate Resistant Cotton

Graham W. Charles, and Ian N. Taylor

ABSTRACT

The commercial adoption of genetically modified, Roundup Ready Flex® cotton (*Gossypium hirsutum* L.) brings to the Australian cotton industry the opportunity to develop new weed management systems that are less reliant on residual herbicides. The development of weed control thresholds will be an important step in optimising such a system based largely on a non-residual post-emergence herbicide, glyphosate. This work explores the development of a weed control threshold and the critical period for weed control (CPWC) for irrigated Roundup Ready Flex cotton. Data from field experiments were used to define the CPWC and fitted to weed competition models. Sunflower (*Helianthus annuus* L.) and Japanese millet (*Echinochloa esculenta* (A. Braun) H. Scholz) were used as mimic weeds in these experiments to reduce variability in the results. The CPWC defined by the data was dependant on the control threshold adopted, weed species and weed density, ranging from 9 to 61 days post-crop emergence for sunflower and 5 to 54 days post-crop emergence for Japanese millet. A simple empirical crop yield loss model was fitted to the data, but was sensitive to season and to achieve a good fit required reparameterization for each data set. This problem was partly addressed by relating model parameters to day degrees and weed density. A statistical model was also applied to the data and gave a similar overall fit, relating yield loss to plant height, leaf area index and day degrees. To further develop the CPWC concept for Australian cotton will require the adoption of a new crop yield loss modelling approach to more accurately predict the impact of weed competition. We conclude that a future model might be improved by including alternative measurements of plant growth such as leaf area index and plant height.

INTRODUCTION

Over the last two decades, the Australian cotton industry developed an aggressive attitude towards controlling weeds in conventional irrigated cotton crops using a range of management tools in an integrated manner to achieve a high level of weed control (Charles and Taylor, 2004). The industry relied heavily on residual herbicides for in-crop weed control, but in some situations, these herbicides adversely affected cotton establishment and growth, and contaminated the riverine environment (Taylor et al., 2004).

The commercial release of genetically modified, glyphosate tolerant, Roundup Ready® cotton in 2000 saw a rapid transition to this material, with approximately 77% of the planted cotton area using Roundup Ready varieties in the 2005/6 season (Charles and Taylor, 2006). The use of these varieties allowed cotton growers to reduce their reliance on pre-emergence residual herbicides, with a reduction in the use of full pre-emergence residual herbicide programs (such as broadcast trifluralin and diuron pre-planting in combination with pendimethalin and fluometuron at planting) and an increase in the use of banded residual herbicides (commonly a 40% band of pendimethalin and fluometuron at planting, with no pre-planting residual herbicide). There was a corresponding large increase in the use of glyphosate in-crop, and small reductions in the use of inter-row cultivation and hand-hoeing (Werth et al., 2006).

The commercial release of Roundup Ready Flex® cotton varieties in Australia in the 2006/7 season brought the potential for cotton growers to further modify their in-crop weed control programs, potentially replacing all pre-emergence residual herbicide applications with targeted post-emergence herbicides. These applications could be strategically targeted to manage weeds post-emergence, controlling identified populations of weeds before they negatively impacted on the crop, or were able to reproduce. Such a system would have the advantages of reducing the time and labor requirements at planting, eliminating the potential damage to cotton seedlings from pre-emergence residual herbicides, and could greatly reduce the risk of off-site movement of residual herbicides.

However, for a post-emergence herbicide application to be efficiently targeted on weeds, it is desirable to have an established weed population threshold for spraying, in combination with a detailed knowledge of the spectrum of weeds controlled by a herbicide and the required rates.

In a Roundup Ready Flex system, it is important that glyphosate is not simply applied every few weeks throughout the crop's life. While such a strategy, based on multiple glyphosate applications alone is simple and would optimize crop yield in the short-term, it would quickly lead to species shift and the development of weed problems with species which are tolerant of, or resistant to glyphosate (Charles and Taylor, 2006). To optimize a sustainable Roundup Ready Flex system, glyphosate needs to used strategically in combination with other weed management tools so that weed management is achieved without imposing excessive selection pressure for glyphosate tolerance or resistance. The development of a weed control threshold is an important step in optimizing a weed management system.

The critical period for weed control. A weed control threshold is a component of the broader concept of the critical period for weed control (CPWC) established by Nieto et al. (1968). In a more recent review of this concept and its development, Knezevic et al. (2002) identified that the CPWC had particular application for use with herbicide tolerant crops, such as Roundup Ready Flex cotton, where the primary method of weed control is using a broad-spectrum, non-residual, post-emergence herbicide; in this case glyphosate. The CPWC concept has the advantage over a density dependant weed control threshold in that it identifies the critical middle period in the season where weeds compete strongly with the crop and can cause yield reductions. The CPWC concept identifies a period earlier in the season before weed control is required, when weeds are too small to effectively compete with the crop and their control is not justified on economic grounds. It also identifies a third period later in the season when the crop is large enough that newly emerging weeds are not able to effectively compete with the crop and again cause no significant yield penalty. From the point of yield, weeds emerging during the first and third periods have no impact on yield, and so no weed control threshold is required during these periods. However, weeds may need to be controlled outside of the middle CPWC for a variety of other reasons, including crop contamination, harvesting difficulties, their contribution to the weed seed bank, or the risk that they may harbor crop pests or diseases. Weed populations which exceed the weed control threshold during the middle CPWC period must be controlled to minimize yield losses.

The CPWC approach has been applied to a wide range of crops including canola (*Brassica napus* L.), chickpeas (*Cicer arietinum* L.), corn (*Zea mays* L.), cotton, peppers (*Capsicum annuum* L.), red beet (*Beta vulgaris* L.) and soybean (*Glycine max* (L.) Merr.) (Amador-Ramirez, 2000; Halford et al., 2001; Martin et al., 2001; Eyherabide and Cendoya, 2002; Tingle et al., 2003; Bukin 2004; Mohammadi et al., 2004; Norsworthy and Oliveira, 2004; Kavaliauskaite and Bobinas, 2006, Williams, 2006).

The objectives of these studies were to use a grass and a large erect weed to: 1) define the CPWC for Australian cotton; 2) evaluate the influence of weed type and density on the CPWC; 3) describe the relationship between cotton yield and the density of these weeds; and 4) evaluate the crop and weed components that contribute to predictive crop yield loss models.

MATERIALS AND METHODS

Experiments to define the CPWC and develop a yield loss model in Australian cotton were undertaken over three seasons, from 2003-04 to 2005-06, at the Australian Cotton Research Institute, Narrabri, NSW, Australia, using sunflower and Japanese millet as model weeds. Sunflower (variety Hyoleic 43), was used to mimic the effect of an erect broadleaf weed species in cotton, ensuring uniform weed emergence, density and growth habit. Sunflower was chosen for its similarity in growth habit to thornapple (*Datura ferox* L.), a common weed of cotton production (Charles and Taylor, 2004). Plots were otherwise maintained weed-free, with trifluralin (TriflurX, 480 g L^{-1}, Nufarm Australia) at 1.1 kg a.i. ha^{-1}, incorporated pre-planting, and hand-hoed as needed. A second experiment using Japanese millet (var. shirohie), as the mimic weed was established beside the sunflower experiment. Japanese millet was chosen for its similarity in growth habit to awnless barnyard grass (*Echinochloa colona* (L.) Link), a common weed of cotton production (Charles and Taylor, 2004). Plots were otherwise maintained weed-free with hand-hoeing as needed.

The site was a heavy alluvial clay soil (fine, thermic, smechitic, Typic Haplustert) and was flood irrigated as required during the growing season. Irrigation scheduling was based on computer modelling of the crop's requirements. The field was irrigated five times during the growing season (six times in 2005-06) and 468, 454 and 501 mm of rain were recorded in 2003-04, 2004-05 and 2005-06, respectively. All field operations were consistent with standard commercial practices.

The field was pre-irrigated prior to planting. Cotton, variety Sicala 289B, was planted at 15 seeds m^{-1} of row on October 19, 2003, October 13, 2004, and October 1, 2005. Sunflower and Japanese millet, were planted parallel to the cotton row, 100 mm off-set to the western-side. The weeds were planted at the same time as the cotton, or added at intervals post-crop emergence (weed additions).

The experiments used a split-plot design within a randomized complete block with 4 replicates. The main plot treatments were five weed densities, with a weed-free control. Sunflower densities were 1, 2, 4, 9 and 16 weeds m^{-1} of row. Millet densities were 9, 17, 40, 75 and 140 weeds m^{-1} of row. Weeds were removed by hand-hoeing. Main plots were 12 rows (12 m) by 20 m, and sub-plots 4 rows by 10 m. Sub-plots of six times of weed addition or weed removal were randomly imposed within each weed density main plot.

Plant height, node number (cotton only), leaf number, leaf area and oven dried biomass were recorded on 10 crop and weed plants at each time of weed removal. These measurements were taken on all weed densities at each removal time. At the end of the season, the cotton was harvested using a modified commercial picker with a single picking head, and sub-samples were ginned using a single-saw gin to determine lint yield. Average lint yield in the weed-free plots was 1583, 1878 and 2286 kg lint/ha in 2003-04, 2004-05 and 2005-06, respectively.

Data from the three seasons were fitted to the empirical crop loss model of Kropff and Spitters (1991) using the model: Yield loss=$q*L_w/(1+(q-1)*L_w)$. The parameter q was the relative damage coefficient and L_w the relative leaf area (leaf area of the weed compared to the total leaf area of crop and weed), calculated as $L_w=LAI_w/(LAI_c+LAI_w)$, where LAI_w and LAI_c were the leaf area index of the weed and crop, respectively. Data from the 2003-04 season were used to define the initial values for the parameter q. Day degrees were determined from daily maximum and minimum temperatures using a base of 12°C (Constable, 1976). Data were tested for significance by analysis of variance and regression analysis using GenStat (GenStat. Ver 9.1. 2006. Lawes Agricultural Trust, Rothamsted Experimental Station, VSN International, Hemel Hempstead, UK). Only results which were significant at the 5% level are discussed. Relationships were fitted using DeltaGraph (DeltaGraph Ver 4.0. 1998. DeltaPoint Inc., Monterey, CA, USA).

RESULTS AND DISCUSSION

The CPWC defined by these experiments was relative to the yield loss threshold adopted and dependant on the density of weeds present. A 5% yield loss threshold defined the CPWC for the large mimic weed, sunflower at 1 weed m^{-1} of row as 164 to 348 day degrees, or from 17 to 35 days post-crop emergence. At 9 weeds m^{-1} of row, the CPWC extended from 74 to 660 day degrees, or 9 to 61 days post-crop emergence (Figure 1).

Insert Figure 1 here

The experimental value for the CPWC was also sensitive to weed species. The CPWC defined by the millet experiment was dependent on the yield loss threshold adopted and the density of weeds present. A 5% yield loss threshold defined the CPWC at 9 millet m^{-1} of row as 40 to 353 day degrees, or from 5 to 36 days post-crop emergence. At 140 millet m^{-1} of row, the CPWC was defined as 76 to 579 day degrees, or from 9 to 54 days post-crop emergence (Figure 2).

Insert Figure 2 here

The CPWCs defined in these experiments were shorter than those defined using a natural weed population in cotton in Turkey (Bukun, 2004), which extended from 100 to 1174 day degrees from crop planting. The differences in estimated CPWC relate to the competitiveness of the weeds, and the steepness of the yield loss relationships, with more rapid response from weed removals and weed additions in the Australian data. It may also relate to differences in seasonal conditions and the competitiveness of the crops, as the Turkish cotton was taller, but lower yielding.

The sensitivity of the CPWC approach to a range of factors limits the value of this approach based on weed density. Experimental field results to define the CPWC are determined by the yield loss threshold adopted and tend to be season, site, crop and weed specific, making it difficult to establish an effective model defining the CPWC. Variables such as crop density and growth habit, weed density and spectrum, tillage system, time of emergence (both crop and weed), temperature, soil moisture and soil fertility over the growing season all add to variability between sites and seasons (Halford et al., 2001; Knezevic et.al, 2002; Norsworthy and Oliveira, 2004). At one site, Halford et al. (2001), for example, failed to define any CPWC for soybeans in consecutive seasons, but in the same seasons observed large effects of weeds on soybean yields on another site.

Theoretically, it should be possible to reduce the impact of some of these factors, such as row spacing, the time of crop and weed emergence (Halford et al., 2001), soil fertility (Knezevic et al., 2002), and seasonal conditions (temperature and soil moisture) by measuring these variables during an experiment and using crop growth and weed competition models to describe their effect on crop competition. However, to be valuable in the commercial world, it is essential that the information required by a model is easily measured and the result is robust.

Crop yield loss models. Simple models relating crop yield loss to weed density have been developed by many researchers. Cousens (1985) compared a number of these simple models and concluded that the rectangular hyperbola model gave the best fit to a range of data sets and was a biologically sensible model. Cousens et al. (1987) developed the concept further, including time of emergence as an important factor in the model.

However, in practice, many of the simpler crop competition models suffer from the same problems as the CPWC relationships. Models can be readily fitted to experimental data, but the results tend to be site and season specific, due to factors such as successive weed germinations over time, making it impossible to clearly define the time of weed emergence. Parameters in the models can vary between sites and seasons and must be recalculated for each data set. Consequently, although the models can accurately describe a data set, they are not able to accurately predict the impact of weeds on a crop without reparameterization.

Kropff and Spitters (1991) identified the difficulty with this approach and developed a more robust empirical model based on relative leaf area (L_w). This model uses leaf area to effectively integrate a range of crop and weed data including weed density, time of weed emergence and the relative growth rates of crop and weed.

Data from the 2003-04 sunflower density study were used to define the parameters of the crop yield model of Kropff and Spitters (1991) based on relative leaf area. The model gave a good correlation between the observed and predicted crop yield loss (r=0.94) for this data set (Figure 3). However, to achieve this fit, it was necessary to estimate the value of the parameter q for each time of observation, as q varied, generally increasing over time. Consequently, this model was descriptive but not predictive. To enable the model to be used predictively, Kropff and Spitters (1991) developed a relationship for q at time t (q_t), as a function of q at time 0 (q_0) and the relative growth rate of leaf area of the crop and weed. However, to use the relationship requires that both q_0 and the relative growth rates are determined for each site and season. Consequently, this relationship offers little advantage as it still requires that q (q_0) is measured for each site and season, and that the relative growth rate of each weed species is known. Relative growth rate will also vary between sites and seasons and is sensitive to weed density and both inter- and intra-specific competition.

Insert Figure 3 here

To use the relationship in a more predictive way, we related the observed values of q from the 2003-04 sunflower study to day degrees since emergence in a similar approach to that used by Wilson et al. (1995). The form of the relationship was: $q=-a+a*\exp(b*x)$, where a and b were parameters of the equation and x was day degrees (Figure 4a). However, the observed values of q not only varied with time (day degrees), but were also related to weed density, with the a parameter in the equation increasing with increasing weed density. The a parameter was subsequently related to weed density in a simple relationship (Figure 4b), allowing the value of q to be described by these functions.

Insert Figure 4 here

The relationships were combined and observed and predicted yield loss compared for the sunflower study, using the value of q estimated by the relationships and the relative leaf area measured in the experiments. The model gave a good fit to the 2003-04 data (Figure 5a) (r =0.94), but a poorer fit for 2004-05 (Figure 5b) (r=0.88) and the 2005-06 data (Figure 5c) (r=0.71). The relationships were also fitted to the Japanese millet data and gave a reasonable fit to the 2004-05 data (Figure 5d) (r=0.86), but a poor fit to the 2005-06 data (Figure 5e) (r=0.46). The fit of the combined data set was (r=0.83), with a high degree of variation occurring towards the middle of the relationship (between 20% and 80% observed yield loss). To improve these fits required reparameterizing the model for each season, site and weed species. The fit might be improved by incorporating the relationship ($q_t=q_0*\exp(RGRL_c-RGRL_w)t$ (Kropff and Spitters,1991), but this approach still requires that the model parameters are determined for each site, season and weed.

Insert Figure 5 here

One of the reasons for the difficulties with this model is that the model is primarily driven by the value of q, and not by the relative leaf area of crop and weeds. Consequently, the model is very sensitive to the value of q, which needs to be re-estimated in each new situation. It is conceivable that in a situation where the crop and weed were of similar size and architecture and equally competitive, the relative leaf area of weed (L_w), may remain relatively constant throughout the life of the crop, giving no information to the model.

This approach using a simple crop and weed model appears to have little value for prescribing weed management decisions in cotton crops, where a complex of weed species is present, with a range of germination times and the model parameters are unknown. Much more sophisticated crop models are now available, but a review by Dean et al. (2003) comparing four sophisticated crop models found that increasing levels of model complexity did not necessarily lead to improvements in model accuracy compared to relatively simple competition models. Given the difficulties these models had in simulating a simple competition scenario with a single weed, it seems unlikely that they are suited to field situations where a complex of weed species is present.

A STATISTICAL MODEL

As an alternative approach, we applied a statistical model to the data from the sunflower and millet studies using regression modelling to determine the crop and weed parameters which were easily measurable and most closely correlated with crop yield loss. Biomass and leaf area index were transformed (natural log and square-root transformations) to normalize their variance. Predicted values that were not meaningful (negative yields losses and yield losses over 100%), were restricted to 0 and 100% yield loss, respectively.

Of the crop parameters measured, crop yield loss was most closely correlated with weed biomass, weed height, weed leaf area index, crop biomass and day degrees at weed removal (r=0.84 for the combined data sets). However, biomass was not easily measured in the field. A relationship correlating crop yield loss with weed height, weed leaf area index, crop height and day degrees was adopted as it gave a good fit to the data and was much more easily estimated in the field (r=0.81 for the combined data sets) (Figure 6f). The statistically derived model gave a good fit to the sunflower data (r=0.93, 0.88 and 0.71 for the 2003-04, 2004-05 and 2005-06 data sets, respectively (Figures 6a, 6b and 6c)), and the 2004-05 Japanese millet data (r=0.86, Figure 6d), but a much poorer fit for the 2005-06 Japanese millet data (r=0.44, Figure 6e). Relative leaf area, the measure used in the earlier empirical model was poorly correlated with crop yield loss in these data. The statistical model was also relatively insensitive to weed species and season.

Insert Figure 6 here

CONCLUSION

While this model does not fulfil the criteria of Cousens (1985) of being biologically meaningful, it gives a statistically similar fit to the data compared to the empirical model and a visually better fit to the data towards the middle of the relationships between 20% and 80% observed yield loss (compare Figures 5f and 6f). The observed poor fit of relative leaf area and the relatively good fit with plant height and leaf area index suggest that these components should be part of a future empirical model for weed competition in cotton. Future models based of leaf area index and plant height are likely to be more robust and give an improved fit compared to models based solely on weed density or relative leaf area.

Future work in this project will explore the development of crop yield loss models based on leaf area index and plant height, and examine the opportunity for using sensors such as the Greenseeker® sensor (NTech Industries Inc., Ukiah, CA.), to capture data quickly and efficiently. A robust relationship based on the use of electronic sensors to assess weed competition would be invaluable for developing a crop yield loss model and weed management threshold approach which is readily accessible to cotton growers.

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CAPTIONS FOR FIGURES

Figure 1. The critical period for weed control (CPWC) for a large model weed, sunflower, at 1 or 9 weeds m^{-1} of row in irrigated cotton. The logistic equation fitted to the weed removals data was $y=a/(1+b*\exp(c*x)$, where y is the relative yield, and x is crop day degrees. The parameter estimates and r coefficient for 1 sunflower m^{-1} of row were a=1.153, b=0.1179, and c=0.003636, r=0.99, and for 9 sunflowers m^{-1} of row were: a=1.011, b=0.0388, and c=0.006740, r=0.99. The Gompertz equation fitted to the weed addition data was $y=a*\exp(-b*\exp(-c*x)$, where y is the relative yield, and x is crop day degrees. The parameter estimates and r coefficient for 1 sunflower m^{-1} of row were a=0.9913, b=2.797, and c=0.01202, r=0.99, and for 9 sunflowers m^{-1} of row were: a=0.9807, b=7.996, and c=0.008375, r=0.99.

Figure 2. The critical period for weed control for a model grass weed, Japanese millet, at nine or 140 weeds m^{-1} of row in irrigated cotton. The logistic equation fitted to the weed removals data was $y=a/(1+b*\exp(c*x)$, where y is the relative yield, and x is crop day degrees. The parameter estimates and r coefficient for 9 Japanese millet m^{-1} of row were a=0.4864, b=0.5219, and c=-0.001683, r=0.97, and for 140 m^{-1} of row were: a=1.859, b=0.7631, and c=0.002975, r=0.98. The Gompertz equation fitted to the weed addition data was $y=a*\exp(-b*\exp(-c*x)$, where y is the relative yield, and x is crop day degrees. The parameter estimates and r coefficient for 9 Japanese millet m^{-1} of row were a=0.9695, b=0.5429, and c=0.009319, r=0.98, and for 140 m^{-1} of row were: a=0.9706, b=0.2098, and c=0.007911, r=0.99.

Figure 3. Comparison of observed and predicted yield loss from the 2003-04 sunflower study. Yield loss was predicted using the emperical model of Kropff and Spitters (1991) based on relative leaf area. The equation of the model was: Yield Loss=$q*L_w/(1+(q-1)*L_w)$, where q was the relative damage coefficient, estimated from the data, and L_w the relative leaf area of weeds, calculated as $L_w=LAI_w/(LAI_c+LAI_w)$. LAI_w was the leaf area index of weeds and LAI_c, the leaf area index of the crop at the time of observation. The r coefficient for the comparison was 0.94.

Figure 4. Relationship between observed values for parameter q and day degrees since emergence (base 12^0C) for the 2003-04 sunflower study. The fitted curves a) were in the form: $q=-a+a*\exp(b*x)$, where a =0.0009886, 0.001122, 0.001419, 0.001726 and 0.002430 for 1, 2, 4, 8 and16 weeds m^{-1} of row respectively, and b=0.007. The a value of the equations was related to

weed density b) by a logistic curve in the form: $a=b/(1+c*\exp(d*x))$, where b=0.002921, c=2.259, d=-0.1560, and x is weed density (weeds m^{-1} of row).

Figure 5. Relationship between observed values and predicted estimates of yield loss using an emperical model with sunflower as a mimic weed in cotton for the a) 2003-04, b) 2004-05 and c) 2005-06 seasons. The relationships for Japanese millet is also shown for d) 2004-05, and e) 2005-06, and f) the combined data set. The *r* coefficients for the comparisons were 0.94, 0.88, 0.71, 0.86, 0.46 and 0.83, respectively.

Figure 6. Relationship between observed values and predicted estimates of yield loss using a statistically derived model with sunflower as a mimic weed in cotton for a) 2003-04, b) 2004-05 and c) 2005-06 seasons. The relationships for the mimic weed Japanese millet are also shown for d) 2004-05, and e) 2005-06, and f) the combined data set. The model fitted was: Yield loss=0.0297+0.000282*day degrees+0.00119*weed height+0.00161*sqrt(weed leaf area index)+0.00234*crop height. The *r* coefficients for the comparisons were 0.93, 0.88, 0.71, 0.86, 0.44 and 0.81, respectively.

FIGURES

Figure 1.

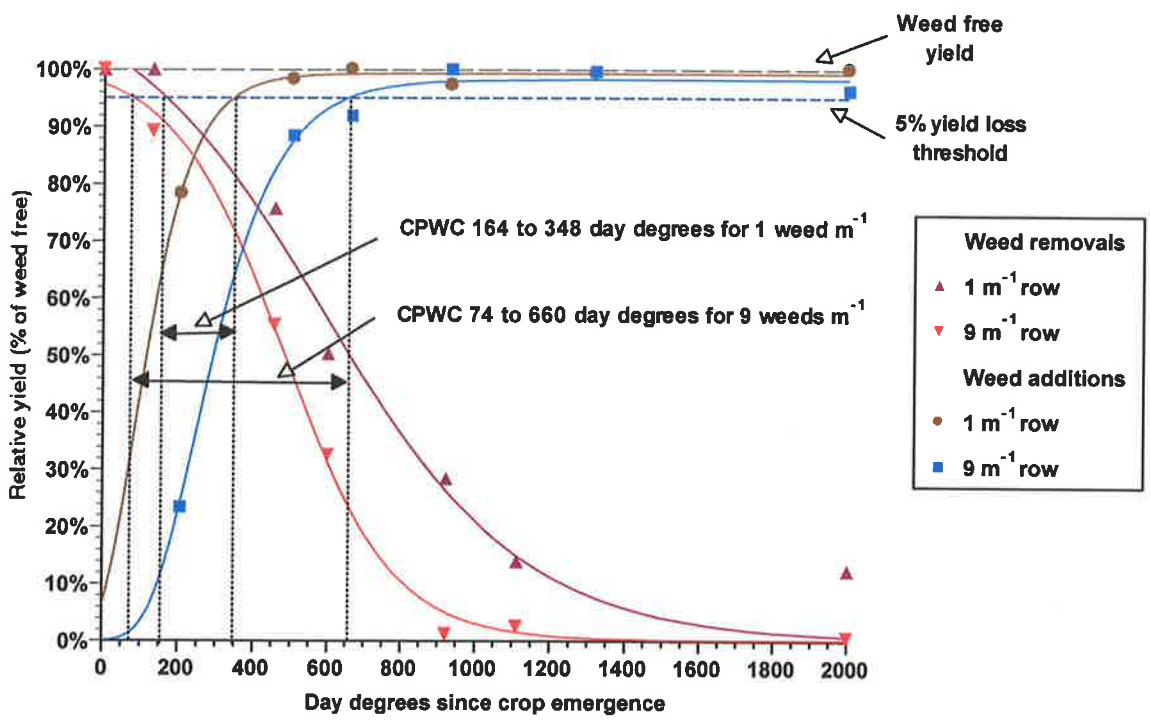
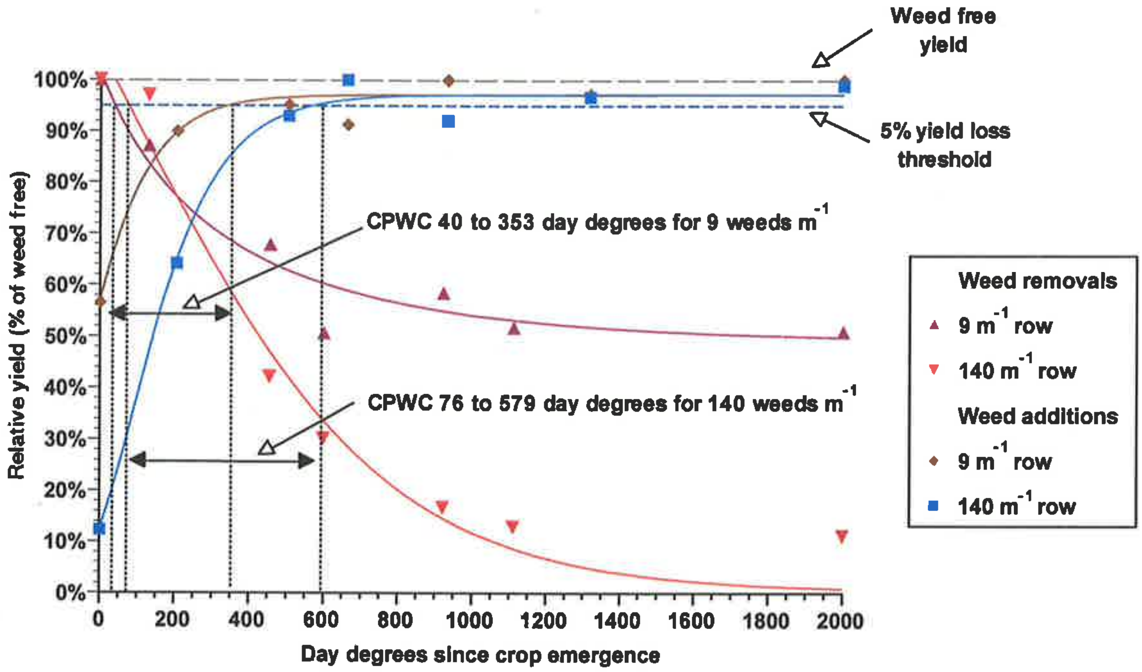


Figure 2.



Weed free yield
5% yield loss threshold
CPWC 40 to 353 day degrees for 9 weeds m-1
CPWC 76 to 579 day degrees for 140 weeds m-1
Weed removals
9 m-1 row
140 m-1 row
Weed additions
9 m-1 row
140 m-1 row
Relative yield (% of weed free)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Day degrees since crop emergence

18

Figure 3.

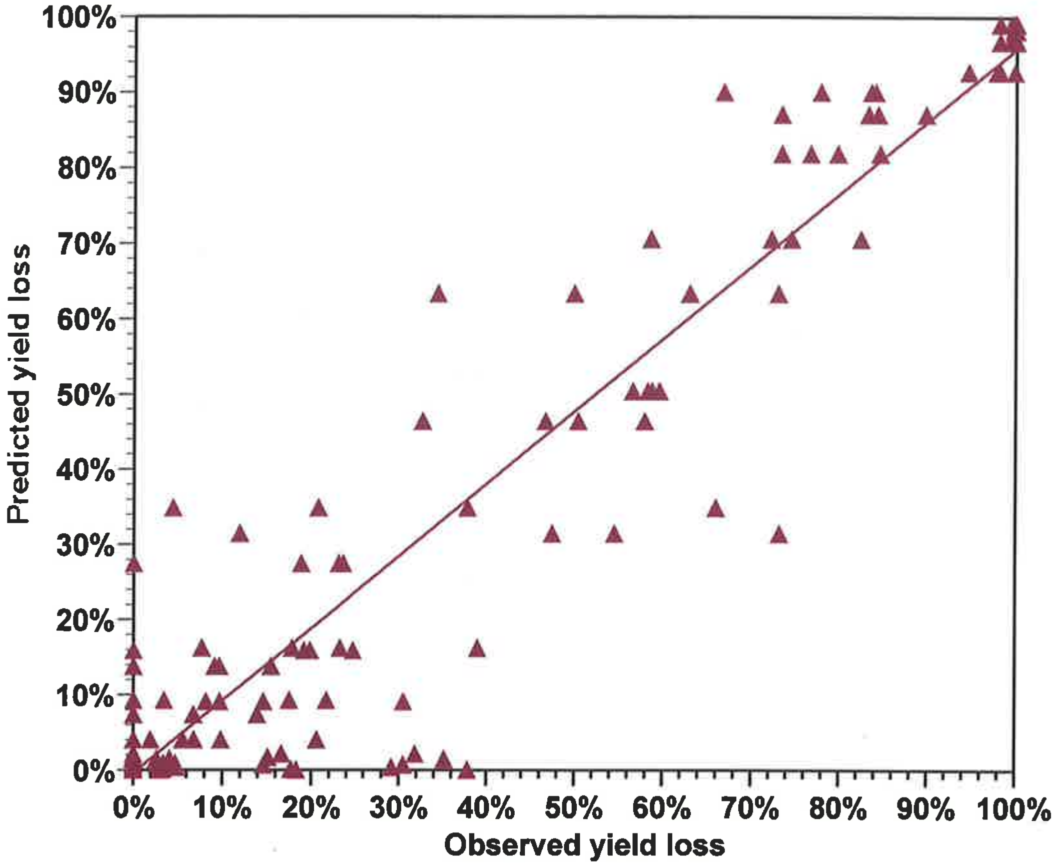

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Predicted yield loss
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Observed yield loss

Figure 4

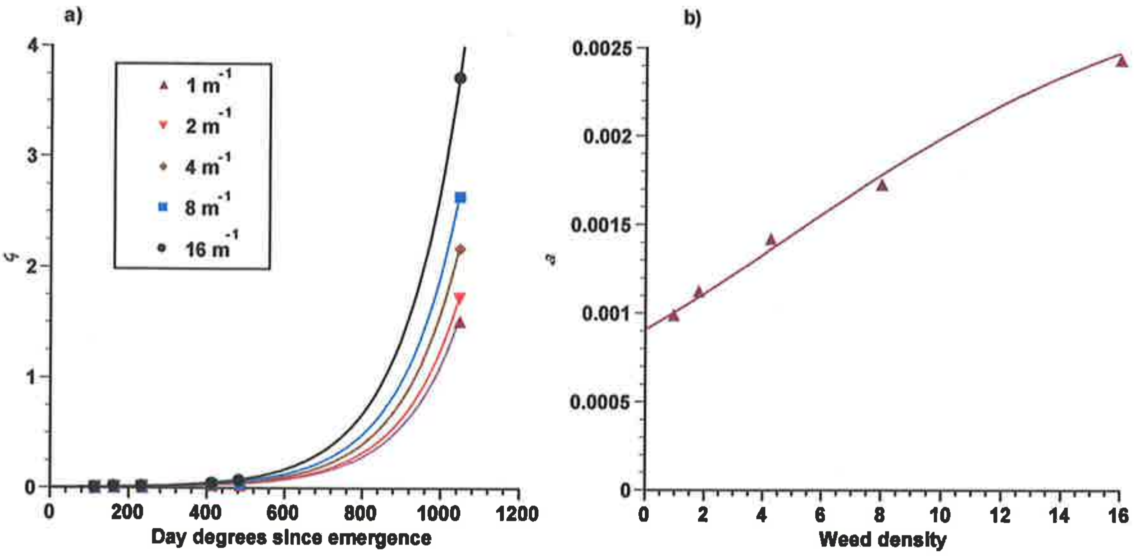
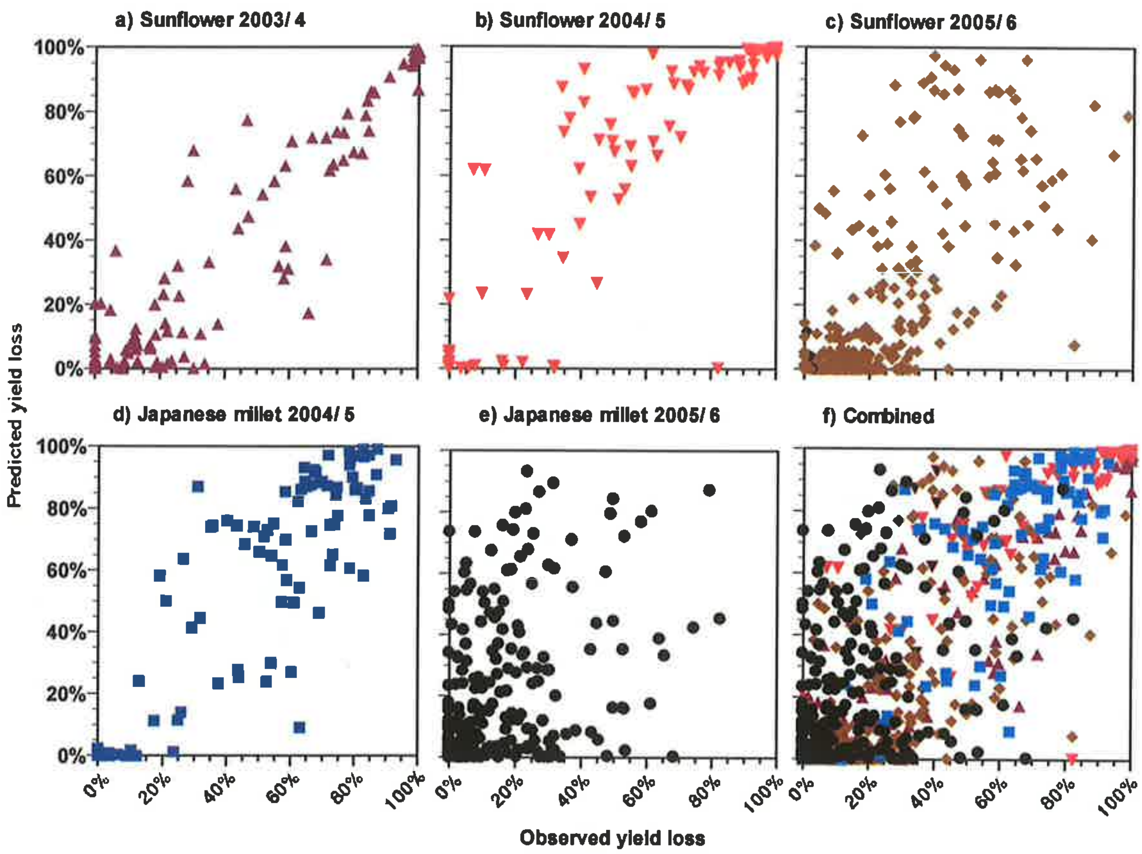

a)
1 m-1
2 m-1
4 m-1
8 m-1
16 m-1
Day degrees since emergence
0
200
400
600
800
1000
1200
0
1
2
3
4
b)
0.0025
0.002
0.0015
0.001
0.0005
0
Weed density
0
2
4
6
8
10
12
14
16

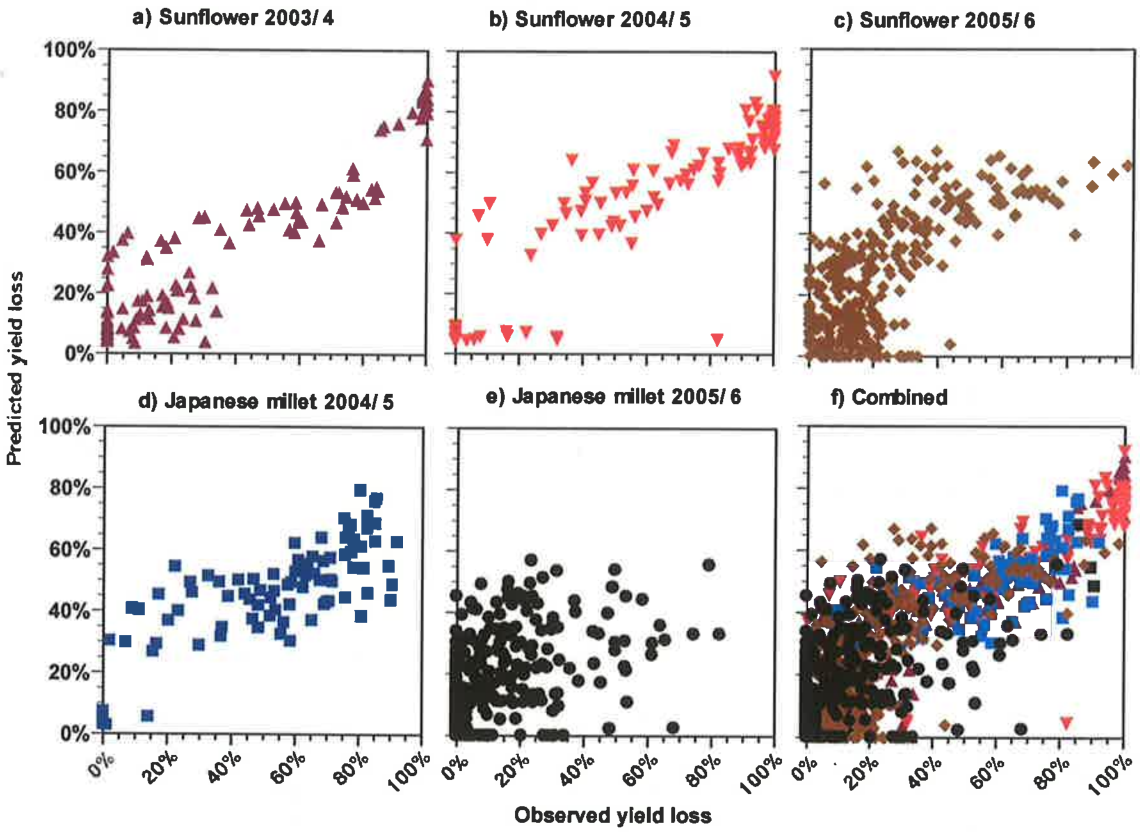
Figure 5



a) Sunflower 2003/ 4
b) Sunflower 2004/ 5
c) Sunflower 2005/ 6
d) Japanese millet 2004/ 5
e) Japanese millet 2005/ 6
f) Combined
Predicted yield loss
Observed yield loss
0%
20%
40%
60%
80%
100%

21

Figure 6



a) Sunflower 2003/ 4
b) Sunflower 2004/ 5
c) Sunflower 2005/ 6
d) Japanese millet 2004/ 5
e) Japanese millet 2005/ 6
f) Combined
Predicted yield loss
Observed yield loss
100%
80%
60%
40%
20%
0%

Weed priorities

Graham Charles
NSW Department of Primary Industries

The cotton industry has been growing genetically modified, herbicide tolerant cotton varieties for the past 8 seasons, with 75% of the area now including the glyphosate tolerance, Roundup Ready® or Roundup Ready Flex® gene. The use of this gene has contributed to improvements in weed control and crop yields, and reductions in the use of residual herbicides and the environmental footprint.
However, increased reliance on glyphosate will lead to species shift and eventually herbicide resistance. These problems can be best managed with strategic inputs of these and more conventional management tools. The development of weed management thresholds is needed to optimise a glyphosate focused system, making best use of strategic inputs.
This project is developing weed control thresholds using the critical Period for Weed Control concept. Preliminary thresholds will be released to the industry this spring. Future work needs to:

- develop models to predict these relationships for a broader range of situations
- establish thresholds for "real" weed populations of mixed age and species
- encompass issues of seed production, lint contamination and weed patchiness, and
- develop "farmer friendly" assessment tools

The project is also looking at herbicide damage, which is an increasing problem with multiple herbicide tolerance gene options now available with the limited release of Liberty Link cotton last season.

Understanding the "critical period for weed control" concept

By Graham Charles and Ian Taylor, NSW DPI and Cotton Catchment Communities CRC

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

These new options allow growers to develop more effective and flexible weed management programs, but the old dilemmas still remain. Growers have to answer the questions:

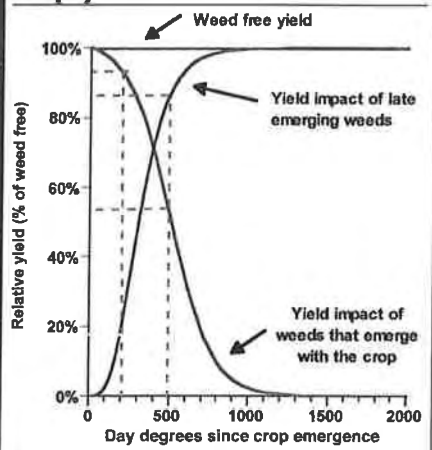
- Should I use multiple pre-emergent herbicide applications, with pre-planting as well as at-planting herbicides?
- Or maybe just one of the options, but if so, which herbicide/s and at what rates, broadcast or banded?
- When should I inter-row cultivate or chip, or should I just apply another herbicide? or,
- Should I use a layby?

Using more and more herbicides gives better weed control, but pre-emergence residual herbicides can contribute to establishment problems and additional post-emergence herbicides will not necessarily result in better yields, or improved returns. In fact, controlling weeds in a fairly clean field may just reduce profits.

Conversely, inadequate weed control can be costly to remedy, and can result in lost yield and weed problems for years to come. So the question is, what herbicide/cultivation/chipping combinations will give optimal weed control, and maximise yields and returns?

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

FIGURE 1: The impact of four thornapples per metre on crop yield



The orange lines demonstrate the impact of control 200 and 500 day degrees after crop emergence.

A WEED CONTROL THRESHOLD

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

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

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

DETERMINING THE ECONOMIC THRESHOLD FOR WEED CONTROL

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

For example, a grower may consider using a Roundup Ready herbicide application costing around $23 per hectare, including application. The grower will probably not use the herbicide unless the weeds will cause at least a $23 per hectare yield loss, with additional benefit expected in harvest efficiency, lint quality and reduced weed problems in later years.

At a bale price of $380 and an expected yield of eight bales per hectare, this establishes an economic threshold for applying Roundup Ready herbicide at around 0.8 per cent yield loss. That is, the economic threshold is 0.8 per cent level of yield loss.

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

UNDERSTANDING THE IMPACT OF WEEDS

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

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

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

DETERMINING THE YIELD LOSS FROM WEEDS

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

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

The red line is the yield loss from a thornapple infestation where the weeds emerged with the crop and were removed some time after emergence. For example, if the thornapples were controlled at 200 day degrees, crop yield would be reduced to 93 per cent, a seven per cent yield reduction (indicated by where the orange line at 200 day degrees hits the red line).

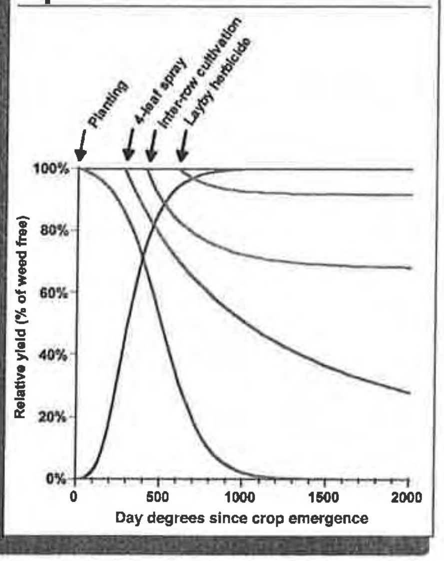
If the thornapples were removed at 500 day degrees, the yield would be reduced to 54 per cent, a 46 per cent yield reduction (500 degrees days orange line). Yield would be reduced by 100 per cent if the thornapples were not controlled before 1300 day degrees.

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

Although a single red line is shown for simplicity in Figure 1, there would actually be a family of red lines, representing

...50 ▷

FIGURE 2: The impact of weed competition on crop yield following weed control inputs



◁49...WEED CONTROL CONCEPT

thornapples that emerged after each weed control input (inter-row cultivation, herbicide and so on), as shown in Figure 2.

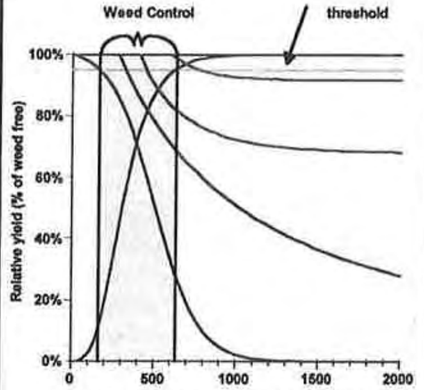
A further set of lines would be needed to show the impact of thornapples at another density, and still more sets of curves to show the impact of other weeds, as the curves are different for each species and density.

THE "CRITICAL PERIOD FOR WEED CONTROL"

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

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

FIGURE 3: Deriving the "critical period for weed control" (the blue shaded area)



The "critical period for weed control" is defined by the economic threshold chosen, the weed species and the weed density. In this example, the "critical period for weed control" for four thornapples per metre of cotton row is 166 to 621 day degrees at a five per cent economic threshold. Thornapples not controlled during this period will cause economic yield loss.

BEYOND THE "CRITICAL PERIOD FOR WEED CONTROL"

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

Conversely, if up to four thornapples per metre establish after 621 day degrees, they would not cause an economic yield loss (using a five per cent yield loss threshold). But they might still need to be controlled to avoid seed production, harvesting difficulties and thornapple problems in later seasons.

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

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

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

TIMING OF HERBICIDE APPLICATIONS

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

But the germination of weed seeds is mainly governed by temperature and soil moisture conditions, (it may also be influenced by seed dormancy). So there are normally a number of weed flushes throughout a season following rainfall and irrigation events.

Cotton growers must take into account the likely number of germination events, the cost of weed control, the capacity to cover a number of fields with the application equipment available, and possible yield reductions due to weed pressure when making a weed control decision. Control of very small weeds prior to the weed removal time would be efficient in terms of herbicide, as lower rates are required to control smaller weeds, but may be very inefficient if subsequent germinations quickly replace the previous weed population, requiring repeated treatments.

PREVENTING WEED SEED SET

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

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

Applying the "critical period for weed control" in the field

By Graham Charles and Ian Taylor, NSW DPI and Cotton Catchment Communities CRC

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

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

THE "CRITICAL PERIOD FOR WEED CONTROL"

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

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

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

The critical periods for weed control defined by these weed competition relationships are dependent on the economic threshold chosen. As an example, results

...52 ▷

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

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

for a one per cent yield threshold are indicated in Figure 1 by the shaded blue areas in each figure. These areas are defined by where the maroon and brown lines cut the economic threshold, and determine the start and end of the critical period in day degrees on the bottom axis.

Figure 1 shows that the critical period for weed control at a one per cent economic threshold for one large broad-leaf weed per metre row starts 30 day degrees after crop emergence and continues till 598 day degrees. In other words, at one large weed per metre row, if weed control starts later than 30 day degrees after crop emergence, a yield loss of greater than one per cent will occur.

Conversely, large broadleaf weeds that emerge at up to one per metre row later than 598 day degrees after crop emergence cause less than a one per cent reduction in crop yields. So controlling these weeds that emerge later than 598 day degrees after the crop can't be justified on the basis of the yield reduction they will cause.

They may still need to be controlled, as they may interfere with harvesting and may produce a seed load that leads to increased weed problems in later seasons. A layby application of a residual herbicide may be the best option at this point in the season.

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

PREDICTING THE CRITICAL PERIOD FOR WEED CONTROL

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

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

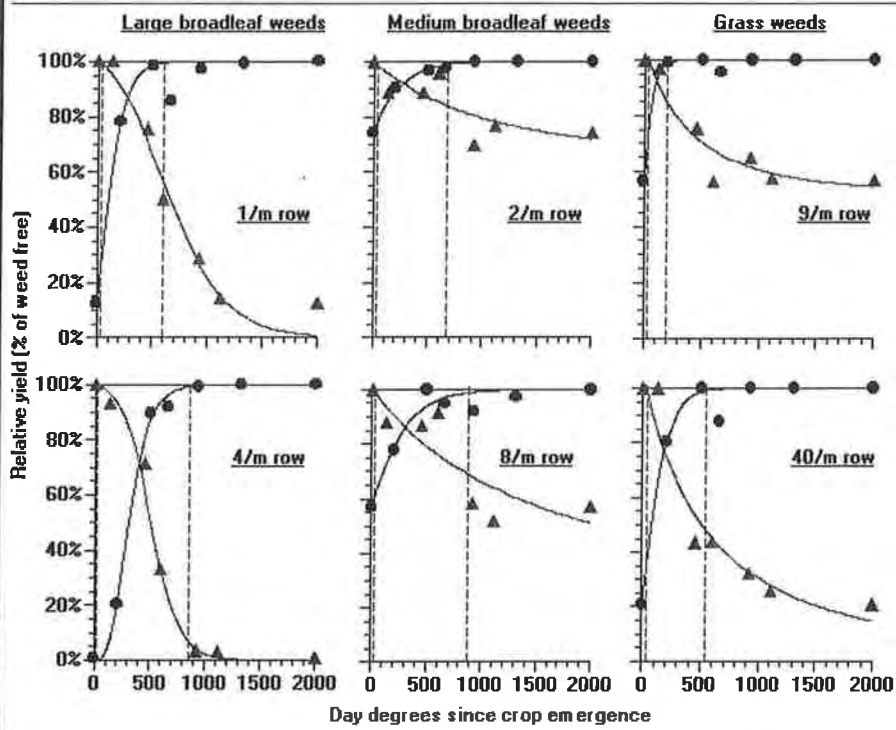
The length of the critical period was much shorter for the grasses compared to the broad-leaf weeds at the same densities. Season long competition from fewer than three grass weeds per metre caused less than one per cent yield loss.

So control of fewer than three grass weeds per metre row can't be justified on the basis of yield loss alone. But failure to control grasses at this density early in the season will lead to problems later in the season with harvesting difficulties and lint contamination.

Not controlling grass weeds will result in seeds being added to the seed bank. This seed may germinate following the next rainfall or irrigation event, resulting in greatly increased weed problems later in the season or in subsequent seasons.

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

FIGURE 1: Yield relationships for weeds competing in irrigated cotton



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

TABLE 1: The predicted start and the end of the "critical period for weed control" for a range of weed species and densities

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

USING THE "CRITICAL PERIOD FOR WEED CONTROL" DATA SET

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

Future research in this project will cover a number of additional points, including developing data sets for mixed populations of real weeds, testing the findings in other regions and developing more robust weed competition assessment tools.

Weed densities are never uniform in the real world, and staggered weed germinations can make for difficult decisions. Developing a weed management guide based on measurements such as weed and crop leaf area may give much more robust guidelines than the current findings simply based on weed density.

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

Secondly, the duration of the weed control period is influenced by weed species and density, but may extend until well into the season in dirtier fields. Weed control may have to be maintained until mid- to late-January, depending on the region and the season.

Conversely, weed control with an over-the-top herbicide in relatively clean fields may be largely cosmetic and not justified on the grounds of competition alone. Controlling these weeds with inter-row cultivation or a lay-by herbicide later in the season would be a better option. This is especially the case in fields that are not going back to cotton.

AVOIDING HERBICIDE RESISTANCE AND SPECIES SHIFT

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

An obvious strategy might seem to be to limit the number of Roundup Ready applications, using maximum rates to control big weeds. This is not advisable for two reasons.

Firstly, the "critical period for weed control" work shows that this strategy will lead to large yield losses. Secondly, using a lesser number of applications of a heavy herbicide rate will not necessarily reduce selection pressure compared to multiple applications of lighter rates on small weeds. The issue is not how many applications are made per season, but whether successive generations are exposed to the same selection pressure.

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

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

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

Using the critical period for weed control to manage weeds in Roundup Ready Flex® cotton in the 2007/8 season

Graham Charles[1] and Ian Taylor[2]
NSW DPI, Cotton Catchment Communities CRC[1], and CRDC[2], Narrabri

SUMMARY

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

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

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

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

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

THE CRITICAL PERIOD FOR WEED CONTROL

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

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

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

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

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

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

It is essential that glyphosate is not the only herbicide used in fields with very heavy weed densities, or where glyphosate tolerant weeds are present. Residual herbicides, such as prometryn, fluometuron and diuron, or alternative contact herbicides, such as Staple® or Envoke®, should be used in fields were significant numbers of glyphosate tolerant weeds, such as burr medic, rhyncho and emu foot are present. The choice of herbicide(s) is determined by the weed species present. Very dirty fields are normally best managed by applying residual herbicides before or at planting, reducing the pressure on glyphosate later in the season. This is generally more satisfactory than applying these herbicides later in the season after problems have already occurred, when it is difficult to achieve good incorporation of the herbicides, especially in the plant line.

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

THE CRITICAL PERIOD IN IRRIGATED COTTON

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

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

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

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

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

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

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

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

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

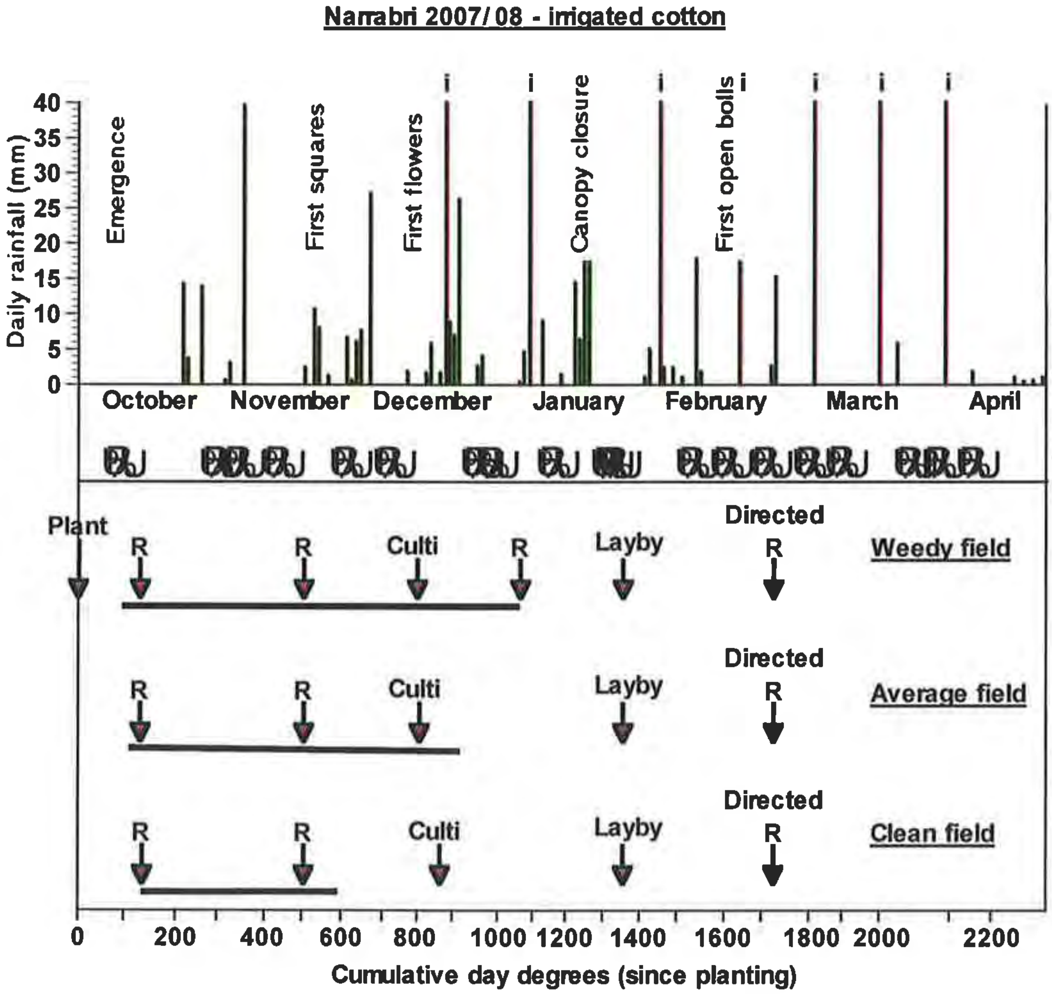


Figure 1. How the critical period for weed control could have been used in the 2007-8 season at Narrabri for weedy, average and clean fields. Symbols are: (top section) rainfall (**vertical bars**) and irrigations (**vertical bars topped by i**); (middle section) periods of peak weed emergence, **[symbol]**;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

THE CRITICAL PERIOD IN DRYLAND COTTON

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

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

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

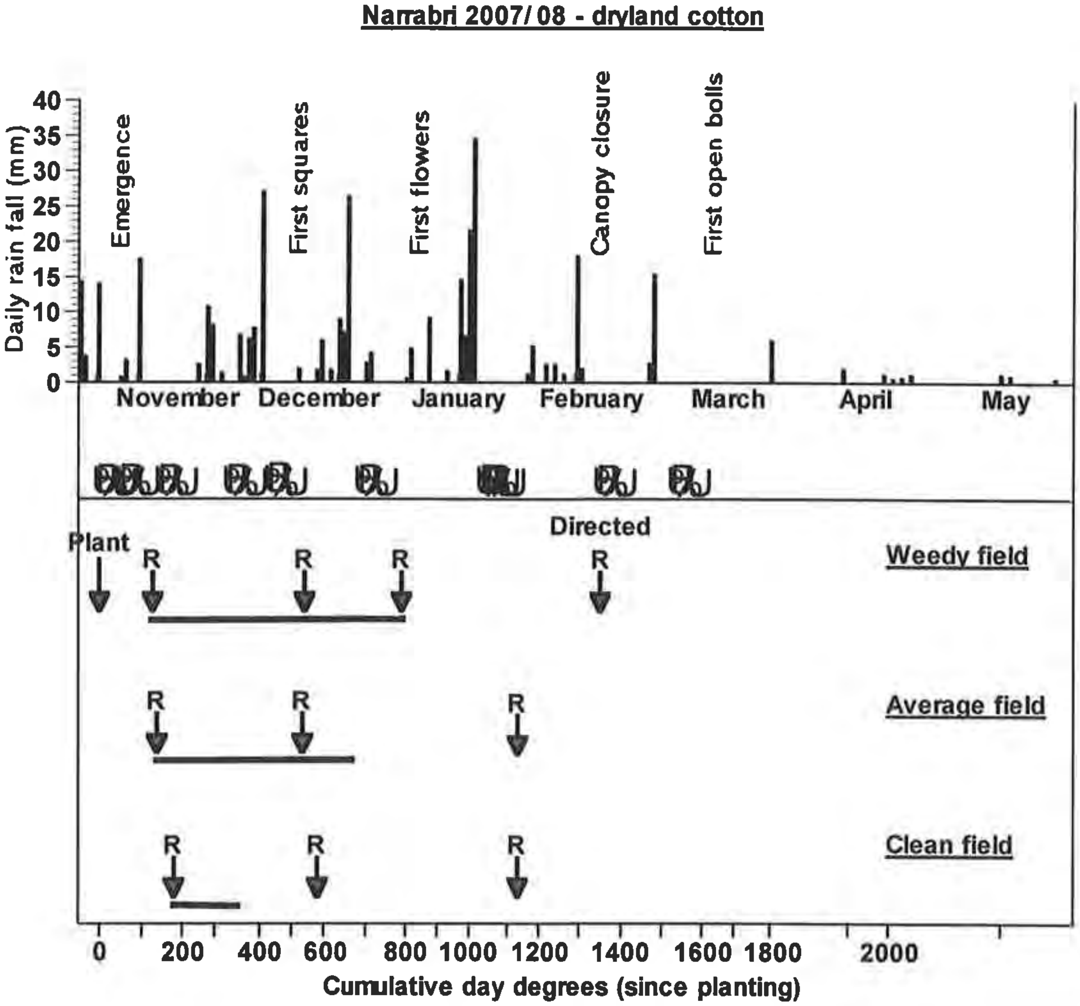


Figure 2. Using the critical period for weed control in dryland cotton in the 2007-8 season at Narrabri for weedy, average and clean fields. Symbols are: (middle section) periods of peak weed emergence, **ᏈᏝ**; and (bottom section) the critical period for weed control, **horizontal lines**; and planting and weed control inputs, **arrows**. Symbols used on arrows are: planting, **Plant**; Roundup sprays, **R**; inter-row cultivation passes, **Culti**; and application and incorporation of a residual herbicide, **Layby.**

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

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

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

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

OBSERVATIONS FROM THE 2007/8 SEASON

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

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

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

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

RESISTANCE TO ROUNDUP

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

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

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

More information on herbicide resistance and strategies for managing resistance are covered in papers by Charles, and Werth & Thornby in these proceedings.

CONCLUSIONS

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

Managing herbicide resistance in cotton: the importance of the Crop Management Plan

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BACKGROUND

Many cotton growers are concerned that relying too heavily on Roundup (glyphosate) will lead to future problems with weeds becoming resistant to this herbicide. The potential for resistance is very real, as shown by the increasing resistance problems with Roundup Ready crops in the US, and emerging problems with glyphosate resistant ryegrass and awnless barnyard grass in the Australian cotton growing area.

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

INTRODUCTION

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

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

Unfortunately, 20 years later, this is no-longer the case. Cotton is now being grown with a rapidly shrinking array of weed management inputs. There are almost certainly herbicide resistant weeds in the cereal component of the cotton farming system on a number of properties, and probably also resistant weeds in the cotton component, somewhere in the industry, although they haven't been detected yet. While these resistance problems may not have been caused by the way weeds are managed in cotton, in the end it doesn't matter, the problem doesn't go away just because it was caused somewhere else.

The stark reality of size of the herbicide resistance problem is brought home in an article by Werth and Thornby in these proceedings. There are now 185 different weed species resistant to a herbicide somewhere in the world. Thirty four weed species have resistance in Australia, and while most of these are resistant to the high risk Group A and B[1] herbicides, there is resistance to nearly every herbicide group, including the groups that include our residual cotton herbicides and glyphosate. In WA and the US, resistance has even developed to 2,4-D (Group I), a herbicide very widely used since the 50's, which had never had a resistance problem anywhere in the world up until a couple of years ago. It just shows that if you push the system hard enough, resistance will eventually occur.

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

In the cotton growing areas there are numerous instances of ryegrass and wild oats populations with resistance to Group A herbicides and ryegrass populations resistant to glyphosate (Group M). We now also have 2 confirmed awnless barnyard grass populations with resistance to glyphosate, with a 3rd suspected population and doubtless other populations yet to be detected. This season we had a suspected resistant awnless barnyard grass population in cotton. It turned out not to be resistant, but it was a wakeup call – it could have been glyphosate resistant awnless barnyard grass in cotton.

So what causes the problems?

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

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

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

So, the selection pressure on glyphosate is not overly strong in a traditional weed management system where survivors from a glyphosate spray are normally controlled by cultivation, chipping or a residual herbicide.

HERBICIDE RESISTANCE IN THE COTTON SYSTEM

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

Unfortunately, this system has its drawbacks, including expense, undesirable off-target impacts of herbicides and unavoidable damage to the cotton crop. Twenty years ago, many chipping bills were in excess of $100/ha, with bills up to $300/ha not uncommon. These bills are not affordable in the current economic climate, even if the large chipping crews are still available, which they generally are not. These issues have forced the weed management system to evolve over the years to one which is less reliant on chipping, substituting residual and contact herbicides for chipping inputs. Unfortunately, the drawbacks of off-target impacts and damage to the cotton crop remain and are accentuated by the heavy reliance on residual herbicides required. While this damage was hardly noticeable in the 2½ bale cotton crops of the 1980's, it is unacceptable in the 5 and 6 bale crops of this decade.

Fortunately, alternative weed management systems became available with the release of Roundup Ready® cotton, and more recently Roundup Ready Flex® and Liberty Link® cotton varieties. Use of these transgenic traits has allowed cotton growers to develop new, lower input, more environmentally friendly weed management systems which are conducive to higher cotton yields. The strength of these systems is that they rely on broad-spectrum, contact herbicides, with excellent crop safety (Roundup Ready Flex and Liberty Link), which are more environmentally benign than the residual herbicides they replaced and are only applied when a weed problem is present, allowing the application rate and number of applications to be tailored to match the problem/s.

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

So, how to maintain a glyphosate based system?

SELECTION IN A GLYPHOSATE BASED SYSTEM

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

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

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

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

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

THE IMPORTANCE OF THE CROP MANAGEMENT PLAN

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

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

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

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

Low weed numbers can be achieved in one of two ways. Firstly, low weed numbers can be the result of good weed management practices over a number of years. Weed surveys over the last 20 years found that generally cotton fields have become cleaner, with fewer weeds over time. Fields with low weed numbers are ideally suited to the transgenic systems where residual herbicides are replaced by contact herbicides.

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

MAINTAINING THE WHOLE GLYPHOSATE SYSTEM

One of the biggest threats to the sustainability of the Roundup Ready system is the use of glyphosate in the rest of the farming system.

For example, where cotton is grown in a wheat rotation in an irrigated system, it would be common for a field to be in fallow for nearly 12 months in every 24 month period. In this system, weeds in the fallow are commonly controlled with glyphosate, and a field may receive 5 or 6 applications (or even more) over the fallow period, especially where wheat stubble is retained. This again places strong selection pressure on glyphosate, but can be addressed using the same approach of controlling any survivors of a glyphosate application using an alternative option before they set seed. This control input could be an alternative herbicide, cultivation or chipping. An approach widely supported in the southern farming system is to follow a glyphosate application with a paraquat/diquat (Spray.Seed) application in a double-knock, with 5 to 7 days between the herbicide applications. This combination is effective for controlling small, annual weeds and the strategy is very effective for preventing resistance developing, provided that resistance to either of these herbicides has not already occurred. The double-knock strategy can be equally applied using a range of alternative inputs, such as cultivation, or other herbicides following closely after the glyphosate application.

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

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

AT RISK WEEDS

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

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

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

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

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

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

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

CONCLUSION

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

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

Cotton Catchment Communities CRC – 3rd Year review – **Project summaries**.

Program	**The Farm**
Project Title:	Developing a weed control threshold and managing herbicide damage in cotton
Project No:	1.01.49
Supervisor, key project staff and affiliation:	**Graham Charles**, Robert Mensah, Craig Chapman, Tim Grant (NSW DPI), Ian Taylor (CRDC), Jeff Werth, David Thornby (QDPI), Mike Bange (CSIRO)

Project Aims:

The projects aims are to:

• Develop integrated weed management strategies that will minimise the risks of herbicide resistance and species shift,

• Develop the critical period for weed control concept for cotton production,

• Validate the timing of herbicide applications in RR Flex cotton farming systems,

• Develop a weed control threshold enabling growers to make better decisions on the timing of herbicide applications,

• To provide growers with information on:

- the impact of glyphosate and 2,4-D damage in cotton at a range of rates and growth stages,
- best-bet management of glyphosate and 2,4-D damaged fields, and

• To continue to provide growers with information and support for integrated weed management through WEEDpak.

Progress:

The project has progressed well, achieving all of its goals to date.

A weed control threshold based on the Critical Period for Weed Control has been developed and disseminated to the cotton industry. This threshold, based on crop growth stage, weed type and weed density highlights the strong competitive effect of early-season weeds on cotton and the need for good early-season weed management. Herbicide damage data for glyphosate and 2,4-D damage has also been released. A large amount of additional data has been collected and awaits processing. Many samples from the 2007/8 season still need to be ginned.

The first seasons data using an infra-red sensor to develop a more robust and user-friendly weed control threshold has been collected. This data needs further analysis but the approach shows promise and will be more readily applied to large fields. Additional experiments have been planted this season.

Potential adoption pathway:

Information from this project is being disseminated through the Australian CottonGrower, CottonTails, WEEDpak on the web, the COTTONpaks CD, the Cotton Pest Management Guide (planned) and meetings with the assistance of the cotton extension team. Detailed information will also be included in scientific papers.

Selected recent publications:

Charles, G and Taylor, I. (2008). Managing Roundup Ready Flex® cotton using the critical period for weed control in the 2007/8 season. Proceedings of the 14th Australian Cotton Conference, Broadbeach, Qld., 12-14 August 2008.

Charles, G and Taylor, I. (2008). Managing herbicide resistance in cotton: why is the Crop Management Plan important. Proceedings of the 14th Australian Cotton Conference, Broadbeach, Qld., 12-14 August 2008.

Charles G. W. and Taylor I. N. (2007). Developing a threshold model for controlling weeds in glyphosate resistant cotton. Proceedings of the World Cotton Research Conference-4, Lubbock TX, Sept. 10-14 2007. M. Stephens (Ed.), Lubbock, Texas.

Roundup Ready Flex and the critical period for weed control

By Graham Charles, Ian Taylor and Tracey Farrell, NSW DPI, Cotton CRC and CRDC

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

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

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

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

SUMMARY

- Application of the Critical Period for Weed Control (CPWC) concept was tested for irrigated and rain-fed Roundup Ready Flex cotton crops using data from the past three seasons.
- The CPWC was applied to a relatively dirty field situation, where large numbers of weeds emerged after each rainfall and irrigation event.
- The CPWC required that weeds were controlled while still small, potentially using up the in-crop Roundup Ready applications early in the season.
- The seasons varied from relatively wet (first half of 2004–05) to extremely dry (2006–07).
- All weed flushes were able to be controlled in each season using the CPWC approach, with an early application of a residual layby herbicide available as a backup additional weed management tool.
- The results show that ensuring weeds are controlled soon after emergence is a practical approach to weed control which will minimise yield losses from weeds.

THE CRITICAL PERIOD FOR WEED CONTROL

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

The CPWC is defined in Table 1 using

...40 ▷

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

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

◁39...FLEX AND THE CPWC

a one per cent threshold for fully irrigated cotton and a three per cent weed control threshold for lower yielding or rain-fed crops. These control thresholds were determined from the point where the yield loss caused by the weeds exceeds the cost of control with Roundup Ready herbicide. As well as reducing lint yield, uncontrolled weeds set seed – increasing weed problems over time, impeding water flow and pesticide penetration, harboring pests and diseases, and causing harvesting difficulties and lint contamination.

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

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

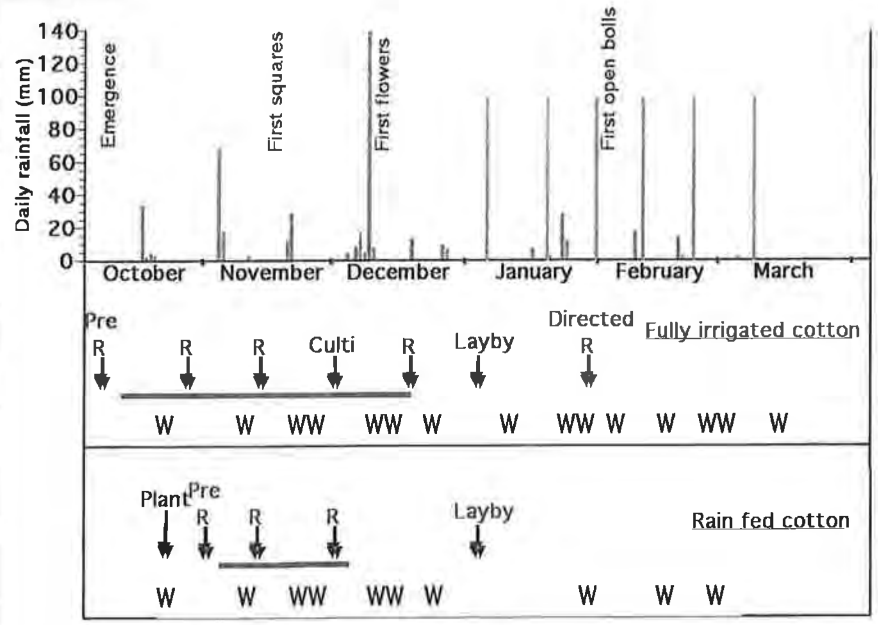
TABLE 1: The predicted start and the end of the CPWC for a range of weed species and densities using one per cent and three per cent thresholds – the critical period is measured in day degrees from planting

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

MODEL INPUTS

We tested the CPWC on a relatively dirty field with a mixed weed population of one large broadleaf weed per square metre (eg thornapple or noogoora burr), five medium sized broadleaf weeds per square metre (eg bladder ketmia) and 10 grass weeds

FIGURE 1: A simulation of how the CPWC might have been applied in the 2004–05 season at Narrabri (ACRI) – simulations are for both fully irrigated and rain fed crops



Symbols are: blue bars, daily rainfall (mm); pink bars, irrigations; red lines, the CPWC; red arrows, weed control inputs (R = Roundup Ready Herbicide, Pre R = a pre-crop emergence Roundup, Culti = inter-row cultivation, Layby = a residual layby herbicide); and green arrow, planting. Periods of peak weed emergence are indicated by W per square metre (eg barnyard grass). Simulations were made for both fully irrigated and rain-fed crops in each season.

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

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

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

THE CPWC IN 2004–05

Reasonable rainfall fell in the first half of the 2004–05 season at Narrabri, with a daily maximum of 138 mm recorded in December. Multiple weed germination events were triggered by early season rainfall and irrigation later in the season (Figure 1).

With no pre-planting or at-planting residual herbicides used, post-emergence weed control was required following weed emergence on four occasions during the critical period – at six nodes, first squares, first flowers and mid-flowering (310, 511, 719 and 946 day degrees). Ideally, weeds need to be controlled within 105 day degrees of their germination, which will be only a few days after seedling emergence. Roundup Ready herbicide could be used on three of these occasions, with inter-row cultivation and chipping used on one occasion.

This combination of inputs conforms with the Roundup Ready Flex Crop Management Plan which requires that:

- No more than three Roundup Ready herbicide applications are made during this crop growth period; and,
- Weeds that survive a Roundup Ready herbicide application are controlled by an alternate method before they set seed (the combination of inter-row cultivation and chipping conforms with this requirement).

Only a very light chipping should have been required as few weeds would have survived two Roundup applications and a cultivation pass.

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

This herbicide program would potentially have used the maximum number of early-season Roundup Ready herbicide inputs allowed by the label, but probably

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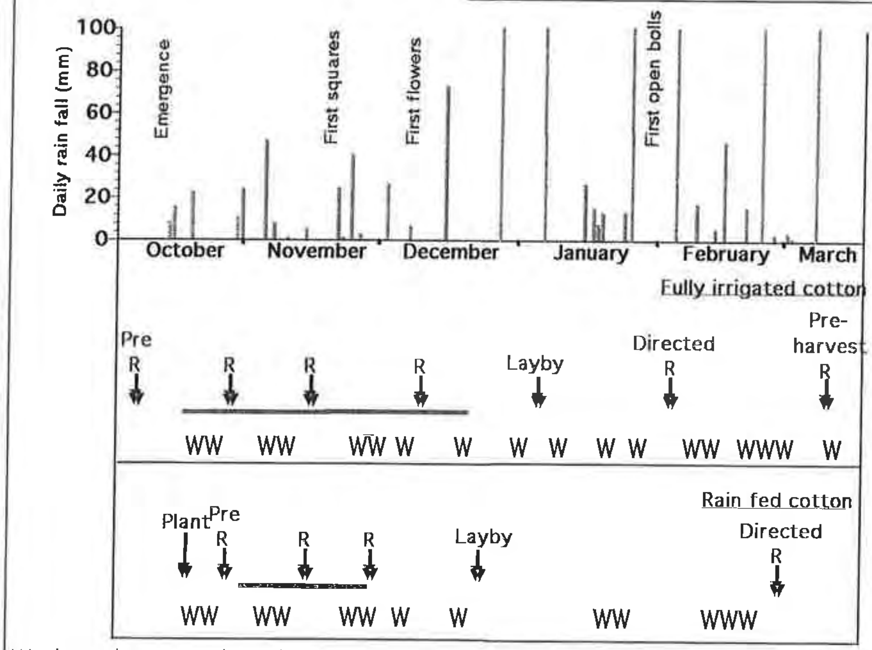
FIGURE 2: Using the CPWC in the 2005–06 season – simulations for fully irrigated and rain-fed crops are shown



Weed control operations during the CPWC protect cotton yield. Weed control operations after the CPWC prevent weeds from adding seed to the soil seed bank, leading to problems in later seasons not all these inputs would have been required in practice, with at least one inter-row cultivation pass replacing a Roundup application.

It is also likely that lower than maximum label rates would have been used for the first two Roundup applications as these were applied to young weeds which are easily controlled with lower rates. Rates of 0.5 to 1.0 kg per hectare would give excellent control of most susceptible weed seedlings. An early lay-by application of residual herbicide could have been applied in late-December if an additional weed control input had been required during the critical period.

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

THE CPWC IN 2005–06

Reasonable rainfall again fell in the 2005–06 season at Narrabri, and multiple weed germination events were triggered by rainfall and irrigation (Figure 2).

Using a one per cent yield loss threshold, post-emergence weed control was required at five nodes, first squares and first flowers (259, 460, and 803 day degrees). Roundup Ready herbicide could have been

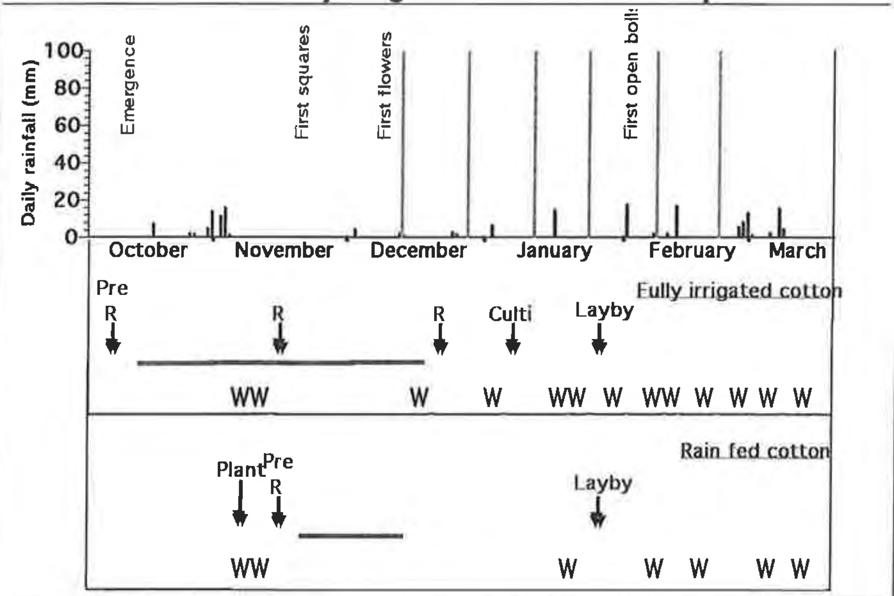
used on all occasions, although an inter-row cultivation and light chipping may have been used once to remove any weeds that survived the Roundup application, as required by the Crop Management Plan.

Weeds which emerged later in the season could have been controlled with a lay-by application of residual herbicide in early January and a directed application of Roundup Ready herbicide during the 16 to 22 node stage if required. A pre-harvest application of Roundup Ready herbicide could also be used to prevent late-season weeds setting seed.

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

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

FIGURE 3: Applying the CPWC in the 2006–07 season – simulations are for fully irrigated and rain-fed crops



THE CPWC IN 2006–07

Very little rain fell in the 2006–07 season at Narrabri, with most weed germination events triggered by irrigation (Figure 3).

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

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

OBSERVATIONS FROM THESE SIMULATIONS

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

In seasons where the early season weed pressure is too high (requiring too many early Roundup applications), an early layby application of residual herbicide can be used to replace a Roundup application and reduce weed pressure.

Prometyrn (Gesagard) or fluometuron (Cotoran), for example, can be applied as an early layby to cotton as small as 15 cm high and will control a wide range of emerged weeds (when they are small), as well as giving residual control, reducing weed pressure.

An alternative residual, such as diuron, could then be applied later in the season as a standard layby application.

RESISTANCE TO ROUNDUP

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

But resistance can be avoided by following two simple rules.

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

CONCLUSIONS

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

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

How well does the critical period for weed control (CPWC) work?

By Graham Charles[1] and Ian Taylor[2]

The critical period for weed control is a concept that relates the yield losses caused by weed competition to an economic threshold. It establishes an initial period when weeds are small and do not need to be controlled as they cause no economic loss, and a period later in the season when the cotton plants are relatively large and small weeds again cause no economic loss.

These periods define the middle, critical period for weed control, in which weeds must be controlled while still small to avoid significant yield losses. Weeds which emerge after the critical period may still need to be controlled to avoid harvesting difficulties and lint contamination and should not be allowed to set seed, as this will lead to increased weed problems in later seasons. These weeds can also harbour pests and diseases. But the timing of this control is flexible, provided seed set is prevented, and can be delayed to minimise the number of spray applications required over the season.

AT A GLANCE...

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

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

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

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

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

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

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

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

The critical period in irrigated cotton

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

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

Lower than maximum label rates would have been suitable for Roundup applications to young weeds, as weeds are more easily controlled while they are small, provided they have sufficient leaf area to catch the spray. Rates of 0.8 to 1.0 kg per hectare should be sufficient to control susceptible weed seedlings, reducing cost and maintaining late-season options (the product label precludes the use of maximum label rates for all applications if the maximum number of in-crop Roundup applications is used).

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

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

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

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

The critical period in dryland cotton

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

The start of the critical period was again relatively insensitive to weed density, pro-

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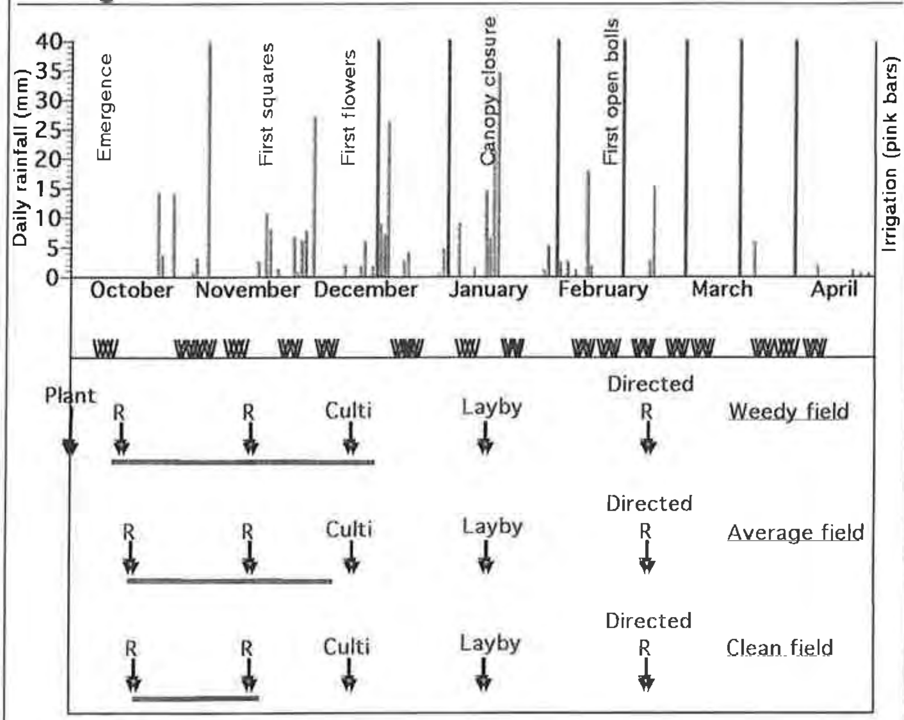
FIGURE 1: How the critical period for weed control could have been used in the 2007–08 season at Narrabri for weedy, average and clean fields



Symbols are: (top section) rainfall (**vertical bars**) and irrigations (**pink bars**); (middle section) periods of peak weed emergence, **W**; and (bottom section) the critical period for weed control, **horizontal lines**; and planting and weed control inputs, **arrows**. Symbols used on arrows are: planting, **Plant**; Roundup Ready Herbicide sprays, **R**; inter-row cultivation passes, **Culti**; and application and incorporation of a residual herbicide, **Layby**.

TABLE 1: The predicted start and end of the critical period for weed control for a range of weed types and densities

Weed density (no./m²)	Start and end of the critical period for weed control (day degrees since planting)											
	Irrigated (high yielding) cotton						Dryland (low yielding) cotton					
	Broad-leaf weeds						Broad-leaf weeds					
	Large		Medium		Grasses		Large		Medium		Grasses	
	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
0.1	145	189	145	172	—	—	—	—	—	—	—	—
0.2	144	275	144	244	—	—	254	229	—	—	—	—
0.5	143	447	143	387	—	—	251	368	—	—	—	—
1	141	600	141	514	—	—	246	498	246	319	—	—
2	139	738	139	627	—	—	238	620	238	421	—	—
5	131	862	131	729	129	174	215	735	215	537	—	—
10	121	915	121	771	127	248	184	785	184	595	152	206
20	106	944	106	795	125	357	142	812	142	631	147	290
50	87	962	87	810	119	531	93	830	93	654	134	431
Minimum density	0.06		0.07		2.5		0.24		0.59		5.4	

Examples of weeds in each category are: thornapples and noogoora burrs (large broad—leaf weeds); bladder ketmia and Chinese lantern (medium broad—leaf weeds); and barnyard grass (grass weed). The minimum weed densities needed to trigger the critical period are also shown.

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

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

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

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

Observations from the 2007–08 season

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

The main difference for crop management with this approach is that weed control is focussed on the critical period, soon after crop emergence, with all inputs during this period necessarily occurring on small weeds. This contrasts with a more common philosophy, that glyphosate applications to Roundup Ready Flex crops can be delayed to maximise the efficiency of each spray, minimising the number of sprays and ensuring that the maximum number of weeds are controlled with each input.

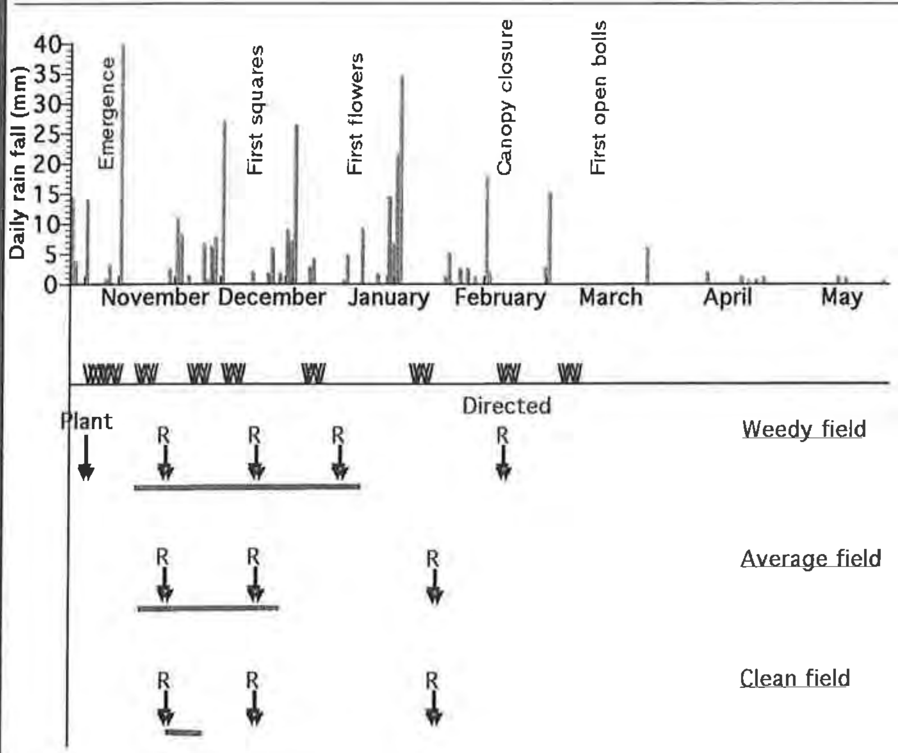
Many cotton growers have concluded that since they are no longer constrained to the four-node over-the-top glyphosate application window, glyphosate applications can be delayed to about six nodes, with a second application at 10 to 12 nodes giving good weed control.

While this approach is valid, the science of the critical period has shown that to avoid yield losses, the first glyphosate application may need to occur soon after crop emergence, with further applications following closely after successive weed germination events. This strategy of controlling very small weeds may require more Roundup applications, but can utilise lower herbicide rates and maintains the potential for higher crop yields.

In seasons where the early season weed pressure is excessive (possibly requiring more Roundup applications than are permitted by the product label), an alternative herbicide or early layby application of residual herbicide could be used to replace a Roundup application and reduce weed pressure.

Prometryn (Gesagard) or fluometuron (Cotoran), for example, can be applied as an early layby to cotton as small as 15 cm high and control a wide range of small emerged weeds, as well as giving residual control, reducing weed pressure. An alternative residual, such as diuron, could be applied later in the season as a standard layby application if necessary.

FIGURE 2: Using the critical period for weed control in dryland cotton in the 2007–08 season at Narrabri



Symbols are: (top section) rainfall (**vertical bars**); (middle section) periods of peak weed emergence, **W**; and (bottom section) the critical period for weed control, **horizontal lines**; and planting and weed control inputs, **arrows**. Symbols used on arrows are: planting, **Plant**; Roundup Ready Herbicide sprays, **R**; inter-row cultivation passes, **Culti**; and application and incorporation of a residual herbicide, **Layby**.

[1]**NSW DPI, Cotton Catchment Communities CRC and [2]CRDC, Narrabri.**

Cotton Catchment Communities CRC

NSW DEPARTMENT OF PRIMARY INDUSTRIES

Glyphosate Resistance: *Know Your Risk!*

Sally Ceeney[1], Graham Charles[1], Mark Hickman[2], David Thornby[2], Steve Walker[2] and Jeff Werth[2]

[1]NSW Department of Primary Industries, [2] Qld Department of Primary Industries and Fisheries

Cotton Catchment Communities CRC

- **Grow mainly glyphosate tolerant cotton varieties?** ☑
- **Frequently use glyphosate to control weeds in fallows?** ☑
- **Rarely use alternative herbicides with different modes of action to control weeds in crop and in fallow?** ☑
- **Have high amounts of one or more of the following weeds:**
  - **Barnyard grass?** ☑
  - **Liverseed grass?** ☑
  - **Fleabane?** ☑
  - **Sowthistle?** ☑
- **Practice zero or minimum tillage?** ☑
- **Only cultivate post season (pupae bust) or pre season (bed preparation)?** ☑
- **Rarely monitor weeds?** ☑
- **Have poor paddock records?** ☑

STOP!

If you answered <u>yes</u> to most of these questions you may be at a <u>high risk</u> of developing glyphosate resistant weeds

Glyphosate resistant liverseed grass. Photo: Graham Charles

Flaxleaf Fleabane. Photo: Yvette Cunningham

Glyphosate Resistance: *Know Your Risk!*

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[1]NSW Department of Primary Industries, [2] Qld Department of Primary Industries and Fisheries
Cotton Catchment Communities CRC

- **Grow a range of crops and varieties?** ☑
- **Use a range of herbicides with different modes of action to control weeds in crop and in fallows?** ☑
- **Use strategic cultivations to control weeds?** ☑
- **Always try to control weed survivors before they set seed?** ☑
- **Achieved a low weed population using a range of IWM tools?** ☑
- **Monitor weeds regularly?** ☑
- **Have good paddock records?** ☑
- **Practice good farm hygiene to prevent importing and moving resistant seeds?** ☑

GO!

If you answered <u>yes</u> to most of these questions you are at a <u>low risk</u> of developing glyphosate resistant weeds

Good IWM is using a range of methods to control weeds in crop and in fallow

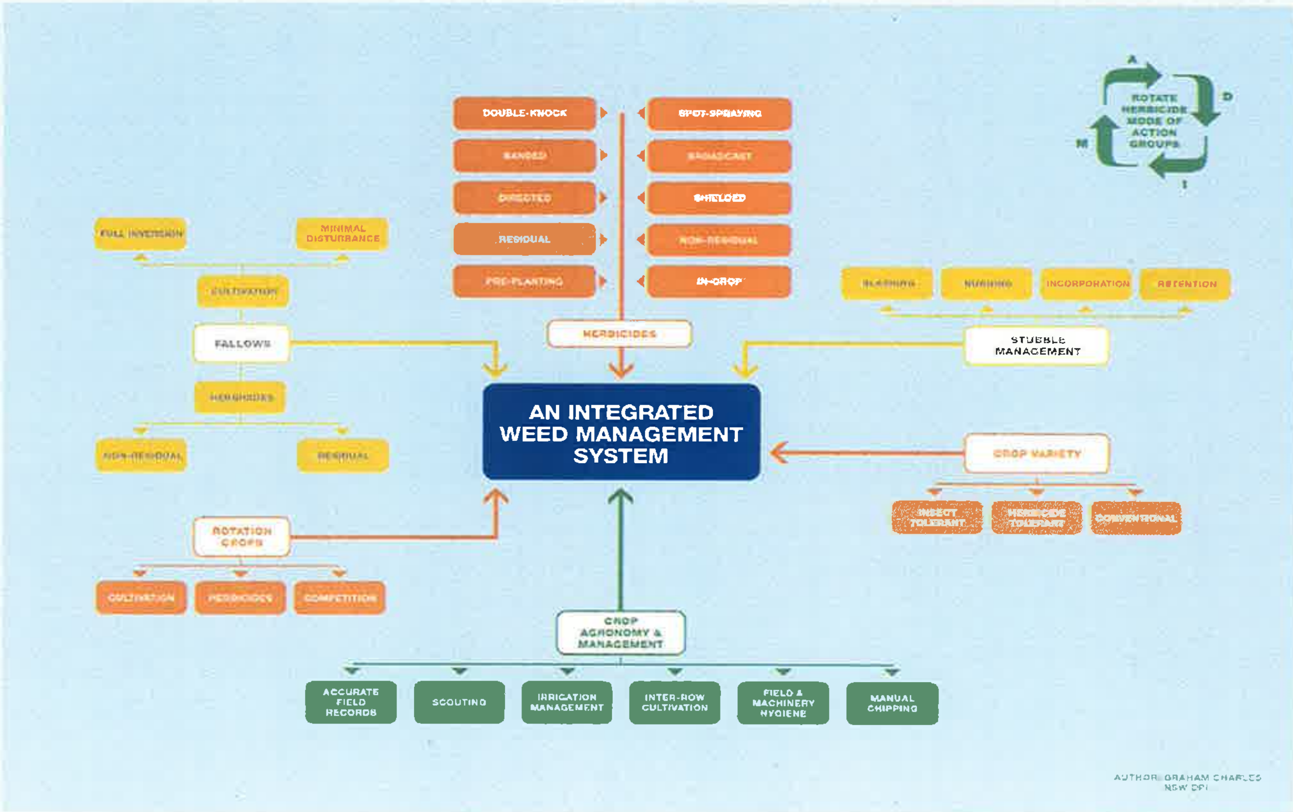
Glyphosate Resistance: *Know Your Risk!*

Graham Charles and Sally Ceeney, NSW DPI and Cotton Catchment Communities CRC

Why Act?

- The potential for herbicide resistance in the Australian cotton industry is very real. Due to the introduction of glyphosate resistant varieties, the industry is now heavily reliant on glyphosate for weed control, both in crop and in fallow
- Currently, there are populations of glyphosate resistant ryegrass, liverseed grass and awnless barnyard grass in cotton growing areas.
- There are now 185 weeds species tolerant to herbicides in the world. Problems with glyphosate resistant weeds in cotton is an increasing problem overseas

An Integrated Weed Management System is essential to prevent glyphosate resistance



Good farm hygiene is essential to ensure non-crop and cropping areas remain weed free

Cotton seedlings compete poorly with weeds

Cotton Catchment Communities CRC

NSW DEPARTMENT OF **PRIMARY INDUSTRIES**

Herbicide Damage Symptoms - Phenoxy

Graham Charles[1] Dave Larsen

[1] NSW Department of Primary Industries, Cotton Catchment Communities CRC

2,4-D


15 days after exposure


28 days after exposure

MCPA


6 days after exposure


28 days after exposure

MCPA plus picloram


9 days after exposure


28 days after exposure

Dicamba


6 days after exposure


28 days after exposure

2,4-D plus picloram


7 days after exposure


28 days after exposure

Triclopyr plus picloram


7 days after exposure


37 days after exposure

Fluroxypyr


6 days after exposure


28 days after exposure

Glyphosate and 2,4-D


15 days after exposure


28 days after exposure

Phenoxy Herbicide Group

A range of herbicides, collectively known as the phenoxy herbicides, affect the plant in a manner similar to endogenous auxin (IAA), a natural plant growth hormone.

At low rates they can distort plant growth. At higher concentrations they affect cell walls and nucleic acid metabolism and inhibit cell division and growth, leading to plant death. They are effective in controlling a wide range of broad-leaf weeds.

Cotton Catchment Communities CRC

NSW DEPARTMENT OF PRIMARY INDUSTRIES

Herbicide Damage Symptoms

Graham Charles & Dave Larsen

[1] NSW Department of Primary Industries, Cotton Catchment Communities CRC

2,4-D


15 days after exposure


28 days after exposure

Glyphosate


6 days after exposure


28 days after exposure

Imazapyr


Symptoms from seedlings exposed to soil residues

Atrazine


15 days after exposure


28 days after exposure

Paraquat plus diquat


6 days after exposure


16 days after exposure

Metsulfuron methyl


Symptoms from seedlings exposed to soil residues

Glufosinate


6 days after exposure


16 days after exposure

Simazine


15 days after exposure


28 days after exposure

A range of herbicides including the phenoxys are commonly used in agriculture and can cause mild to severe damage to cotton.

Damaged plants can display a wide range of symptoms.

The 3 WHATS of managing herbicide damage

Graham Charles
NSW Department of Primary Industries & Cotton Catchment Communities CRC, ACRI Narrabri

Generally the second response after discovering herbicide damage in a cotton crop is to ask the 3 whats. The first response of course involves the expression of some frustration and disappointment, especially if this is not the first damage event for the season!

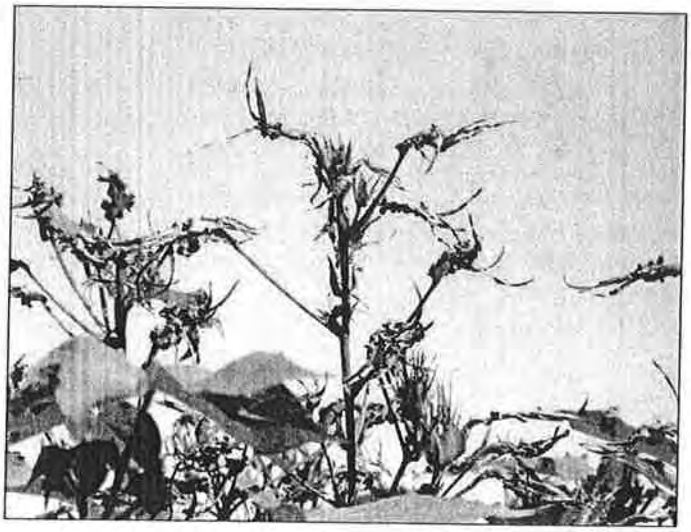
The 3 whats are:

- What caused the damage?
  - Which herbicide, and
  - At what rate?
- What will it do to the crop, and
- What do I do now?

The best solution to herbicide damage is to avoid it, but this is not always possible. Herbicide damage is becoming increasingly common in cotton crops, with 2,4-D the more common culprit.

Damage may have come from a wide range of sources, with drift from an application to another target a far too common problem. Damage can also result from poorly set-up or contaminated equipment, operator error, operating in unsuitable conditions, or residues from a previous spray.

So, after damage occurs, what next?



Above: A cotton crop starting to show symptoms of 2, 4-D damage.

The 3 whats

What caused the damage?
Information on the symptoms and effects of 2,4-D and glyphosate damage to cotton is available on the Cotton CRC web site under Publications>Weeds. Information on Starane®, dicamba, MCPA, bromoxynil and Spray.Seed® damage will be added to this site soon.

No information is currently available for the range of other herbicides, but work is underway to cover as many of these as is possible. This information will be added to the CRC website as it becomes available.

Work is also planned over the next few seasons to cover a range of lower rates of 2,4-D and multiple exposures.

Even with this information, determining the cause of the damage may be a difficult challenge, with a range of herbicides causing similar symptoms. Generally the hormone type herbicides (2,4-D, dicamba, MCPA and Starane) cause leaf distortion, but it may be almost impossible to positively identify which of these herbicides was the culprit.

Damage from some other herbicides, such as glyphosate (Roundup and various other trade names) is even more difficult to identify, with no obvious symptoms of damage from low rates. In some cases damage may be most readily determined by comparing growth rates on neighboring Roundup Ready and non-Roundup Ready crops.

What will it do to the crop?
The impact of known rates of 2,4-D and glyphosate at various crop stages is shown on the website. A range of photos show the development of visual symptoms and figures and a table show the impact on plant growth, flowering, fruit development and retention.

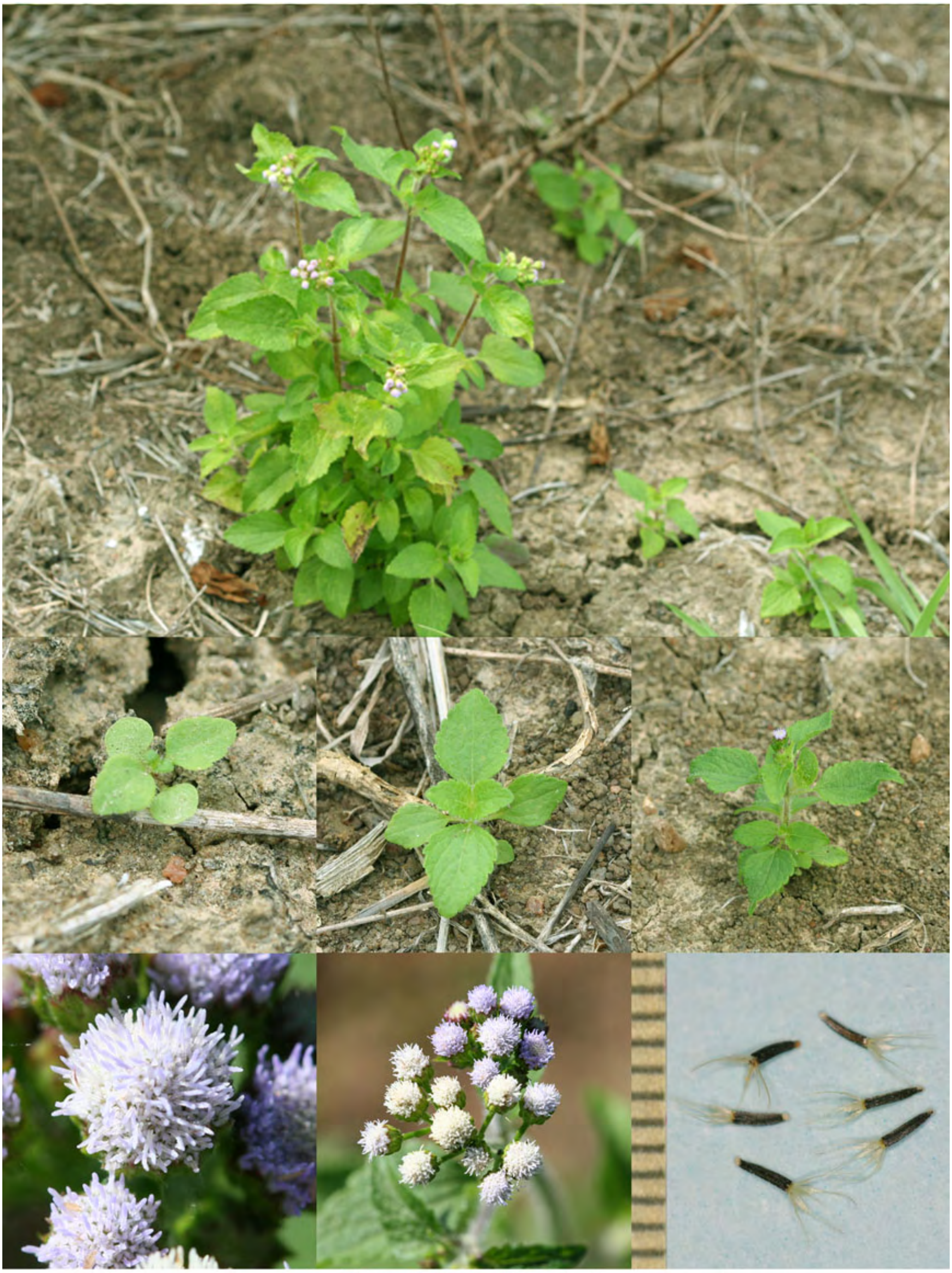
Growers can compare this data to their own crops and make predictions on the likely impact of these herbicides on their crops. Closely monitoring crop boll loads will probably give the best guide to the crop's likely response.

What do I do now?
This, the million dollar question, can only be made on the bases of crop growth stage, current boll retention and expected outcome.

The aim of this project over the next few years is to provide a more robust data set to assist growers to make the hard decisions. A wider range of herbicides will be included on the website and additional information included for the more common herbicides.

Ageratum conyzoides L.

Billygoat weed



Photographs: Graham Charles

Australian Government
Cotton Research and Development Corporation

Ageratum conyzoides

Family:

Asteraceae (Daisy family).

Common names:

Billygoat weed, Blue bonnet, Bluetop, Goatweed.

Confused with:

Billygoat weed and blue billygoat weed (*A. houstonianum*) are very similar and readily confused. Billygoat weed is more common in northern Queensland.

Description:

Seedlings – cotyledons leaves are circular to egg shape, 3 mm long by 3.5 mm wide.

Early leaves – are broadly egg-shaped, with lightly serrated margins. The serrations are widely spaced, rounded and shallow. Later leaves have obviously serrated margins and clearly defined veins.

Leaves – are egg shaped to triangular, arranged in opposite pairs along the stems. Leaves are 10 – 100 mm long and 10 - 60 mm wide, borne on stems 5 – 50 mm long. Leaves are mid-green and lightly hairy.

Mature plants – an erect annual or short-lived perennial plant 30 – 100 cm high with hairy stems.

Flowers – are 4 – 5 mm across, pale lavender blue to white. They occur in fluffy clusters on the end of erect or slightly drooping stems.

Fruit – seeds 1 - 3 mm in length, black and topped by a fluffy pappus of 5 white hairs, 1.5 - 3 mm in length which assists the seeds in wind dispersal.

Lifecycle / Biology:

An annual or short-lived perennial plant which emerges and flowers year round.

Ecology:

Occur on a wide variety of soil types.

The problem:

Billygoat weed is a major weed of cropping in northern Queensland and a common weed of pastures and disturbed areas.

Distribution:

Occurs New South Wales north coast, Queensland and the Northern Territory. It is most common in northern Queensland and the Northern territory. It is a major weed in the Burdekin region.

Origin:

An introduced species from tropical America.

Reference:

Crop Weeds of Northern Australia, p. 104 - 105.

Compiled by:

Graham Charles

Alternanthera nodiflora R.Br

Common joyweed

Photographs: Graham Charles

Alternanthera nodiflora

Family:

Amaranthaceae (Amaranth family).

Common names:

Common joyweed, Joyweed, Native carpetweed.

Confused with:

The joyweed family includes several similar species.

Description:

Seedlings – cotyledons leaves are roughly elliptical in shape, being broadest at about 1/3rd of their length and tapering to a rounded tip. They have a noticeable mid-rib. Both the mid-rib and the leaf margins may have a red tinge.

Leaves – are arranged in opposite pairs along the stems. Leaves are 2 - 8 cm long and 6 - 8 mm wide, with a light green central rib.

Mature plants – a semi-prostrate annual plant which may have ascending stems to 30 cm in length. Adventitious roots may develop from the stem nodes.

Flowers – are clustered in the leaf axils. Clusters are white and up to 10 – 25 mm in diameter.

Fruit – seeds are brown and covered in fine protrusions. They are elongated, 1.1 mm in length and 3 mm in width.

Lifecycle / Biology:

Seedlings emerge in winter and spring and summer and flower over spring and early summer.

Ecology:

Occur on a wide variety of soil types and is most common in wetter spots. Plants that establish in moist and shaded locations may survive well into summer.

The problem:

Common joyweed is a minor weed in the cotton cropping system but can occur in high densities when conditions allow. It can be a weed of winter fallows and cereal crops.

Distribution:

Common in all states of Australia and throughout the cotton growing area.

Origin:

A native species.

Reference:

Plants of Western New South Wales, p. 281 - 282.

Compiled by:

Graham Charles

Anagallis arvensis L.

Scarlet pimpernel

Photgraphs: Graham Charles

Anagallis arvensis

Family:

Primulaceae (Primula family).

Common names:

Scarlet pimpernel, Blue pimpernel, Pimpernel, Red pimpernel.

Description:

Seedling leaves - are glossy, angular and diamond to egg shaped, 6 mm long and 6 mm wide.

Leaves - are egg shaped with a pointed end, hairless and with no stalk, 5 - 25 mm long and 3 - 10 mm wide. The leaves are lightly glossy, yellowish-green to mid-green, soft and dotted with small black glands on the under side. Mature leaves have a prominent, indented mid-vein.

Mature plants – a small, prostrate to semi-prostrate annual plant with spreading branches and weak 4-angled stems 5 - 30 cm long.

Flowers – are 5 – 12 mm across with 5 petals. They are very open, almost flat in sunlight but fold up in the dark. Flowers can be bright red, orange-red, or violet-blue with a dark purplish centre. Flowers emerge from the leaf forks, borne on slender stalks 7 – 12 mm in length

Seeds – form in a green, spherical capsule 3 – 5 mm across. The capsule is thin walled and becomes brown and brittle as it dries. When dry it splits around the middle, releasing the seeds. It is surrounded at the base by five, narrow, pointed sepals 5 – 7.5 mm long which remain attached to the capsule. Seeds are very small, 1 – 1.5 mm long, dark brown and angular with 3 sides.

Lifecycle / Biology:

A winter-growing annual herb which flowers in late winter and spring. Plants can flower over the summer and perenniate under suitable conditions, but will not survive in hot summers.

Ecology:

A common weed of pastures, fallows, gardens and waste areas. Scarlet pimpernel grows on a range of soil types, usually in moister situations.

The problem:

A common but minor weed in temperate areas.

Distribution:

Found through much of Australia.

Origin:

An introduced species from the Mediterranean region.

References:

Crop Weeds of Northern Australia, p. 86 - 87.

Plants of Western New South Wales, p. 546 - 547.

Compiled by:

Graham Charles

Cajanus cajan (L.) Millsp.

Pigeon pea

Photgraphs: Graham Charles

Cajanus cajan

Family:

Fabaceae (Pea family).

Common names:

Pigeon pea, Congo pea, No-eye pea, Red gram, Tree pea.

Description:

Seedlings – the cotyledon leaves are oblong, 30 – 40 mm long and 10 - 15 mm wide, with an indented, central vein.

Early leaves – the first true leaves and all subsequent leaves are trifoliate, the central leaflet longer than the side leaflets.

Leaflets – are broadly spear shaped, 25 – 100 mm long and 10 – 35 mm wide. The central leaflet is longer than the side leaflets and is borne on a short stalk, 10 – 16 mm long. Leaves are green, with a velvety upper surface. The underneath of the leaf is silvery green, covered with whitish hairs. Leaves have small, yellowish glands which give them a subtle golden hue.

Plants - an annual or short-lived erect perennial, 1 - 3 m tall. Plants may regenerate from the taproot, allowing them to perenniate.

Flowers – are produced along slender stalks 20 – 70 mm long, that emerge from the leaf axils, with 6 – 12 flowers per stalk. Flowers are a typical pea-shape, bright yellow, with reddish-brown markings on the backs of the petals.

Pods – are 45 – 100 mm long, 8 – 15 mm wide and contain 4 – 7 seeds.

Seeds – are ovoid, 4 - 7 mm in length and reddish-brown.

Lifecycle / Biology:

An annual or short-lived perennial plant that flowers in spring, summer and autumn. Plants are frost-sensitive.

Ecology:

Adapted to a range of soil types. Plants generally occur as volunteers following a pigeon pea crop. Isolated plants may occur on channels, beside roads or in other areas where trash has accumulated.

The problem:

Grown as an insect refuge in combination with Bollgard II cotton varieties. Volunteer pigeon pea plants can be problematic in following crops.

Distribution:

Commonly planted throughout the cotton area. May be planted as a commercial grain crop. Small naturalised populations occur in northern New South Wales and Queensland.

Origin:

May have originated in India.

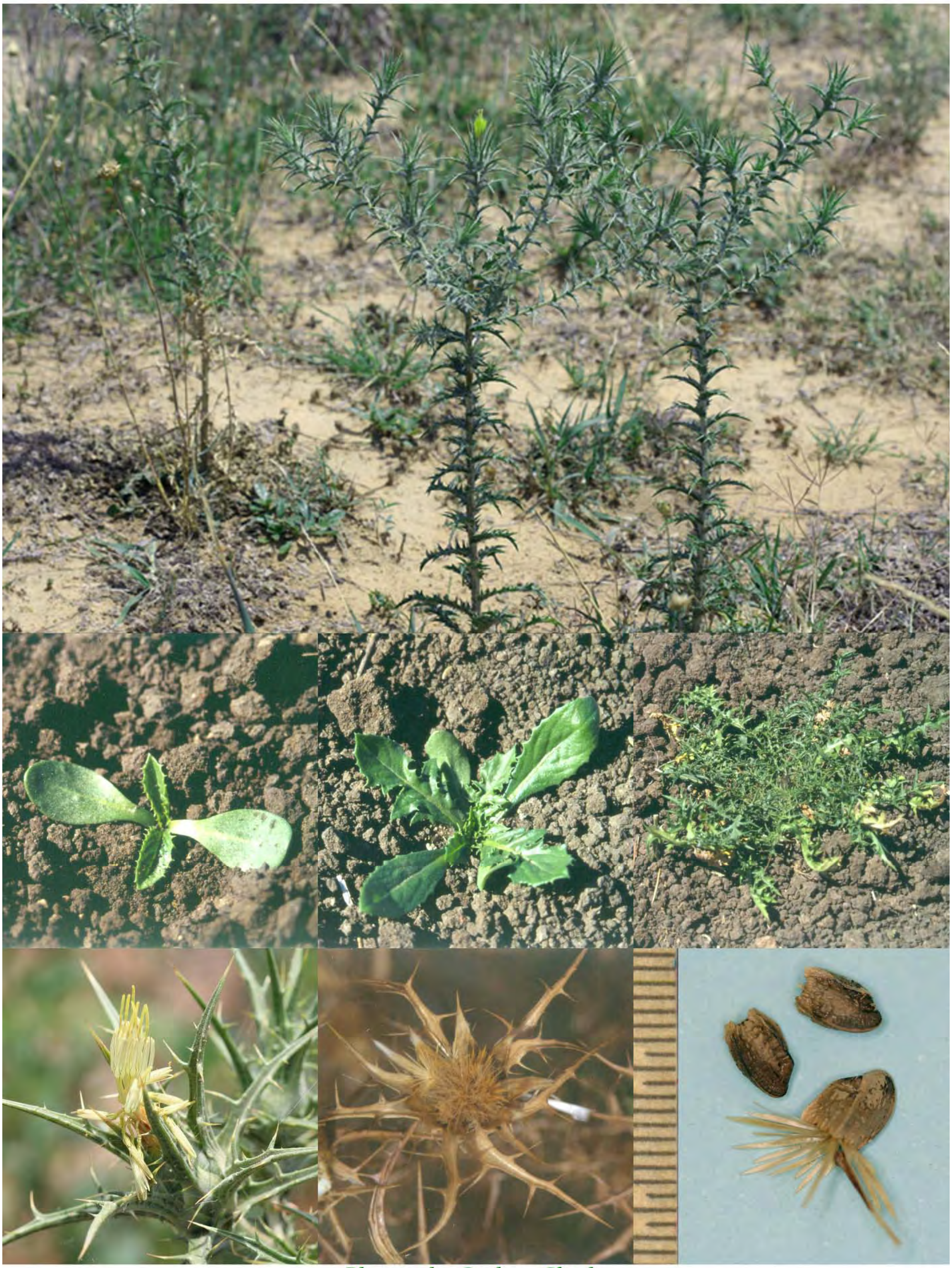
References:

Compiled by:

Graham Charles

Carthamus lanatus L.

Saffron thistle



Photgraphs: Graham Charles

Australian Government
Cotton Research and Development Corporation

Carthamus lanatus

Family:

Asteraceae (Daisy family).

Common names:

Saffron thistle, Distaff thistle, False star thistle, Woolly safflower, Woolly star thistle, Woolly thistle, Yellow star thistle.

Confused with:

There are a number of thistles which may appear similar in the rosette stage. Saffron thistle is distinctive at the mature stage. Could be confused with safflower (*C. tinctorius*), star thistle (*Centaurea calcitrapa*), golden thistle (*Scolymus hispanicus*) and spotted golden thistle (*S. maculates*).

Description:

Seedlings – the cotyledon leaves are glossy green and spoon shaped, 12 – 17 mm long by 6 – 9 mm wide.

Early leaves – the first true leaves spoon shaped, but with a more pointed tip. They are lightly serrated, with each serration tipped by a short spine, and have an indented, white central vein. Later leaves are more heavily serrated and become highly multi-lobed with each protrusion tipped by a sharp spine. Leaves grow up to 150 mm long. Plants form a dense rosette.

Later leaves – plants develop a central rigid, erect stem as temperatures rise in spring. Clasping, stalkless, rigid leaves develop along the stem. They are prominently veined, lobed and terminate with long, rigid, sharp spines. Numerous smaller spines tip the lobes along the sides of the leaves.

Plants - an erect annual herb, 80 - 120 cm tall with rigid stems. Plants are unbranched at the base, but become multi-branched towards the top. Each branch terminates with a flower head.

Flower heads – single heads develop at the end of each branch. The flowers are creamy yellow and are clasped within the flower head. The flowered head is surrounded by several rows of rigid, lobed leaves tipped and edged with spines. Head are 50 – 70 mm wide, including the spined leaves.

Seeds – are 5 – 7 mm long, grey-brown and wedge shaped. They are topped with a stiff pappus 7 – 10 mm long.

Lifecycle / Biology:

An annual plant that germinates after rain in autumn or early winter and forms a dense, competitive rosette. In spring a rigid, erect central stem develops and the rosette leaves die off. Flowers develop in spring and early summer. Some plants may germinate following rain in spring and flower in late summer and autumn. Seeds of saffron thistle may remain dormant in the soil for several years.

Ecology:

Adapted to a range of soil types, but most common on better soils with high fertility. Saffron thistle is a common invader of improved pastures and winter crops.

The problem:

A competitive, widely occurring, major weed of winter crops, pastures and waste areas. Plants are palatable to livestock in the rosette stage, but are not eaten once the central stem develops. Spines can cause injuries and remain problematic for months after the plants mature. Mature plants can be a serious problem in cereal crops, choking harvesting equipment and contaminating grain samples. Seeds are difficult to remove by grading. Saffron thistle is readily controlled with herbicides such as 2,4-D amine in cereal crops, but is difficult to control in pastures where legumes are a valuable component of the pasture.

Distribution:

One of the most widely distributed introduced weeds in Australia. Saffron thistle occurs in every state.

Origin:

Originating from Europe.

References:

Plants of Western New South Wales, p. 721 - 722.

Compiled by:

Graham Charles

Cicer arietinum L.

Chickpea

Photgraphs: Graham Charles

Cicer arietinum

Family:

Fabaceae (Pea family).

Common names:

Chickpea, Garbanzo bean, Gram.

Confused with:

A diverse range of chickpea varieties can be grown. They may vary widely in leaf shape, flower colour, and seed colour and shape. Only one type is described here.

Description:

Seedlings – the first leaves have 2 or 3 pairs of leaflets with a terminal leaflet. Leaflets are 3 – 5 mm long and 2 – 3 mm wide, with serrated edges. Pairs are arranged along a short stem 15 – 20 mm long, borne on a stem 4 – 6 mm long. These leaves continue to grow as new leaves emerge.

Older leaves – are made up of 4 to 8 pairs of leaflets with a terminal leaflet. Leaflets are 6 – 20 mm long, 3 – 14 mm wide with a serrated margin. Leaves are green to bluish in colour.

Plants – a multi-branched annual plant growing into a clumpy bush 30 – 50 cm high. The leaves have a very distinctive oily feel due to a secretion of malic and oxidic acid from glandular heirs that cover the leaves and stems.

Flowers – are a typical pea shape, with bright maroon red petals borne on stems 6 – 20 mm long which emerge from the leaf axils. Flowers are 10 – 20 mm in width.

Seeds – are borne in a light green pea-pod 25 – 35 mm long, with 2 – 3 seeds per pod. Pods become brown as they dry. Seeds are an unusual, angular shape, brown and 8 – 10 mm long, depending on variety.

Lifecycle / Biology:

Germinates in autumn and winter, flowering in spring.

Ecology:

Most commonly grown on fertile and heavy clay soils. Isolated plants may grow from seed lost from trucks etc.

The problem:

Volunteer chickpeas can be a minor weed in a following crop. Volunteers can be very problematic if a crop such as cotton is planted immediately following a chickpea crop, as emerging chickpeas may be readily predated by heliothus grubs. These grubs will move to the main crop when the volunteers are controlled.

Distribution:

An alternative winter legume crop grown in most States.

Origin:

A native of the Mediterranean region.

References:

Compiled by:

Graham Charles

Helianthus annuus L.

Sunflower

Photgraphs: Graham Charles

Helianthus annuus

Family:

Asteraceae (Daisy family).

Common names:

Sunflower, Annual sunflower, Common sunflower.

Confused with:

Wild sunflower (*Verbesina encelioides*). These plants can be distinguished by:

- **seedling leaf shape** - sunflower leaves are a slightly flattened oval shape with a pointed end. Wild sunflower are a blade shape, with a tapering, pointed end.
- **adult plants** - sunflowers have dark green leaves and a single stem or may have some branching towards the top. Wild sunflowers are blue/green in colour and highly branched, with branches emerging from near the base.
- **seeds** - sunflower has a flattened, wedge shape black seed with grey stripes. Wild sunflower has a smaller brown seed. The inner seeds in the head are winged, with a prominent pale wing surrounding the seed

Description:

Seedlings - can emerge from very deep in the soil. Cotyledon leaves are oar-shaped, 15 - 20 mm long and 5 - 8 mm wide. The first true leaves are rounded, with a pointed tip and prominent, white central vein, 20 - 30 mm long and 10 - 15 mm wide. A strong, hairy central stem quickly develops, lifting these leaves above the ground.

Leaves - are large, alternate, spade shaped, with a pointed and prominent veins. They have serrated edges and are up to 30 - 40 cm long and to 35 cm wide, borne on stalks 15 - 25 cm long.

Plants - in cultivation may be large, to 2 m in height, terminating in a large, dinner plate sized flower head. Sunflowers have a long taproot. In waste areas, plants are often shorter, multi-branched, with much smaller leaves and many, much smaller flower heads.

Flower heads - may be up to 30 cm across, with a ring of bright yellow "petals" 2 - 4 cm long surrounding the centre of the flower head. The flower head arranged in a complex pattern of whorls and is surrounded by 2 layers of green, pointed bracts. Flower heads generally face the sun, following the sun's path during the day. This pattern ceases as the heads mature. Heads become black at maturity as the flower parts drop off, exposing the seeds.

Seeds - are large, wedge shaped and flattened, 5 - 16 mm long, grey to black with longitudinal streaks.

Lifecycle / Biology:

An annual or biennial, summer growing plant which is relatively drought tolerant. Volunteer plants can be seen at most times of the year, following rain, and will flower from spring through to autumn.

Ecology:

Can occur on a range of soil types and situations, but prefers sandy soils and wetter places. Can be found on road sides, disturbed areas, waste area and fallow paddocks wherever sunflower is grown.

The problem:

Sunflower is a minor weed, with scattered plants occurring along roadsides wherever sunflowers are grown.

Distribution:

Found throughout most of Australia where sunflowers are grown. It can also be a garden escape.

Origin:

A native of North America.

Reference:

Plants of Western New South Wales, p. 679 - 680.

Compiled by:

Graham Charles

Medicago sativa L. ssp. *sativa*

Lucerne

Photgraphs: Graham Charles

Medicago sativa ssp. *sativa*

Family:

Fabaceae (Pea family).

Common names:

Lucerne, Alfalfa, Perennial lucerne, Violet-flowered lucerne.

Confused with:

Seedlings of lucerne are easily confused with number of similar plants in this family. Adult plants are readily distinguished by their erect growth habit, flower colour and seed pods.

Description:

Seedlings – the cotyledon leaves are oar-shaped, with a rounded end, 5 – 7 mm long and 3 – 5 mm wide.

Leaves - the true leaves are trifoliate, with 3 leaflets with lightly serrated edges. All leaflet are borne on short stalks, the stalk of the terminal leaflet is longer than the side leaflets, at about 4 mm. The leaflets are a pointed oval shape, 8 – 28 mm long and 3 – 15 mm wide. The leaves are borne on stems 20 to 40 mm long

Plants – an erect, multi-branched perennial plant with a very deep tap root. Plants develop a woody crown at ground level, with stems rising from the crown to around 1 m height.

Flowers – are purplish/mauve, with lighter strips. Flowers are a typical pea shape 12 – 15 mm long and develop in dense clusters of 20 – 30 flowers at the tips of the branches.

Seeds – form in a pod which develops in a whorl shape 5 – 9 mm across with 2 to 4 loose coils. Pods are initially green, but become brown and tough as they mature. The seeds are a typical bean shape, light- to mid-brown in colour, 2 – 3 mm in length, with 2 – 6 per pod.

Lifecycle / Biology:

Lucence is a perennial plant which will grow year round, but grows most actively in the warmer months. Some lucerne varieties grow more actively over winter, while others will be relatively dormant (winter active and winter dormant varieties). Plants can flower and set seed throughout the warmer months.

Ecology:

Lucerne grows on most soil types, but prefers alkaline soils and doesn't tolerate water logging.

The problem:

Established and volunteer lucerne plants can be very difficult to control in fallows and following crops.

Distribution:

A widely planted species, used in pastures and for hay production in much of temperate and sub-tropical Australia. Lucerne strips have been used in conjunction with cotton production on some properties. Established plants can be very difficult to remove after the lucerne phase is completed and volunteer seedlings can be problematic in crops and fallows. The plant is not highly competitive, but develops a very deep tap-root which allows it to continue to grow through dry conditions.

Origin:

Introduced from the Mediterranean region.

References:

Plants of Western New South Wales, p. 404.

Compiled by:

Graham Charles

Parthenium hysterophorus L.

Parthenium weed

Photgraphs: Graham Charles

Australian Government
Cotton Research and Development Corporation

Parthenium hysterophorus

Family:

Asteraceae (Daisy family).

Common names:

Parthenium weed, Bitterweed, Carrot grass, Congress grass, Escoba amarga, False ragweed, Feverfew, Parthenium, Ragweed, Ragweed parthenium, Whitetop.

Description:

Seedlings – cotyledons are a rounded paddle shape, 3 - 4 mm long, borne on short stalks 1 – 2 mm long. The first true leaves are egg-shaped and covered in fine, white hairs. Older leaves become increasingly lobed and deeply divided.

Young plants – develop into a rosette, with leaves to 80 - 200 mm long and 40 - 50 mm wide.

Older plants – develop an erect, highly branched stem 30 – 150 cm high, and a deep taproot. Deeply divided leaves develop along the stem, which is deeply grooved. Stems and leaves are covered in short, white hairs. Plants develop a bluish or greyish appearance.

Flower heads – occur in clusters at the top of the plant, borne on short stalks, arising from the leaf forks. Flower heads are white, 4 - 10 mm across and form an unusual, 5-sided shape, with longer white flowerlets (ray flowers) in the corners. Flower heads become hard and brown as they mature.

Seeds – are striped grey to black and a narrow diamond shape, 2 mm long and flattened. They have a brown tuft on the end formed from 2 broad scales 0.5 mm long. Seeds are tightly grasped in a brown outer coat, which gives them more of a tufted triangle appearance. Generally only 4 seeds develop in each head.

Lifecycle / Biology:

Parthenium weed can germinate at any time of the year, with the main germination in spring and early summer. Plants can flower 4 – 8 weeks after germination, and flowering may continue for 6 to 8 months. Seed has no dormancy. Mature plants have some frost tolerance.

Ecology:

Parthenium weed is a perennial plant which is well adapted to invade much of the Australian farmland area.

The problem:

Parthenium weed is an aggressive invader of fallows, wastelands, roadsides, overgrazed pastures and less competitive crops. It produces a range of toxins which affect other plants and animals. It is not commonly eaten by livestock but can taint meat and toxins will pass into milk. Regular contact with parthenium causes dermatitis in animals and humans and can cause respiratory problems including asthma.

Distribution:

Parthenium weed has become established in central and northern Queensland, the western Downs and the Northern Territory.

New South Wales is a parthenium weed exclusion zone. Any parthenium plants observed in New South Wales must be immediately reported to the NSW Dept. Primary Industries or a Local Council Weeds Inspector who will organise for their eradication.

Farmers should pay particular attention to sites of header breakdowns, as these have been a common source of infestation due to the release of parthenium seeds following the removal of panels during repairs.

Origin:

An introduced weed from North and South America.

Reference:

Crop Weeds of Northern Australia, p. 63 - 64.

Noxious Weeds of Australia, p. 292 - 296.

Compiled by:

Graham Charles

Sisybrium thellingii O.E.Schulz

African turnip weed

Photographs: Graham Charles

Sisybrium thellingii

Family:

Brassicaceae (Cabbage family).

Common name:

African turnip weed.

Confused with:

Turnip weed (*Rapistrum rugosum*), Wild radish (*Raphanus raphanistrum*), and Wild turnip (*Brassica tournefortii*). These species can be distinguished by:

- Cotyledons – the cotyledons of African turnip weed are squarish, with a notched tip, and 2 – 3 mm long stems. Wild radish cotyledons have 12 – 20 mm long stalks and are heart shapes, where turnip weed are also heart shaped, but the stalks of are 8 mm long. Wild turnip cotyledons are kidney shaped, rather than heart shaped.

- Flowers – wild radish flower are white or pale yellow with purple veins. Turnip weed has a bright yellow flower with rounded petals5 – 10 mm long and wide, and wild turnip a pale yellow flower which becomes white with age. The petals are 5 – 8 mm long and 2 – 3 mm wide. African turnip weed has a bright yellow flower, with petals 6 – 8 mm long and 2 – 3 mm wide.

- Seed pods – wild radish has a highly segmented pod containing multiple seeds. These pods break off at maturity and enclose the seed. Turnip weed has a short, bulbous pod that does not break apart at maturity. Wild turnip and African turnip weed pods are long and cylindrical, breaking apart at maturity to release the seeds. Wild turnip pods have a beak 1 – 2 cm long at the tip, where African turnip weed pods have no beak.

Description:

Seedlings – the cotyledon leaves are squarish in shape with a notched tip, 4 – 5 mm long and wide, borne on stalks 2 - 3 mm long.

Leaves – the first true leaves are oval in shape, 10 – 15 mm long and 7 – 8 mm wide and coarsely haired. Later leaves may be heavily lobed, 10 - 30 cm long, 8 - 12 cm wide. Leaves have prominent, indented central and lateral veins.

Plants – a hairy annual weed that forms a rosette to 1 m in diameter. The plant has a woody taproot and at maturity develops numerous erect stems and branches, 70 – 100 cm high. Leaves are smaller towards the tops of the stems and branches and are not lobed or stalked.

Flowers – develop at the tips of the branches, with 4 bright yellow petals 6 – 8 mm long and 2 – 3 mm wide. The flowers are about 2 cm in diameter.

Seeds – seedpods are stem-like in shape 3 – 11 cm long and 2 mm in diameter, on stalks 1 – 3 cm long. Pods contain 60 - 80 seeds or more that are retained within the pod at maturity. Seeds area brown, egg-shaped, 1 -1.5 mm in length.

Lifecycle / Biology:

Seedlings emerge in late autumn and winter, growing over winter and early spring and flowering in spring and early summer. The lifecycle can match closely that of a cereal crop, with seeds maturing before or with the crop.

Ecology:

Well adapted to the more westerly cropping and grazing zones. African turnip weed can dominate pastures in winter and spring, out competing other more valuable species and can be a major weed problem in fallows and winter crops.

The problem:

African turnip weed emerges with the winter crop and competes very strongly with the crop. Plants are well adapted to dry conditions and grow aggressively even when soil moisture is limiting to the crop, as is the case in the WEEDpak photos. Plants set seed before the crop is matures.

Distribution:

A weed of Northern New South Wales and Queensland.

Origin:

A native of South Africa.

Reference:

Crop weeds of Northern Australia, p. 48 - 51.

Compiled by:

Graham Charles

Stachys arvensis (L.) L.

Stagger weed

Photgraphs: Graham Charles

Stachys arvensis

Family:

Lamiaceae (Mint family).

Common names:

Stagger weed, Corn woundwort, Field stachys, Field wound root, Field woundwort, Hedge nettle, Mintweed, Woundwort.

Confused with:

Deadnettle (*Lamium amplexicaule*) and dwarf nettle (*Urtica urens*). These can be distinguished by:

- **Seedlings** – dwarf nettle leaves are dark green with sharply serrated edges. Stems are reddish towards the base. Stagger weed leaves are yellowish-green and egg-shaped, longer than they are wide. Stagger weed leaves have a minty smell when crushed. Deadnettle are darker green than stagger weed and more of a pointed-fan shape, wider than they are long.
- **Flowers** – Dwarf nettle flower are white and very small. The flower head is green. Stagger weed pale pink to pale lilac. Deadnettle flowers are purple to bright red.

Description:

Seedling leaves – are round, 3 - 5 mm in diameter and yellowish-green with short stalks. The first true leaves are broadly egg-shaped, with an indented base where they meet the leaf stalk. Leaves are lightly covered in hairs, and are corrugated by central and lateral veins. The leaf margins are roundly toothed.

Older leaves - are yellowish-green, opposite and on stems less than 20 mm long. New branches arise from the leaf axils. Leaves are 8 – 45 mm long and 4 – 32 mm wide. Leaves are lightly covered in hairs, and are corrugated by central and lateral veins. The leaf margins are roundly toothed.

Plants – a semi-erect annual to 35 cm high, yellowish-green in colour. Stems are slender and 4-angled, 15 – 45 cm high and covered with spreading hairs. Plants emit a mint-like odour when crushed.

Flowers – are white to pale pink, 5 – 7 mm long, borne in clusters of 2 – 6 in the forks of the leaves.

Seeds – 1 – 4 seeds develop in a “cup” in the leaf forks. Seeds are dark brown and lightly mottled, 2 – 2.5 mm long.

Lifecycle / Biology:

An annual plant that emerges in autumn and winter, flowering in winter and spring.

Ecology:

A common weed of cereal cops and winter fallows, and will established in pastures.

The problem:

Stagger weed is a minor pest of cereal crops and winter fallows, irrigation channels and waste areas. Stagger weed can be eaten by livestock and will cause staggers. The poison is cumulative and the effects become apparent in stressed stock. Stagger weed can kill stock.

Distribution:

A widespread weed, occurring in all states, except the Northern Territory.

Origin:

An introduced species from Europe and the Mediterranean region.

References:

Plants of Western New South Wales, p. 576 - 577.

Crop Weeds of Northern Australia, p. 84 - 85.

Compiled by:

Graham Charles

Urtica urens L.

Dwarf nettle

Photgraphs: Graham Charles

Urtica urens

Family:
Urticaceae (Nettle family).

Common names:
Dwarf nettle, Annual nettle, Burning nettle, English stinging nettle, Lesser nettle, Lesser stinging nettle, Nettle, Small nettle, Stinging nettle.

Confused with:
Deadnettle and stagger weed. The species can be distinguished by:

- **Seedlings** – dwarf nettle leaves are dark green with sharply serrated edges. Stems are reddish towards the base. Stagger weed leaves are yellowish-green and egg-shaped, longer than they are wide. Stagger weed leaves have a minty smell when crushed. Deadnettle are darker green than stagger weed and more of a pointed-fan shape, wider than they are long.
- **Flowers** – Dwarf nettle flower are white and very small. The flower head is green. Stagger weed pale pink to pale lilac. Deadnettle flowers are purple to bright red.

Description:
Seedling leaves – are roundly oval, 3 - 5 mm in diameter and with stalks 1 – 2 mm long. The first true leaves are broadly circular, with noticeable indentations on the sides. Leaves are lightly covered in hairs, and are corrugated by central and lateral veins. The leaf margins are roundly toothed.

Older leaves - are dark green, 10 – 50 mm long and 10 – 40 mm wide, borne on leaf stems 10 – 30 mm long. The underside of the leaf is paler in colour than the top. Leaves are lightly covered in stinging hairs, and are corrugated by central and lateral veins. The leaf margins are sharply toothed, with a serrated appearance.

Plants – an erect annual to 60 cm high, dark green in colour. Stems are green at the top with vertical red stripes for much of the length and covered with stinging hairs.

Flowers – are very small and white, and occur in clusters in the upper leaf axils. The green flowering structures are much more apparent than the flowers.

Seeds – are a pointed oval shape, flattened, light brown, 2 – 2.5 mm long.

Lifecycle / Biology:
An annual plant that emerges over the cooler months, flowering soon after emergence in winter and spring.

Ecology:
A weed of gardens, waste areas, cultivation and stock camps. Well adapted to all soil types, but favours high organic matter content.

The problem:
A common and minor weed of cultivation. Dwarf nettle is not controlled by typical field rates of glyphosate and rarely eaten by livestock.

Distribution:
Common in all states.

Origin:
A cosmopolitan weed, originating in Europe.

References:
Plants of Western New South Wales, p. 210 - 211.

Compiled by:
Graham Charles

Vicia faba L.

Faba bean

Photgraphs: Graham Charles

Vicia faba

Family:

Fabaceae (Pea family).

Common names:

Faba bean, Broad bean, Horse bean, Pigeon bean, Tick bean.

Confused with:

There are a number of different faba bean varieties commercially available. These vary in some morphological details, especially seed size.

Description:

Seedling leaves – emerge from the seed and soil as an erect shoot (the cotyledons remain in the soil). The seedling leaves unfurl from this shoot. The first true leaves are in pairs, each leaflet 30 – 40 mm long and 25 – 35 mm wide. Leaflets are a rounded diamond shape, glossy green on top and paler underneath and are borne on a short leaf stem, 5 – 10 mm long. Central and lateral veins are apparent on the bottom side of the leaflets. Two scale leaves clasp the stem at the junction of the stem and the leaf stems. Leaflets may not initially emerge from the bottom 2 pairs of scale leaves.

Later leaflets – are more rounded, to oval in shape, 60 – 70 mm long and 30 – 40 mm wide. They consist of a terminal pair of leaflets, borne on a stem 10 – 60 mm long. An additional 2 to 4 leaflets may be spaced along the leaf stem in an alternate pattern.

Plants – an erect, branched annual plant, 1 to 1.5 m tall, additional branches emerge from the base of the main stem. Stems are square, with vertical ridges defining the sides of the square and appear to be very robust, 10 - 13 mm wide, However, they are relatively weak and easily damaged. Stems may be red-tinged towards the top.

Flowers – are yellowish-white, with black stripes on the inside of the upper petal. The keel petals are black with white edges. Flowers emerge in clusters in the leaf axils, with 3 – 6 flowers in each cluster.

Seed pods – develop in the leaf terminals from the flowers, initially green and fleshy, 60 – 100 mm long, depending on variety. Pods are furry and have a sharp point on the end. Pods blacken and shrivel as they mature.

Seeds – are 8 – 15 mm long or more, depending on variety. Seeds are light to dark brown and flattened, with a black strip running around the outside edge from the embryo to the end.

Lifecycle / Biology:

Faba bean has no hardseedness, and seedlings will emerge at any time of the year when moisture allows. Plants die quickly in hot summer conditions. Commercial crops are planted in late autumn. Seedlings emerge and grow rapidly over winter and spring. Flowering commences in winter but pods will not form until after the frost period.

Ecology:

Suited to most soils, and grows well on heavy clay soils. Faba bean is susceptible to a range of pests and diseases and will not compete well with weeds. Control of broadleaf weeds in faba beans can also be problematic.

The problem:

Faba bean is a minor weed of following crops and fallows. High densities of seedlings can emerge soon after the crop is harvested and may be a source of heliothus grubs.

Distribution:

Faba beans are commercially grown in all states.

Origin:

A native of Europe.

Compiled by:

Graham Charles

Vicia villosa Roth. ssp. *eriocarpa* (Hausskn) P.W. Ball

Woollypod vetch

Photgraphs: Graham Charles

Vicia villosa ssp. *eriocarpa*

Family:
Fabaceae (Pea family).

Common names:
Woollypod vetch.

Confused with:
There are a number of similar naturalised vetch species and varieties. Wollypod vetch can be readily distinguished by the flowers, with 3 – 30 flowers along a stem which arises from the leaf axil; the flower stem is 25 – 70 mm long. Other vetch species have around 1 to 5 flowers in each cluster.

Description:
Seedling leaves – emerge from the seed and soil as an erect shoot (the cotyledons remain in the soil). The seedling leaves unfurl from this shoot. The first true leaves have around 5 leaflets, each leaflet 8 – 10 mm long and 1 – 2 mm wide. Leaflets are a narrow, rounded oblong in shape, darker green on top and paler underneath and are borne on a short leaf stem, 5 – 10 mm long. Two small scale leaves 4 – 8 mm long and 1 – 3 mm wide clasp the stem at the junction of the stem and the leaf stems.

Later leaflets – are more rounded, oblong in shape, 5 – 40 mm long and 2 – 8 mm wide. They are borne on a stem 40 – 50 mm long, which terminates in 2 or 3 clasping tendrils. Leaves are 50 – 110 mm long, with 8 – 24 leaflets.

Plants – a spreading, branched annual or biennial plant, 30 – 40 cm tall.

Flowers – are deep purplish-red, 10 – 20 mm long. 3 – 40 flowers are clustered along a flower stem, 25 – 70 mm long, with the first flower about half way along the stem, and subsequent flowers spaced along the stem. Flower stems arise from the leaf axils.

Seed pods – develop along the flower stems. They are initially green, but become light-tan with age. Pods are 20 – 40 mm long, 6 – 12 mm wide, and flattened, 3 – 6 mm wide.

Seeds – are 3 – 6 mm wide, light to dark brown and may be mottled, with a black strip running around the outside edge from the embryo to the end.

Lifecycle / Biology:
Woollypod vetch seedlings normally emerge in autumn and winter, and begin flowering in late winter and spring. Woollypod vetch can persist in suitable conditions, but plants normally die in hot summer conditions. Commercial crops are planted in late autumn. Most vetch varieties are very hardseeded, and seed may persist in the soil for many years.

Ecology:
Suited to most soils and does well on heavy clay and alkaline soils. Woollypod vetch is susceptible to a range of pests and diseases and does not compete well with weeds during early growth. Control of broadleaf weeds in vetch can be problematic.

The problem:
Ideally woollypod vetch is grown as a green manure crop, plowed in before it can set seed. If vetch does set seed, it may be an annoying weed for many years in following crops and fallows. Some woollypod vetch varieties are very hardseeded, so seed can persist for many years, with weedy escapes adding to the seed bank over time. Seedlings may emerge after a following crop is watered up and can be difficult to remove from the crop.

Distribution:
Woollypod vetch is grown as a pasture, for hay production and as a green manure crop in all states except the Northern Territory and has become naturalised in many of the wetter areas. It is readily eater by livestock

Origin:
A native of Europe.

Compiled by:
Graham Charles

INTEGRATED WEED MANAGEMENT

Introduction

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

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

Contents:

B2 Integrated Weed Management (IWM) Guidelines

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

B3 Managing Weeds in Cotton

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

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

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

B4.1 The Critical Period Weed Sampling Sheet

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

The assessment technique given in this sheet is due to be reviewed at the end of the 2008/9 season.

B4.2 Understanding the Critical Period for Weed Control

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The Critical Period Weed Sampling Sheet

Date: Recorder:

Property: Field: Assessment:

Number per 50 m of row

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

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

Medium broadleaf – all other broadleaf weeds

Grasses – grasses and all grass like weeds

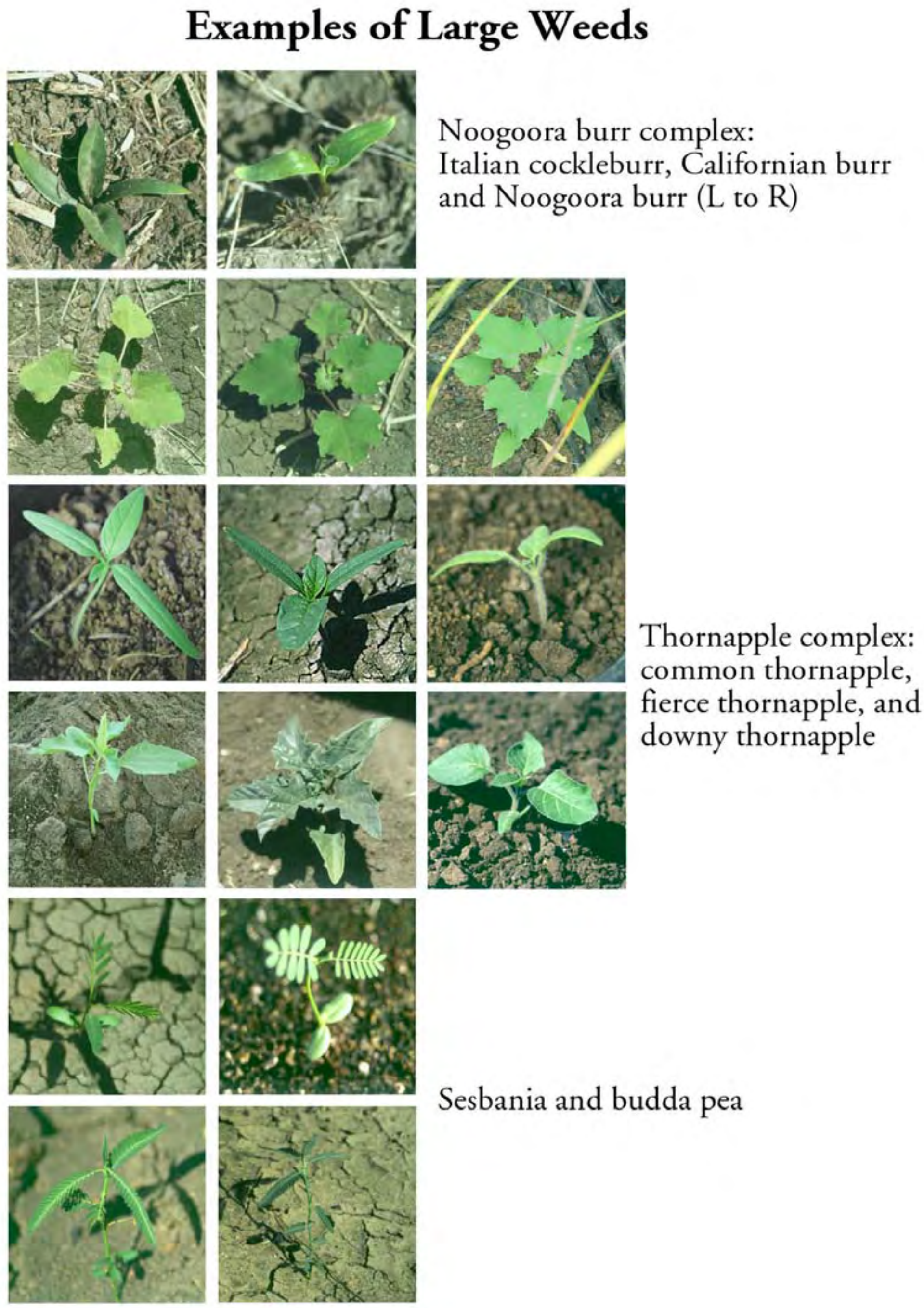
Medium broadleaf weeds	<5 1	5 - 50 2	50 - 500 3	>500 4	
0-50 m					
50-100 m					
100-150 m					
150-200 m					
200-250 m					
250-200 m					
200-150 m					
150-100 m					
100-50 m					
50 - 0 m					Total
Sum	___	___	___	___	

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

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

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

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



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

Weed density (no./m²)	High yielding cotton crops						Low yielding cotton crops					
	Broad-leaf weeds				Grasses		Broad-leaf weeds				Grasses	
	Large		Medium				Large		Medium			
	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
0.1	145	189	145	172	-	-	-	-	-	-	-	-
0.2	144	275	144	244	-	-	254	229	-	-	-	-
0.5	143	447	143	387	-	-	251	368	-	-	-	-
1	141	600	141	514	-	-	246	498	246	319	-	-
2	139	738	139	627	-	-	238	620	238	421	-	-
5	131	862	131	729	129	174	215	735	215	537	-	-
10	121	915	121	771	127	248	184	785	184	595	152	206
20	106	944	106	795	125	357	142	812	142	631	147	290
50	87	962	87	810	119	531	93	830	93	654	134	431
Min. density	0.06		0.07		2.5		0.24		0.59		5.4	

UNDERSTANDING THE CRITICAL PERIOD FOR WEED CONTROL

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

Contents	Page

Introduction

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

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

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

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

A weed control threshold

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

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

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

Determining the economic threshold for weed control

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

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

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

Understanding the impact of weeds

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

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

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

Determining the yield loss from weeds

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

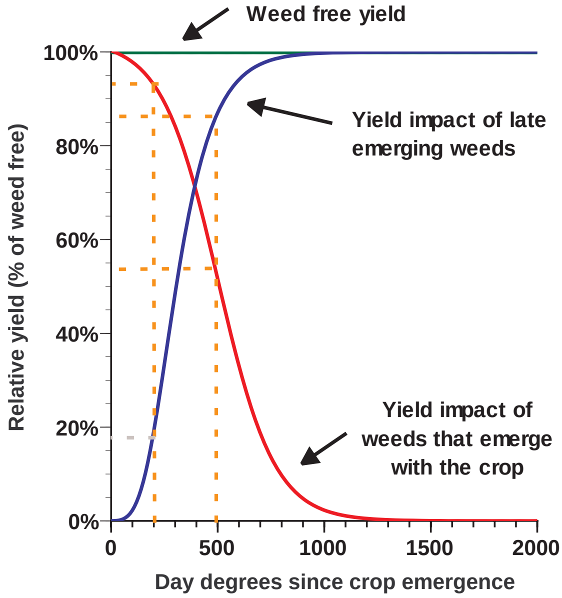


Figure 1. *The impact of 4 thornapples/m on crop yield. The orange lines demonstrate the impact of control 200 and 500 day degrees after crop emergence.*

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

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

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

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

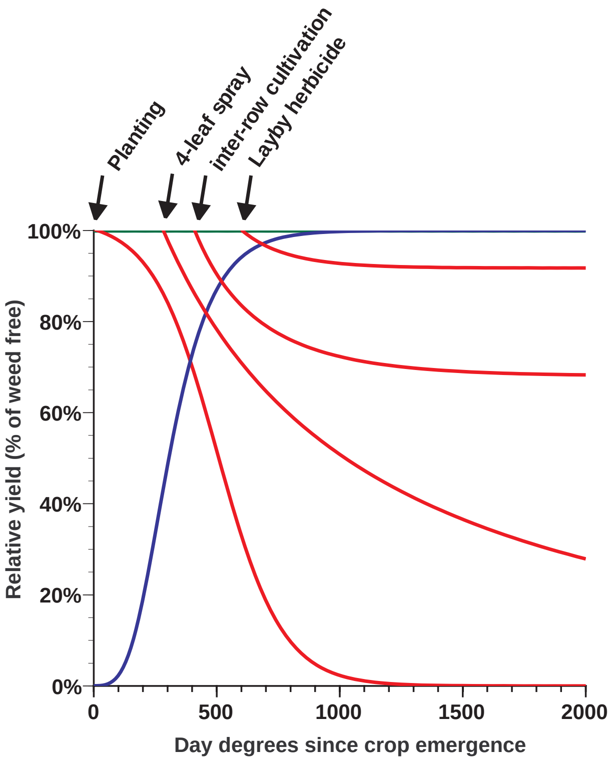


Figure 2. *The impact of weed competition on crop yield following weed control inputs.*

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

The critical period for weed control

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

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

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

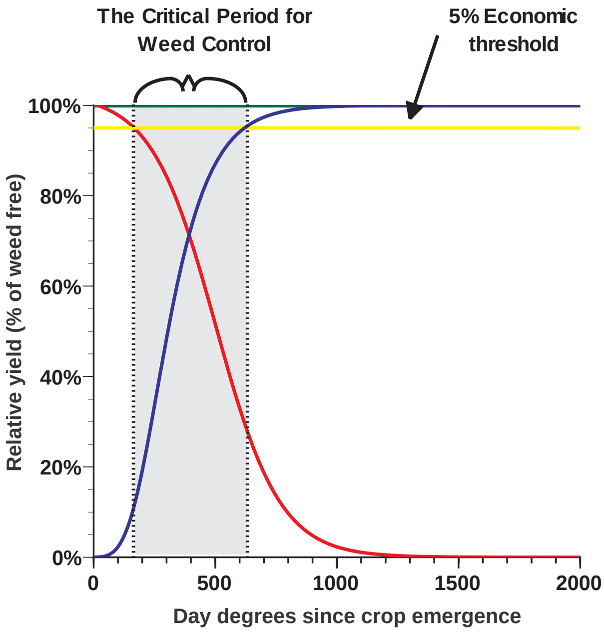


Figure 3. *Deriving the critical period for weed control (the blue shaded area).*

Beyond the critical period for weed control

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

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

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

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

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

Timing of herbicide applications

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

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

Preventing weed seed set

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

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

APPLYING THE CRITICAL PERIOD FOR WEED CONTROL IN THE FIELD

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

Contents | Page

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

Introduction

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

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

The critical period for weed control

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

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

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

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

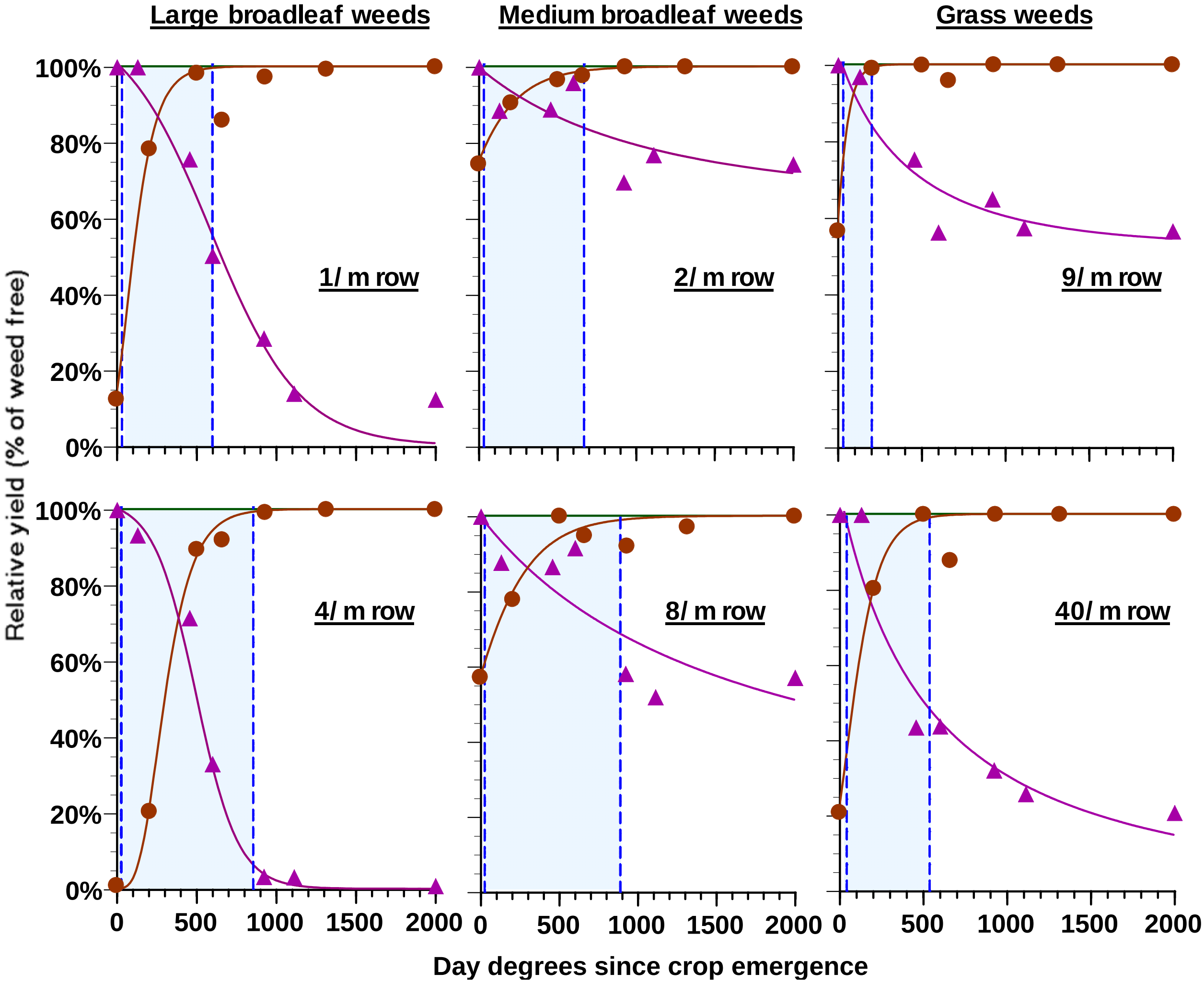


Figure 1. *Yield relationships for weeds competing in irrigated cotton. Data for large and medium broadleaf and grass weeds are shown. Weed densities are indicated on each figure. The critical period for weed control at a 1% yield threshold is the shaded blue area in each figure. This area is determined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

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

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

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

Predicting the critical period for weed control

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

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

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

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

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

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

Using the 'critical period for weed control' data set

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

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

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

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

Avoiding herbicide resistance and species shift

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

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

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

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

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

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

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

Contents	Page

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

Introduction

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

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

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

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

The critical period for weed control

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

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

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

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

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

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

Model inputs

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

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

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

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

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

The CPWC in 2004-5

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

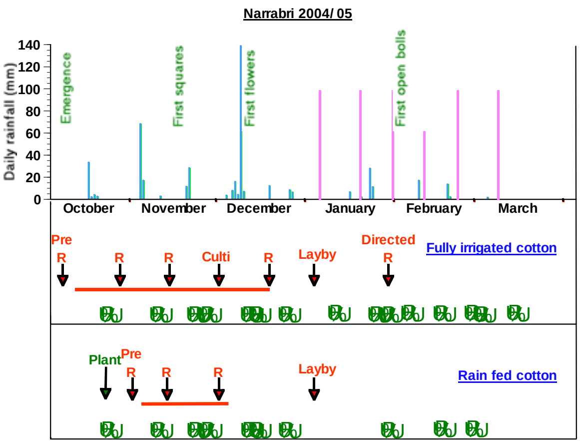


***Figure 1**. A simulation of how the CPWC might have been applied in the 2004-5 season at Narrabri (ACRI). Simulations are for both fully irrigated and rain fed crops. Symbols are: blue bars, daily rainfall (mm); pink bars, irrigations; red lines, the CPWC; red arrows, weed control inputs (R = Roundup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

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

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

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

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

The CPWC in 2005-6

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

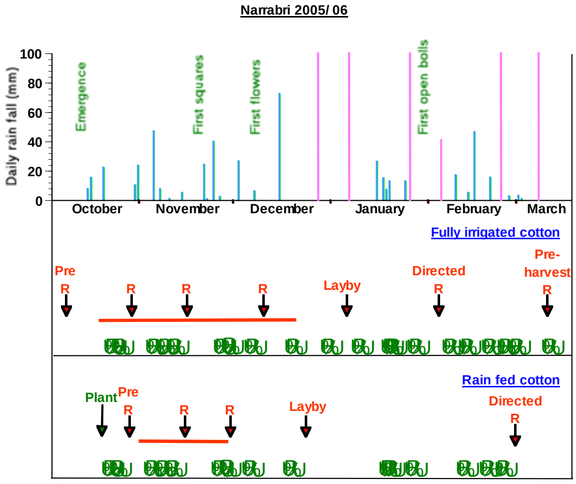


__Figure 2__. Using the CPWC in the 2005-6 season. Simulations for fully irrigated and rain-fed crops are shown. Weed control operations during the CPWC protect cotton yield. Weed control operations after the CPWC prevent weeds from adding seed to the soil seed bank, leading to problems in later seasons.

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

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

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

The CPWC in 2006-7

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

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

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

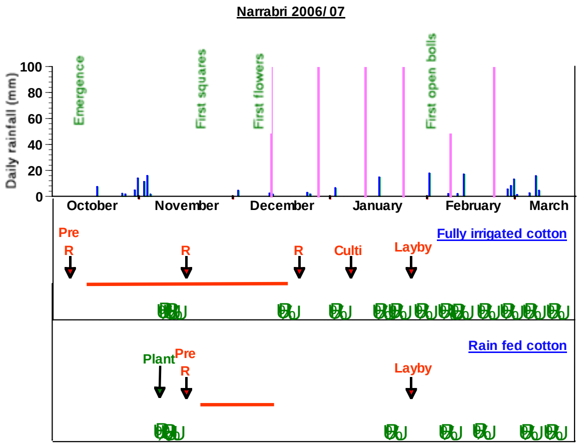


__Figure 3__. Applying the CPWC in the 2006-7 season. Simulations are for fully irrigated and rain-fed crops.

Observations from these simulations

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

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

Resistance to Roundup

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

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

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

Conclusions

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

Acknowledgements

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

Summary

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

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

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

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

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

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

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

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

Contents Page

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

The critical period for weed control

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

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

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

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

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

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

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

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

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

The critical period in irrigated cotton

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

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

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

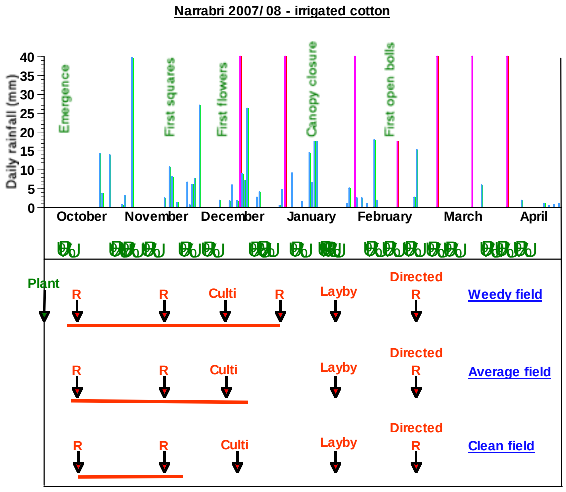


Figure 1*. How the critical period for weed control could have been used in the 2007-8 season at Narrabri for weedy, average and clean fields. Symbols are: (top section) rainfall (****vertical blue bars****) and irrigations (****vertical pink bars****); (middle section) periods of peak weed emergence,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

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

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

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

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

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

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

The critical period in dryland cotton

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

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

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

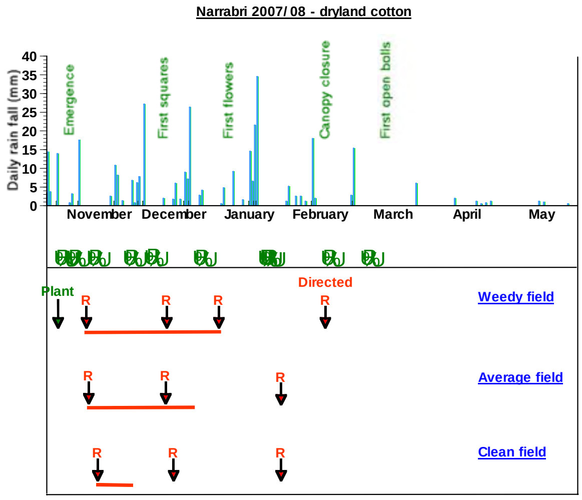


Figure 2. Using the critical period for weed control in dryland cotton in the 2007-8 season at Narrabri for weedy, average and clean fields.

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

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

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

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

Observations from the 2007/8 season

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

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

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

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

Resistance to Roundup

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

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

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

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

Conclusions

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

[B4.5.6]

Summary

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

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

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

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

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

MANAGING WEEDS USING THE CRITICAL PERIOD FOR WEED CONTROL

Graham Charles and Ian Taylor

(NSW Dept of Primary Industries)

Contents

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

The critical period for weed control

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

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

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

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

Australian Government
Cotton Research and Development Corporation

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

Weed density (no./m²)	Start and end of the critical period for weed control (day degrees since planting)											
	Irrigated (high yielding) cotton						Dryland (low yielding) cotton					
	Broad-leaf weeds						Broad-leaf weeds					
	Large		Medium		Grasses		Large		Medium		Grasses	
	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
0.1	145	189	145	172	-	-	-	-	-	-	-	-
0.2	144	275	144	244	-	-	254	229	-	-	-	-
0.5	143	447	143	387	-	-	251	368	-	-	-	-
1	141	600	141	514	-	-	246	498	246	319	-	-
2	139	738	139	627	-	-	238	620	238	421	-	-
5	131	862	131	729	129	174	215	735	215	537	-	-
10	121	915	121	771	127	248	184	785	184	595	152	206
20	106	944	106	795	125	357	142	812	142	631	147	290
50	87	962	87	810	119	531	93	830	93	654	134	431
Min. density	0.06		0.07		2.5		0.24		0.59		5.4	

The critical period in irrigated cotton

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

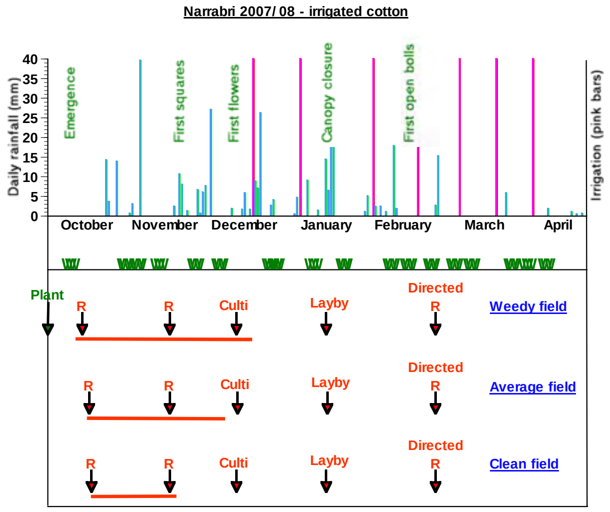


__Figure 1__. How the critical period for weed control could have been used in the 2007-8 season at Narrabri for weedy, average and clean fields. Symbols are: (top section) rainfall (__vertical blue bars__) and irrigations (__vertical pink bars__); (middle section) periods of peak weed emergence, __W__;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

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

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

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

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

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

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

The critical period in dryland cotton

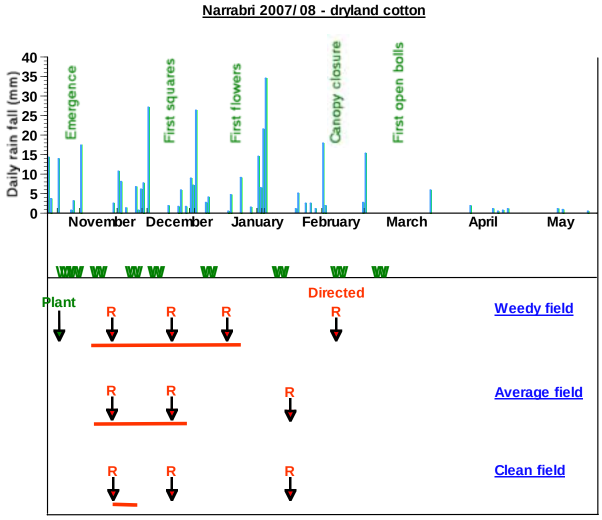


Figure 2. *Using the critical period for weed control in dryland cotton in the 2007-8 season at Narrabri. Symbols are explained in the caption to Figure 1.*

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

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

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

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

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

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

Observations from the 2007/8 season

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

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

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

Summary

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

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

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

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

SAMPLING METHODS FOR THE CRITICAL PERIOD FOR WEED CONTROL

Graham Charles
(NSW Dept of Primary Industries)

Contents	Page

What is the critical period for weed control

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

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

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

Applying the critical period

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

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

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

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

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

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

The Critical Period for Weed Control in cotton (day degrees since planting)												
	High yielding cotton crops						Low yielding cotton crops					
Weed	Broad-leaf weeds				Grasses		Broad-leaf weeds				Grasses	
density	Large		Medium				Large		Medium			
(no./m²)	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
0.1	145	189	145	172	-	-	-	-	-	-	-	-
0.2	144	275	144	244	-	-	254	229	-	-	-	-
0.5	143	447	143	387	-	-	251	368	-	-	-	-
1	141	600	141	514	-	-	246	498	246	319	-	-
2	139	738	139	627	-	-	238	620	238	421	-	-
5	131	862	131	729	129	174	215	735	215	537	-	-
10	121	915	121	771	127	248	184	785	184	595	152	206
20	106	944	106	795	125	357	142	812	142	631	147	290
50	87	962	87	810	119	531	93	830	93	654	134	431
Min. density	0.06		0.07		2.5		0.24		0.59		5.4	

- Medium broadleaf weeds:

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

- Grasses:

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

The field sampling technique

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Summary

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

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

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

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

The Critical Period Weed Sampling Sheet

Date: Recorder:

Property: Field: Assessment:

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

Medium broadleaf – all other broadleaf weeds

Grasses – grasses and all grass like weeds

Number per 50 m of row

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

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

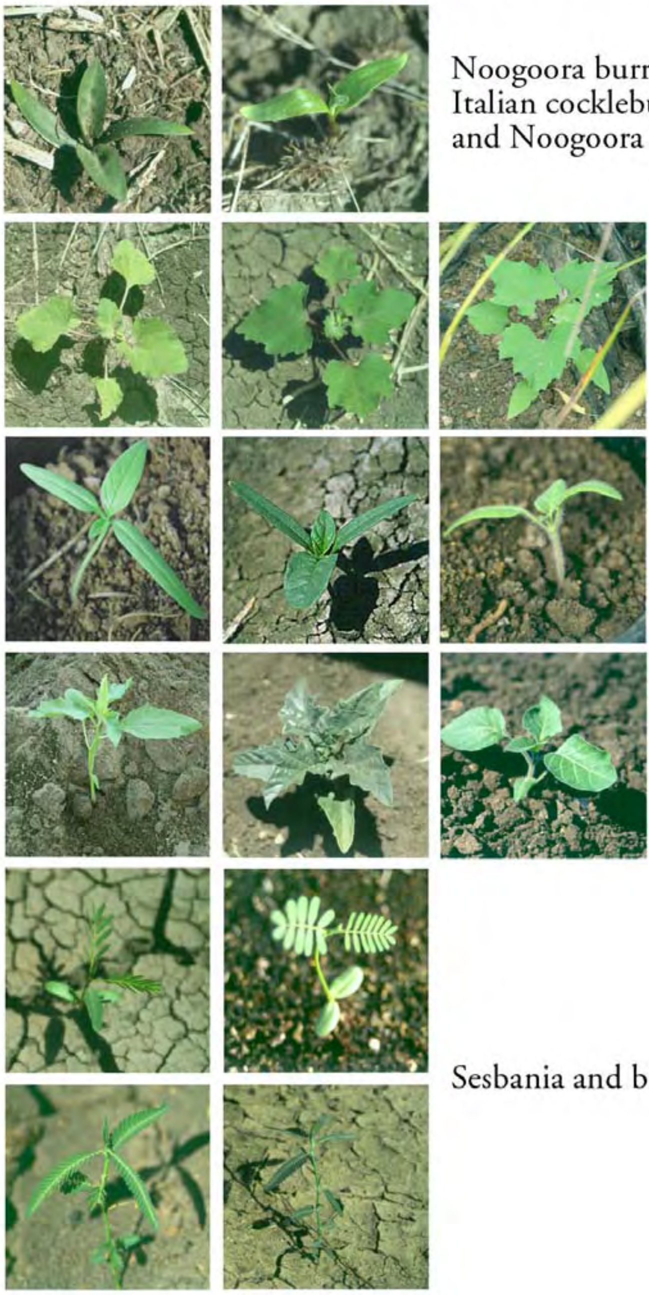
Grasses	<5 1	5 - 50 2	50 - 500 3	>500 4	
0-50 m					
50-100 m					
100-150 m					
150-200 m					
200-250 m					
250-200 m					
200-150 m					
150-100 m					
100-50 m					
50 - 0 m					Total
Sum	___	___	___	___	

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

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

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

Examples of Large Weeds



Noogoora burr complex:
Italian cockleburr, Californian burr and Noogoora burr (L to R)

Thornapple complex:
common thornapple, fierce thornapple, and downy thornapple

Sesbania and budda pea

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

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

HERBICIDE RESISTANCE

Introduction

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

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

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.

C3. Herbicide Resistance and the Crop Management Plan

Many cotton growers are concerned that relying too heavily on Roundup (glyphosate) will lead to future problems with weeds becoming resistant to this herbicide. The potential for resistance is very real, as shown by the increasing resistance problems with Roundup Ready crops in the US, and emerging problems with glyphosate resistant ryegrass and awnless barnyard grass in the Australian cotton growing area.

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

HERBICIDE RESISTANCE AND THE CROP MANAGEMENT PLAN

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Contents

Background

Many cotton growers are concerned that relying too heavily on Roundup (glyphosate) will lead to future problems with weeds becoming resistant to this herbicide. The potential for resistance is very real, as shown by the increasing resistance problems with Roundup Ready crops in the US, and emerging problems with glyphosate resistant ryegrass and awnless barnyard grass in the Australian cotton growing area.

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

Introduction

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

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

Unfortunately, 20 years later, this is no-longer the case. Cotton is now being grown with a rapidly shrinking array of weed management inputs. There are almost certainly herbicide resistant weeds in the cereal component of the cotton farming system on a number of properties, and probably also resistant weeds in the cotton component, somewhere in the industry, although they haven't been detected yet. While these resistance problems may not have been caused by the way weeds are managed in cotton, in the end it doesn't matter, the problem doesn't go away just because it was caused somewhere else.

The stark reality of size of the herbicide resistance problem is brought home in an article by Werth and Thornby (2008). There are now 185 different weed species resistant to a herbicide somewhere in the world. Thirty four weed species have resistance in Australia, and while most of these are resistant to the high risk Group A and B[1] herbicides, there is resistance to nearly every herbicide group, including the groups that include our residual cotton herbicides and glyphosate. In WA and the US, resistance has even developed to 2,4-D (Group I), a herbicide very widely used since the 50's, which had never had a resistance

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

problem anywhere in the world up until a couple of years ago. It just shows that if you push the system hard enough, resistance will eventually occur.

In the cotton growing areas there are numerous instances of ryegrass and wild oats populations with resistance to Group A herbicides and ryegrass populations resistant to glyphosate (Group M). We now also have 2 confirmed awnless barnyard grass populations with resistance to glyphosate, with a 3rd suspected population and doubtless other populations yet to be detected. This season we had a suspected resistant awnless barnyard grass population in cotton. It turned out not to be resistant, but it was a wakeup call – it could have been glyphosate resistant awnless barnyard grass in cotton.

So what causes the problems?

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

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

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

So, the selection pressure on glyphosate is not overly strong in a traditional weed management system where survivors from a glyphosate spray are normally controlled by cultivation, chipping or a residual herbicide.

Herbicide resistance in the cotton system

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

Unfortunately, this system has its drawbacks, including expense, undesirable off-target impacts of herbicides and unavoidable damage to the cotton crop. Twenty years ago, many chipping bills were in excess of $100/ha, with bills up to $300/ha not uncommon. These bills are not affordable in the current economic climate, even if the large chipping crews are still available, which they generally are not. These issues have forced the weed management system to evolve over the years to one which is less reliant on chipping, substituting residual and contact herbicides for chipping inputs. Unfortunately, the drawbacks of off-target impacts and damage to the cotton crop remain and are accentuated by the heavy reliance on residual herbicides required. While this damage was hardly noticeable in the 2½ bale cotton crops of the 1980's, it is unacceptable in the 5 and 6 bale crops of this decade.

Fortunately, alternative weed management systems became available with the release of Roundup Ready® cotton, and more recently Roundup Ready Flex® and Liberty Link® cotton varieties. Use of these transgenic traits has allowed cotton growers to develop new, lower input, more environmentally friendly weed management systems which are conducive to higher cotton yields. The strength of these systems is that they rely on broad-spectrum, contact herbicides, with excellent crop safety (Roundup Ready Flex and Liberty Link), which are more environmentally benign than the residual herbicides they replaced and are only applied when a weed problem is present, allowing the application rate and number of applications to be tailored to match the problem/s.

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

So, how to maintain a glyphosate based system?

Selection in a glyphosate based system

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

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

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

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

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

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

The importance of the crop management plan

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

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

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

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

Low weed numbers can be achieved in one of two ways. Firstly, low weed numbers can be the result of good weed management practices over a number of years. Weed surveys over the last 20 years found that generally cotton fields have become cleaner, with fewer weeds over time. Fields with low weed numbers are ideally suited to the transgenic systems where residual herbicides are replaced by contact herbicides.

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

Maintaining the whole glyphosate system

One of the biggest threats to the sustainability of the Roundup Ready system is the use of glyphosate in the rest of the farming system.

For example, where cotton is grown in a wheat rotation in an irrigated system, it would be common for a field to be in fallow for nearly 12 months in every 24 month period. In this system, weeds in the fallow are commonly controlled with glyphosate, and a field may receive 5 or 6 applications (or even more) over the fallow period, especially where wheat stubble is retained. This again places strong selection pressure on glyphosate, but can be addressed using the same approach of controlling any survivors of a glyphosate application using an alternative option before they set seed. This control input could be an alternative herbicide, cultivation or chipping. An approach widely supported in the southern farming system is to follow a glyphosate application with a paraquat/diquat (Spray.Seed) application in a double-knock, with 5 to 7 days between the herbicide applications. This combination is effective for controlling small, annual weeds and the strategy is very effective for preventing resistance developing, provided that resistance to either of these herbicides has not already occurred. The double-knock strategy can be equally applied using a range of alternative inputs, such as cultivation, or other herbicides following closely after the glyphosate application.

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

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

At risk weeds

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

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

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

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

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

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

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

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

Summary

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

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

HERBICIDE DAMAGE IDENTIFICATION AND INFORMATION GUIDE

Introduction

Finding herbicide damage in a cotton crop has been an unfortunate experience for far too many cotton growers over the years. Damage may be from residues in the soil from a herbicide applied to a previous crop, from residues in contaminated spraying equipment, from accidental application of an inappropriate herbicide, or from aerial drift from herbicide applied to a different crop. The source of the damage is not a consideration in this guide, as in most cases the damage is the same, regardless of the source.

Damage will always have some impact on the crop, but the nature of the impact is influenced by crop growth stage at the time of exposure, the type of herbicide (damage can be from a wide range of different herbicides), the intensity of exposure (amount of herbicide impacting the crop), the crop potential, and the seasonal conditions at, and following, exposure.

At best, crop damage may delay crop maturity and in favourable conditions may result in no crop yield loss, or even an increase in crop yield. At worst, the crop may never recover from the damage.

The intent of this guide is to give cotton growers information relating the impact of known concentrations of a herbicide on crop growth, exposed at a given crop growth stage, on crop growth and development and final yield. While every crop and every season is different, this information should provide some guidance as to the likely impact of herbicide exposure to a cotton crop.

The Herbicide Damage Guide is a work in progress and covers only a limited range of herbicides and exposure rates. This data base will be expanded over time.

Information can be sourced directly where the nature of the herbicide exposure is known via the Herbicide Damage Information, or indirectly, using the Herbicide Damage Identification Guide to identify the likely herbicide or herbicides that may have caused the damage.

Contents:

J3.1. 2,4-D

Cotton plants were exposed to 2,4-D amine at 10% and 1% of a typical field dose rate. The 2,4-D formulation used was Baton® (2,4-D amine 800 g a.i./kg, present as the dimethylamine salt), a Nufarm product, at 100 g/ha and 10 g/ha. Baton was applied at 6, 8, 12 and 16 nodes of cotton growth, broadcast over the crop in 100 L water/ha. All data were compared to an untreated control.

J3.2. Dicamba

Cotton plants were exposed to dicamba at 50% and 10% of a typical field dose rate. The dicamba formulation used was Kamba® 500 (dicamba 500 g a.i./L, present as the dimethylamine salt), a Nufarm product, at 280 ml/ha and 56 ml/ha. Kamba 500 was applied at 6, 11 and 15 nodes of cotton growth, broadcast over the crop in 100 L water/ha. All data were compared to an untreated control.

J3.3. Fluroxypyr

Cotton plants were exposed to fluroxypyr at 50% and 10% of a typical field dose rate. The fluroxypyr formulation used was Starane® 300 (fluroxypyr 300 g a.i./L, present as the methylheptyl ester), a Dow AgroSciences product, at 600 ml/ha and 120 ml/ha. Starane® 300 was applied at 6, 11 and 15 nodes of cotton growth, broadcast over the crop in 100 L water/ha. All data were compared to an untreated control.

J3.4. Glufosinate

Cotton plants were exposed to glufosinate at 50% and 10% of the recommended dose rate. The glufosinate formulation used was Liberty® 200 (glufosinate-ammonium 200 g a.i./L), a Bayer CropScience product, at 1.875 L/ha and 375 ml/ha. Liberty 200 was applied at 6, 11 and 15 nodes of cotton growth, broadcast over the crop in 100 L water/ha. All data were compared to an untreated control.

J3.5. Glyphosate

Cotton plants were exposed to glyphosate at 17% and 3% of the field dose commonly used in cotton. The glyphosate formulation used was Roundup Ready Herbicide® (glyphosate 690 g a.i./kg, present as the mono-ammonium salt), a Nufarm product, at 250 g/ha and 50 g/ha. Roundup Ready Herbicide was applied at 6, 8, 12 and 16 nodes of cotton growth, broadcast over the crop in 100 L water/ha. All data were compared to an untreated control.

J3.6. MCPA

Cotton plants were exposed to MCPA at 50% and 10% of a typical field dose rate. The MCPA formulation used was MCPA 500 (MCPA 500 g a.i./L, present as the dimethylamine salt), a Nufarm product, at 1.05 L/ha and 210 ml/ha. MCPA 500 was applied at 6, 11 and 15 nodes of cotton growth, broadcast over the crop in 100 L water/ha. All data were compared to an untreated control.

J3.7. Glyphosate plus 2,4-D

Cotton plants were exposed to a combination of glyphosate and 2,4-D amine. The glyphosate was applied at 17% and 3% of the field dose rate commonly used in cotton, and the 2,4-D was applied at 10% and 1% of a typical field dose rate. The glyphosate formulation used was Roundup Ready Herbicide® (glyphosate 690 g a.i./kg, present as the mono-ammonium salt), a Nufarm product, at 250 g/ha and 50 g/ha. The 2,4-D formulation used was Baton® (2,4-D amine 800 g a.i./kg, present as the dimethylamine salt), a Nufarm product, at 100 g/ha and 10 g/ha. The combinations were applied at 6, 8, 12 and 16 nodes of cotton growth, broadcast over the crop in 100 L water/ha. All data were compared to an untreated control.

J3.8. Paraquat plus diquat

Cotton plants were exposed to the combination of paraquat plus diquat at 50% and 10% of a typical field dose rate. The paraquat plus diquat formulation used was Spray.Seed® 250 (paraquat 135 g a.i./L, present as paraquat dichloride, plus diquat 115 g a.i./L, present as diquat dibromide), a Syngenta product, at 1.6 L/ha and 320 ml/ha. Spray.Seed was applied at 6, 11 and 15 nodes of cotton growth, broadcast over the crop in 100 L water/ha. All data were compared to an untreated control.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

		Damage key:	
Herbicide:	2,4-D amine	Leaf loss	
Rate:	8 g a.i./ha	Leaf distortion	x
% of typical field rate	1%	Petiole distortion	x
Date of exposure:	12th Dec (4 weeks post-emergence)	Plant stunting	
Growth stage at exposure:	6 nodes	Square shedding	x
		Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily moves to the plant growth points
Mode of action: A phenoxy (auxin-type) herbicide that affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause abnormal increases in RNA, DNA & protein synthesis, resulting in uncontrolled cell division & growth.
Residual activity: limited
Soil half-life: 10 days in moist soil

Baton (2,4-D amine) applied broadcast at 10 g/ha to 6 node cotton. Photo taken on 5th Jan, 24 days after exposure.

Leaves on the main stem were affected by the herbicide, with leaf distortion on all subsequent growth. Leaf damage was less extreme than occurred at the 80 g a.i./ha rate.

Baton (2,4-D amine) applied broadcast at 10 g/ha to 6 node cotton. Photo taken on 5th Jan, 24 days after exposure.

The new leaves on the main stem were distorted by the herbicide. Leaves were cupped and twisted with distorted edges. These symptoms are typical of 2,4-D damage.

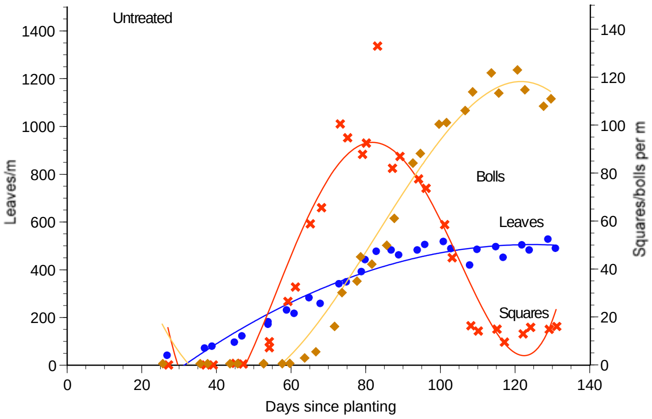
Baton (2,4-D amine) applied broadcast at 10 g/ha to 6 node cotton. Photo taken on 24th Mar, 102 days after exposure.

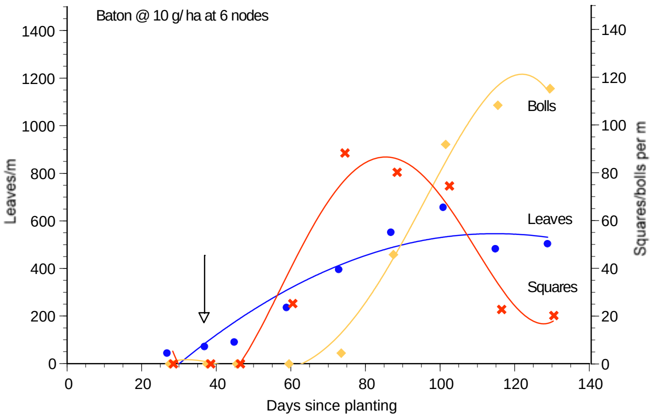
The main stem continued to produce distorted leaves throughout the season, but the growth on the vegetative branches was unaffected by the 2,4-D application.

Baton (2,4-D amine) applied broadcast at 10 g/ha to 6 node cotton. Photo taken on 24th Mar, 102 days after exposure.

This plate shows a close-up of the centre of the plants in the previous photo.

Vegetative branches that developed after the herbicide exposure were not affected by the 2,4-D, with no distorted leaves, and produced normal squares, flowers and bolls.





Impact on plant growth

Leaves: the 2,4-D exposure initially caused some bending and twisting of the petioles (leaf stems), giving a wilted appearance. This effect was transitory.

The primary effect was on leaves on the main stem that developed following the herbicide exposure, causing an increase in leaf production, mainly through the production of small, distorted leaves.

Squares: the1% rate of 2,4-D has little effect on squares production, although peak squaring was delayed for about 5 days.

Bolls: some early bolls were shed, but later bolls were retained and developed on the vegetative branches. 2,4-D had little impact on boll production but did delay crop maturity by 23 days.

Final plant count data		
	Untreated	**2,4-D**
Nodes/plant	21.5	22.5
Leaves/m	502	501
Light interception	87%	79%
Leaf area (cm²/m)	22921	21274
Bolls/m	114	104
Boll weight (g/boll)	4.4	3.9
Days to 50% open	154	177
% Open bolls at picking	82%	64%
Lint yield/ha	1649	1474

2,4-D exposure at 6 nodes caused leaf deformation on the main stem and a loss of fruit from the main stem.

The plant compensated for this damage, setting bolls on the vegetative branches, producing a late crop, with a delay in crop maturity.

In this instance the damage only caused a small (11%) reduction in lint yield.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: 2,4-D amine
Rate: 8 g a.i./ha
% of typical field rate 1%
Date of exposure: 21st Dec
(5½ weeks post-emergence)
Growth stage at exposure: 8 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily moves to the plant growth points
Mode of action: A phenoxy (auxin-type) herbicide that affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause abnormal increases in RNA, DNA & protein synthesis, resulting in uncontrolled cell division & growth.
Residual activity: limited
Soil half-life: 10 days in moist soil

Baton (2,4-D amine) applied broadcast at 10 g/ha to 8 node cotton. Photo taken on 5th Jan, 15 days after exposure.

All eaves were severely affected by the herbicide, with severe leaf distortion on subsequent growth.

Baton (2,4-D amine) applied broadcast at 10 g/ha to 8 node cotton. Photo taken on 5th Jan, 15 days after exposure.

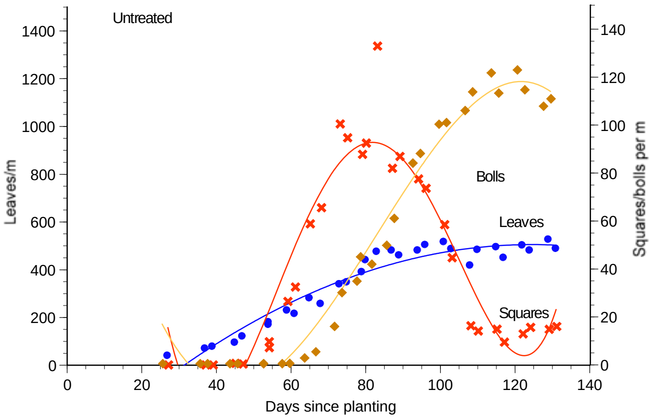
All new leaves were distorted by the herbicide. Leaves were cupped and twisted, with distorted edges. These symptoms are typical of 2,4-D damage.

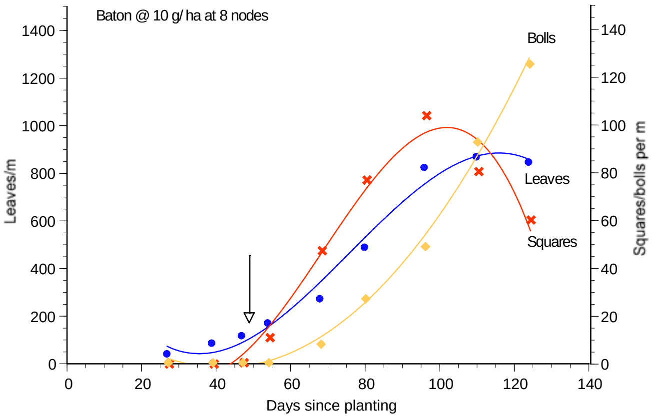
Baton (2,4-D amine) applied broadcast at 100 g/ha to 8 node cotton. Photo taken on 24th Mar, 93 days after exposure.

The main stem and most vegetative branches produced distorted leaves throughout the season. These branches produced few squares and few of these squares developed.

Baton (2,4-D amine) applied broadcast at 100 g/ha to 8 node cotton. Photo taken on 24th Mar, 93 days after exposure.

Some of the late vegetative branches did develop normally, producing some late squares, flowers and bolls, but few of these bolls opened before harvest.





Impact on plant growth

Leaves: the 2,4-D exposure initially caused some bending and twisting of the petioles (leaf stems), giving a wilted appearance. This effect was transitory.

The primary effect was on leaves that developed following the herbicide exposure, causing cupping and distortion of these leaves and an increase in leaf number, mainly through the production of smaller, distorted leaves.

Squares: the 1% rate of 2,4-D caused a delay in the production of squares, with peak squaring delayed by about 19 days.

Bolls: some early bolls were shed, but most later bolls were retained and developed on the vegetative branches. However, most of these bolls were small and few developed through to maturity on the upper branches following the 2,4-D exposure.

Final plant count data		
	Untreated	**2,4-D**
Nodes/plant	21.5	25.3
Leaves/m	502	844
Light interception	87%	91%
Leaf area (cm²/m)	22921	17210
Bolls/m	114	125
Boll weight (g/boll)	4.4	1.9
Days to 50% open	154	-
% Open bolls at picking	82%	36%
Lint yield/ha	1649	1383

2,4-D exposure at 8 nodes caused leaf deformation on the main stem.

There was an increase in leaf number, but most leaves were smaller and distorted, giving a reduction in total leaf area. Light interception was not reduced by this level of 2,4-D exposure at 8 nodes.

The plant retained most early bolls and retained a large number of late bolls, most of which didn't open, resulting in a 16% reduction in yield.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: 2,4-D amine
Rate: 8 g a.i./ha
% of typical field rate 1%
Date of exposure: 4th Jan (7 ½ weeks post-emergence)
Growth stage at exposure: 12 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily moves to the plant growth points
Mode of action: A phenoxy (auxin-type) herbicide that affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause abnormal increases in RNA, DNA & protein synthesis, resulting in uncontrolled cell division & growth.
Residual activity: limited
Soil half-life: 10 days in moist soil

Baton (2,4-D amine) applied broadcast at 10 g/ha to 12 node cotton. Photo taken on 25th Jan, 21 days after exposure.

Symptoms of 2,4-D damage are just becoming apparent on new growth.

Baton (2,4-D amine) applied broadcast at 10 g/ha to 12 node cotton. Photo taken on 25th Jan, 21 days after exposure.

Symptoms of 2,4-D damage are just becoming apparent on new growth. New leaves are cupped, with distorted margins.

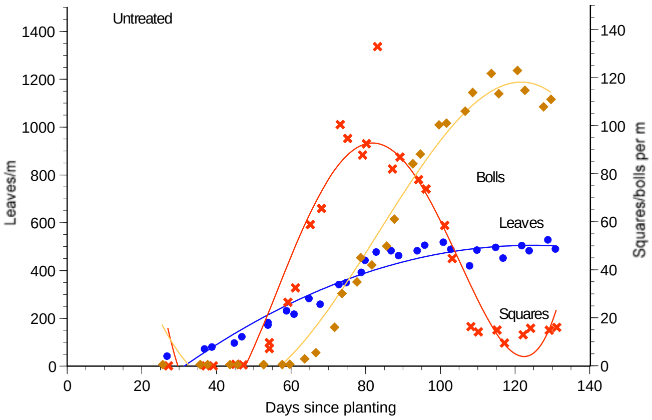
Baton (2,4-D amine) applied broadcast at 10 g/ha to 12 node cotton. Photo taken on 24th Mar, 79 days after exposure.

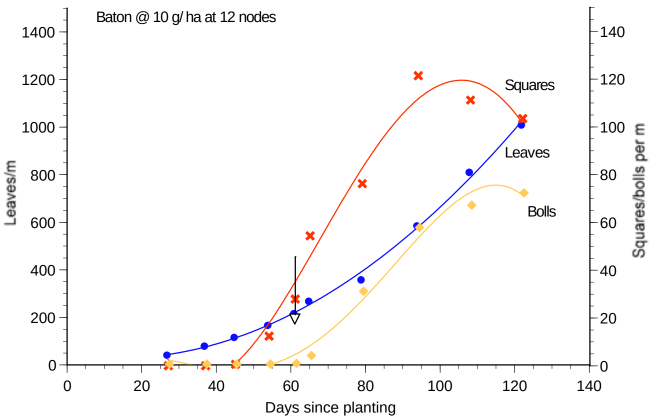
The 2,4-D damage was still apparent, with normal growth up to the 12 node stage. Subsequent growth was distorted. The leaves were short, narrow, cupped, twisted and leathery, with prominent veins. These symptoms are typical of 2,4-D damage.

Baton (2,4-D amine) applied broadcast at 10 g/ha to 12 node cotton. Photo taken on 24th Mar, 79 days after exposure.

Most new growth following the herbicide exposure was distorted. The leaves were short, narrow, cupped, twisted and leathery, with prominent veins.

A large number of distorted squares and flowers developed on the damaged parts of the plant late-season, but few fruit were retained on these parts. What fruit did develop was small and didn't reach maturity.





Impact on plant growth

Leaves: the 2,4-D exposure initially caused bending and twisting of the petioles (leaf stems), giving a wilted appearance. This effect was transitory.

The primary effect was on leaves that developed following the exposure, causing a large increase in leaf number, mainly through the production of small, distorted leaves. The increase in leaf number didn't adequately compensate for their small size and poor orientation, resulting in a reduction in leaf area and light interception.

Squares: many of the early squares were shed. The plant compensated by producing large numbers of late season squares, but none of these squares developed into harvestable bolls. Peak squaring was delayed by 28 days.

Bolls: bolls were retained on the lower branches, but no harvestable bolls developed above the 12th node (point of herbicide exposure). The bolls which did develop on the upper branches were small.

Final plant count data		
	Untreated	**2,4-D**
Nodes/plant	21.5	25.6
Leaves/m	502	1006
Light interception	87%	77%
Leaf area (cm²/m)	22921	16512
Bolls/m	114	72
Boll weight (g/boll)	4.4	2.3
Days to 50% open	154	153
% Open bolls at picking	82%	81%
Lint yield/ha	1649	623

2,4-D exposure at 12 nodes caused leaf deformation and a loss of squares and bolls.

There was an increase in leaf number, but most leaves were small, distorted and poorly orientated, giving a reduction in total leaf area and light interception.

The plant retained most bolls on the lower branches, but produced no harvestable bolls on the top part of the plant, resulting in a 62% reduction in yield.

There was no delay in crop maturity with the development of these bottom bolls.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: 2,4-D amine
Rate: 8 g a.i./ha
% of typical field rate 1%
Date of exposure: 24th Jan (10 ½ weeks post-emergence)
Growth stage at exposure: 16 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily moves to the plant growth points
Mode of action: A phenoxy (auxin-type) herbicide that affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause abnormal increases in RNA, DNA & protein synthesis, resulting in uncontrolled cell division & growth.
Residual activity: limited
Soil half-life: 10 days in moist soil

Baton (2,4-D amine) applied broadcast at 10 g/ha to 16 node cotton. Photo taken on 31st Jan, 7 days after exposure.

The only evidence of 2,4-D damage at this stage is some slight reddening on the leaves.

Baton (2,4-D amine) applied broadcast at 10 g/ha to 16 node cotton. Photo taken on 6th Feb, 13 days after exposure.

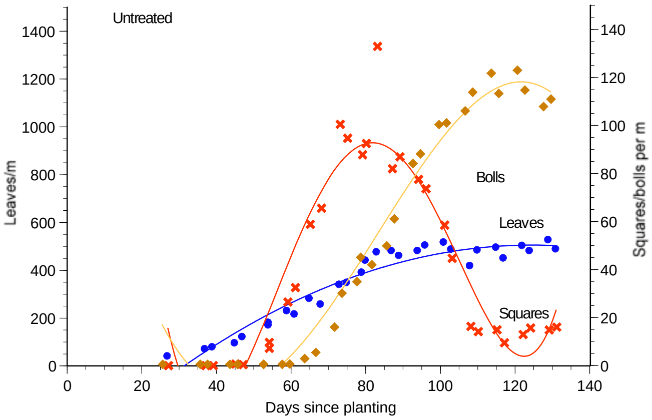
No evidence of 2,4-D damage is apparent at this stage.

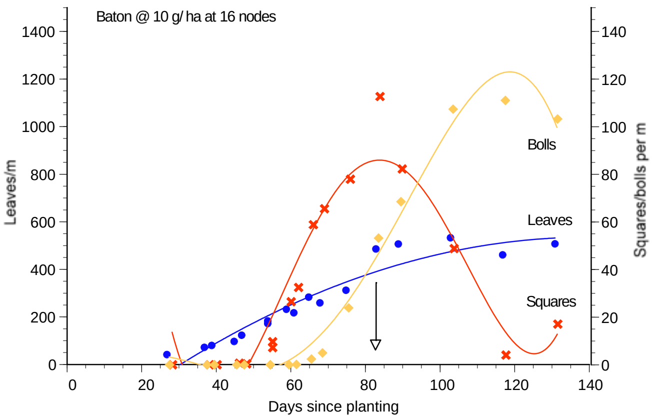
Baton (2,4-D amine) applied broadcast at 10 g/ha to 16 node cotton. Photo taken on 22nd Feb, 29 days after exposure.

Little 2,4-D damage was apparent on these plants, with normal growth up to the 16 node stage. However, newly emerging leaves are distorted, showing typical signs of phenoxy damage. The leaves are cupped and leathery but are not as narrow as leaves damaged at earlier growth stages.

Baton (2,4-D amine) applied broadcast at 10 g/ha to 16 node cotton. Photo taken on 5th April, 72 days after exposure.

Fruit set prior to the herbicide exposure have developed normally. However, most leaves which emerged since the exposure were highly distorted and few bolls were retained above 16 nodes. This gives the plants a "rank" appearance. Some "normal" leaves have now emerged at the top of the plant.





Impact on plant growth

Leaves: the 1% rate of 2,4-D had little impact on these plants, although there was some decrease in the size of the leaves produced post-exposure, reducing the total leaf area of the plant.

Squares: the 1% 2,4-D exposure at 16 nodes had no impact on square production.

Bolls: the 1% 2,4-D exposure at 16 nodes had little impact on boll production or retention, but did delay crop maturity by 18 days.

Final plant count data		
	Untreated	**2,4-D**
Nodes/plant	21.5	20.9
Leaves/m	502	504
Light interception	87%	86%
Leaf area (cm²/m)	22921	16692
Bolls/m	114	103
Boll weight (g/boll)	4.4	4.9
Days to 50% open	154	172
% Open bolls at picking	82%	74%
Lint yield/ha	1649	1504

2,4-D exposure at 16 nodes had relatively little impact on the plant.

There was no increase in leaf number, but a reduction in total leaf area.

The herbicide exposure had no apparent impact on square or boll production with new squares and bolls produced post-herbicide exposure.

The herbicide exposure did delay crop maturity by 18 days and reduced yield by 9%.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	**2,4-D amine**	
Rate:	**80 g a.i./ha**	
% of typical field rate	**10%**	
Date of exposure:	**12th Dec** (4 weeks post-emergence)	
Growth stage at exposure:	**6 nodes**	

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I

Translocation: readily moves to the plant growth points

Mode of action: A phenoxy (auxin-type) herbicide that affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause abnormal increases in RNA, DNA & protein synthesis, resulting in uncontrolled cell division & growth.

Residual activity: limited

Soil half-life: 10 days in moist soil

Baton (2,4-D amine) applied broadcast at 100 g/ha to 6 node cotton. Photo taken on 5th Jan, 24 days after exposure.

Leaves on the main stem were severely affected by the herbicide, with severe leaf distortion on all subsequent growth.

Baton (2,4-D amine) applied broadcast at 100 g/ha to 6 node cotton. Photo taken on 5th Jan, 24 days after exposure.

The new leaves on the main stem were severely distorted by the herbicide. Leaves were short, narrow, cupped, twisted and leathery, with prominent veins. These symptoms are typical of 2,4-D damage.

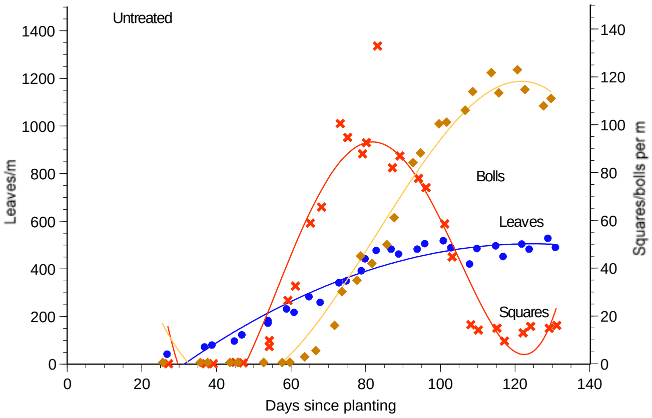
Baton (2,4-D amine) applied broadcast at 100 g/ha to 6 node cotton. Photo taken on 8th Mar, 86 days after exposure.

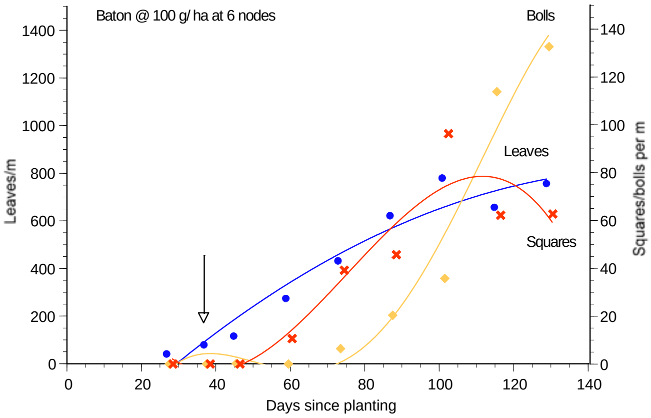
This plate shows a close-up of the centre of the plants in the following photo.

The main stem continued to produce distorted leaves throughout the season, but the growth on the vegetative branches was unaffected by the 2,4-D application.

Baton (2,4-D amine) applied broadcast at 100 g/ha to 6 node cotton. Photo taken on 8th Mar, 86 days after exposure.

Vegetative branches that developed after the herbicide exposure were not affected by the 2,4-D, with no distorted leaves, and produced normal squares, flowers and bolls.





Impact on plant growth

Leaves: the 2,4-D exposure initially caused bending and twisting of the petioles (leaf stems), giving a wilted appearance. This effect was transitory.

The primary effect was on leaves that developed following the exposure, causing an increase in leaf production, mainly through the production of small, distorted leaves on the main stem.

Squares: many of the early squares were shed, but later squares were retained and developed.

Bolls: some early bolls were shed, but later bolls were retained and developed. The plant produced a large number of late bolls, the majority of which didn't reach maturity.

Final plant count data		
	Untreated	**2,4-D**
Nodes/plant	21.5	23.9
Leaves/m	502	753
Light interception	87%	90%
Leaf area (cm²/m)	22921	19737
Bolls/m	114	133
Boll weight (g/boll)	4.4	2.6
Days to 50% open	154	-
% Open bolls at picking	82%	26%
Lint yield/ha	1649	1471

Heavy 2,4-D exposure at 6 nodes caused extensive leaf deformation on the main stem and a loss of fruit from the main stem.

The plant compensated for this damage, setting the crop on the vegetative branches, producing a late crop, with a delay in crop maturity. Many of these bolls were still green at harvest.

In this instance the damage only caused a small (11%) reduction in lint yield. This yield loss would have been reduced had picking been delayed.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	**2,4-D amine**	
Rate:	**80 g a.i./ha**	
% of typical field rate	**10%**	
Date of exposure:	**21st Dec** (5½ weeks post-emergence)	
Growth stage at exposure:	**8 nodes**	

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily moves to the plant growth points
Mode of action: A phenoxy (auxin-type) herbicide that affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause abnormal increases in RNA, DNA & protein synthesis, resulting in uncontrolled cell division & growth.
Residual activity: limited
Soil half-life: 10 days in moist soil

Baton (2,4-D amine) applied broadcast at 100 g/ha to 8 node cotton. Photo taken on 5th Jan, 15 days after exposure.

All leaves were severely affected by the herbicide, with severe leaf distortion on subsequent growth.

Baton (2,4-D amine) applied broadcast at 100 g/ha to 8 node cotton. Photo taken on 5th Jan, 15 days after exposure.

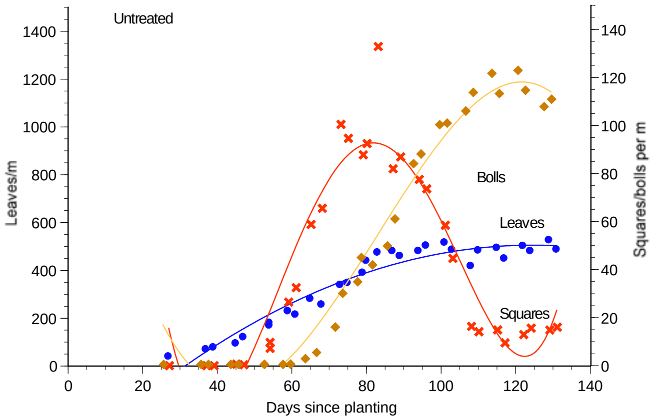
All new leaves were severely distorted by the herbicide. Leaves were short, narrow, cupped, twisted and leathery, with prominent veins. These symptoms are typical of 2,4-D damage.

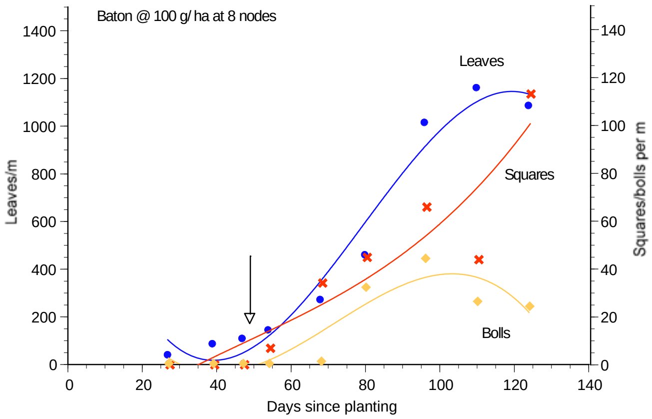
Baton (2,4-D amine) applied broadcast at 100 g/ha to 8 node cotton. Photo taken on 24th Mar, 93 days after exposure.

The main stem and most vegetative branches produced distorted leaves throughout the season. These branches produced few squares and few of these squares developed.

Baton (2,4-D amine) applied broadcast at 100 g/ha to 8 node cotton. Photo taken on 24th Mar, 93 days after exposure.

Some of the late vegetative branches did develop normally, producing some late squares, flowers and bolls, but few of these bolls opened before harvest.





Impact on plant growth

Leaves: the 2,4-D exposure initially caused bending and twisting of the petioles (leaf stems), giving a wilted appearance. This effect was transitory.

The primary effect was on leaves that developed following the exposure, causing a large increase in leaf number, mainly through the production of small, distorted leaves. The increase in leaf number did not adequately compensate for their small size and poor orientation, resulting in a reduction in leaf area and light interception.

Squares: most of the early squares were shed. The plant compensated later in the season by producing large numbers of new squares, but none of these squares developed into harvestable bolls.

Bolls: some bolls were retained on the lower branches, but almost no bolls developed following the 2,4-D exposure. Bolls which were retained were very small and few opened before harvest.

Final plant count data		
	Untreated	**2,4-D**
Nodes/plant	21.5	24.6
Leaves/m	502	1084
Light interception	87%	79%
Leaf area (cm²/m)	22921	14693
Bolls/m	114	24
Boll weight (g/boll)	4.4	0.4
Days to 50% open	154	-
% Open bolls at picking	82%	8%
Lint yield/ha	1649	277

Heavy 2,4-D exposure at 8 nodes caused extensive leaf deformation on the main stem and most vegetative branches, and a loss of squares and bolls.

There was an increase in leaf number, but most leaves were small, distorted and poorly orientated, giving a reduction in total leaf area and light interception.

The plant retained only a few, small bolls, most of which didn't open, resulting in an 83% reduction in yield.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	**2,4-D amine**	**Damage key:**
Rate:	**80 g a.i./ha**	**Leaf loss**
% of typical field rate	**10%**	**Leaf distortion** x
Date of exposure:	**4th Jan** (7 ½ weeks post-emergence)	**Petiole distortion** x
		Plant stunting
Growth stage at exposure:	**12 nodes**	**Square shedding** x
		Boll shedding x

Herbicidal action

Herbicide group: I
Translocation: readily moves to the plant growth points
Mode of action: A phenoxy (auxin-type) herbicide that affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause abnormal increases in RNA, DNA & protein synthesis, resulting in uncontrolled cell division & growth.
Residual activity: limited
Soil half-life: 10 days in moist soil

Baton (2,4-D amine) applied broadcast at 100 g/ha to 12 node cotton. Photo taken on 25th Jan, 21 days after exposure.

Symptoms of 2,4-D damage are just becoming apparent.

Baton (2,4-D amine) applied broadcast at 100 g/ha to 12 node cotton. Photo taken on 25th Jan, 21 days after exposure.

Symptoms of 2,4-D damage are just becoming apparent. New leaves are cupped, with distorted margins.

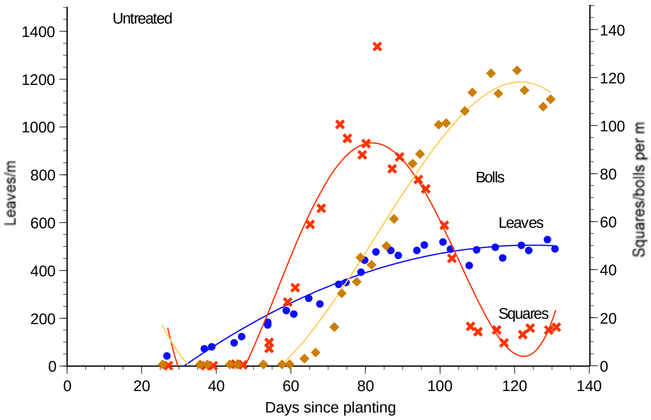
Baton (2,4-D amine) applied broadcast at 100 g/ha to 12 node cotton. Photo taken on 8th Mar, 63 days after exposure.

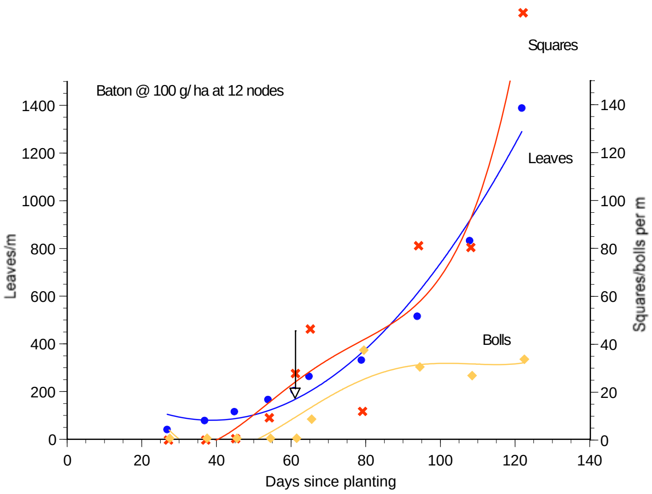
The 2,4-D damage is very obvious, with normal growth up to the 12 node stage. All subsequent growth was very distorted. The leaves were short, narrow, cupped, twisted and leathery, with prominent veins. These symptoms are typical of 2,4-D damage.

Baton (2,4-D amine) applied broadcast at 100 g/ha to 12 node cotton. Photo taken on 24th Mar, 79 days after exposure.

Almost all growth following the herbicide exposure was highly distorted. The leaves were short, narrow, cupped, twisted and leathery, with prominent veins. These symptoms are typical of 2,4-D damage.

A large number of distorted squares developed on the damaged parts of the plant late-season, but few fruit were retained on these parts.





Impact on plant growth

Leaves: the 2,4-D exposure initially caused bending and twisting of the petioles (leaf stems), giving a wilted appearance. This effect was transitory.

The primary effect was on leaves that developed following the exposure, causing a large increase in leaf number, mainly through the production of small, distorted leaves. The increase in leaf number did not adequately compensate for their small size and poor orientation, resulting in a reduction in leaf area and light interception.

Squares: many of the early squares were shed. The plant compensated later in the season by producing large numbers of new squares, but none of these squares developed into harvestable bolls.

Bolls: bolls were retained on the lower branches, but no harvestable bolls developed above the 12th node (point of herbicide exposure). The bolls which were retained were small.

Final plant count data		
	Untreated	**2,4-D**
Nodes/plant	21.5	24.0
Leaves/m	502	1386
Light interception	87%	72%
Leaf area (cm²/m)	22921	14376
Bolls/m	114	33
Boll weight (g/boll)	4.4	0.8
Days to 50% open	154	152
% Open bolls at picking	82%	84%
Lint yield/ha	1649	192

Heavy 2,4-D exposure at 12 nodes caused extensive leaf deformation and a loss of squares and bolls.

There was an increase in leaf number, but most leaves were small, distorted and poorly orientated, giving a reduction in total leaf area and light interception.

The plant retained only a few, small bolls on the lower branches, resulting in an 88% reduction in yield.

There was no delay in crop maturity with the development of these bolls.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: 2,4-D amine
Rate: 80 g a.i./ha
% of typical field rate: 10%
Date of exposure: 24 Jan
(10½ weeks post-emergence)
Growth stage at exposure: 16 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily moves to the plant growth points
Mode of action: A phenoxy (auxin-type) herbicide that affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause abnormal increases in RNA, DNA & protein synthesis, resulting in uncontrolled cell division & growth.
Residual activity: limited
Soil half-life: 10 days in moist soil

Baton(2,4-D amine) applied broadcast at 100 g/ha to 16 node cotton. Photo taken on 31st Jan, 7 days after exposure.

The only evidence of herbicide damage at this stage is some reddening on the leaves.

Baton(2,4-D amine) applied broadcast at 100 g/ha to 16 node cotton. Photo taken on 6th Feb, 13 days after exposure.

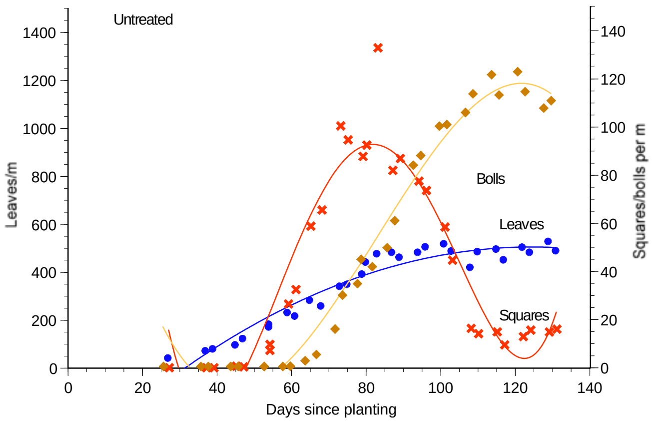
By 13 days the reddening on some leaves has intensified and some degree of reddening as apparent on most leaves. Many of the petioles at the top of the plant are also twisted, misaligning the leaves.

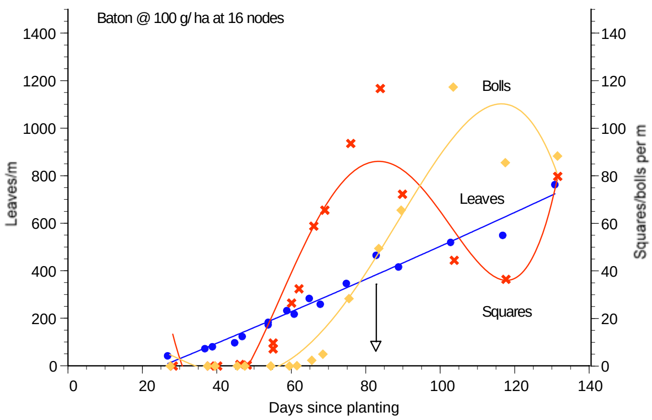
Baton(2,4-D amine) applied broadcast at 100 g/ha to 16 node cotton. Photo taken on 22nd Feb, 29 days after exposure.

The leaf discolouration has disappeared by 29 days after exposure, but all newly emerged leaves are distorted, showing typical symptoms of phenoxy damage. The leaves are cupped and leathery but are not as narrow as leaves damaged at earlier growth stages.

Baton(2,4-D amine) applied broadcast at 100 g/ha to 16 node cotton. Photo taken on 5th April, 72 days after exposure.

Fruit set prior to the herbicide exposure have developed normally. However, most leaves which emerged since the exposure were highly distorted and few if any bolls were retained above 16 nodes. This gives the plants a "rank" appearance. Some "normal" leaves have now emerged at the top of the plant.





Impact on plant growth

Leaves: the 2,4-D exposure initially caused bending and twisting of the petioles (leaf stems), giving a wilted appearance. This effect was transitory.

The primary effect was on leaves that developed following the exposure, causing an increase in leaf number through the production of small, distorted leaves. The increase in leaf number did not adequately compensate for their poor orientation, resulting in a reduction in light interception.

Squares: the herbicide exposure, occurring at peak squaring, had little impact on squaring, with an increase in the production of late squares.

Bolls: most bolls were retained, although these was an increased loss off bolls late in the season.

Final plant count data

	Untreated	Gly + 2,4-D
Nodes/plant	21.5	25.1
Leaves/m	502	759
Light interception	87%	80%
Leaf area (cm²/m)	22921	23203
Bolls/m	114	88
Boll weight (g/boll)	4.4	4.7
Days to 50% open	154	155
% Open bolls at picking	82%	93%
Lint yield/ha	1649	1148

Heavy 2,4-D exposure at 16 nodes had little impact on the lower part of the plant, but caused some late season boll shedding.

There was an increase in leaf number and leaf area, but most damaged leaves were distorted and poorly orientated, giving a reduction in light interception.

The plant retained most lower bolls, resulting in a 30% yield reduction.

2,4-D exposure did not delay the maturity of this crop.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	dicamba
Rate:	28 g a.i./ha
% of typical field rate	10%
Date of exposure:	12th Nov (6 weeks post-emergence)
Growth stage at exposure:	6 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily absorbed by leaves
Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production
Residual activity: limited
Soil half-life: 4 – 14 days

Kamba 500 applied broadcast at 56 ml/ha to 6 node cotton. Photo taken on 15th Nov, 3 days after exposure.

There are no initial symptoms of dicamba damage apparent 3 days after exposure.

Kamba 500 applied broadcast at 56 ml/ha to 6 node cotton. Photo taken on 22nd Nov, 10 days after exposure.

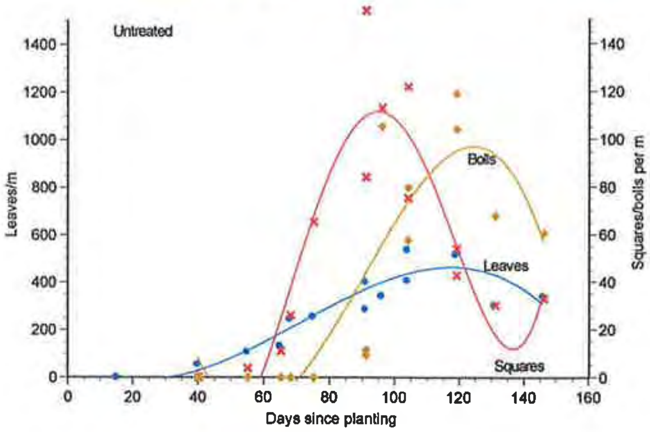
By 10 days, plants were showing some cupping of the new leaves and reddening of the leaf margins.

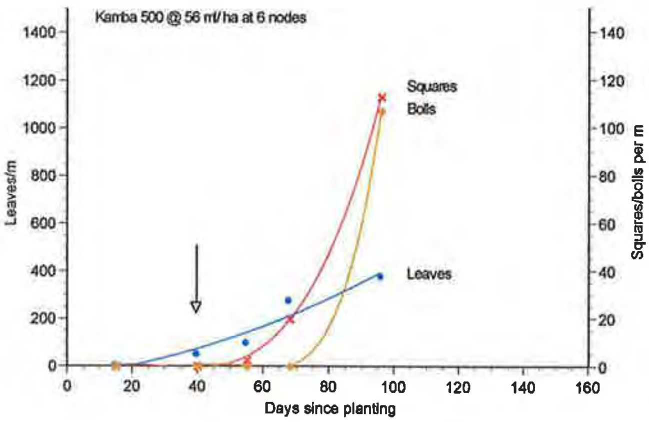
Kamba 500 applied broadcast at 56 ml/ha to 6 node cotton. Photo taken on 11th Dec, 29 days after exposure.

Plants have resumed growth, but new growth is showing typical phenoxy damage. Distortion ranges from almost normal leaves with a leathery appearance and heavy venation, to cupped leaves and more typical "wedge" shaped leaves ending in multiple "fingers".

Kamba 500 applied broadcast at 56 ml/ha to 6 node cotton. Photo taken on 2nd Jan, 51 days after exposure.

Most leaves appear to be normal at this stage. A few distorted leaves with crinkled edges are still apparent.





Impact on plant growth

Leaves: plants exposed to a 10% rate of dicamba showed few initial symptoms of herbicide damage, with some discolouration and cupping of young leaves.

The main effect was on leaves which emerged following the herbicide exposure, with the production of some distorted leaves, typical of phenoxy damage. This damage had little impact on leaf number or leaf area mid-season.

Squares: dicamba damage delayed square production by around 10 days, but did not affect peak squaring.

Bolls: boll production and retention were largely unaffected by the herbicide, with a small reduction (4%) in boll weight.

Final plant count data		
	Untreated	**Dicamba**
Nodes/plant	27.8	30.0
Leaves/m*	342	374
Leaf area (cm²/m)*	16870	15730
Reduction in leaf area*		7%
Bolls/m	176	175
Boll weight (g/boll)	4.8	4.6
Bolls/node (nodes 10-20)#	0.86	0.85
Days to 50% open	183	187
Maturity delay (days)		4
% Open bolls at picking	86%	80%
Lint yield/ha	2147	1614

Exposure to 10% of a typical field rate of dicamba at 6 nodes caused only relatively mild symptoms of herbicide damage.

The herbicide had little negative impact on leaf number, leaf area or square production. The retention of mature bolls was unaffected, and boll weight was reduced by only 4%.

Crop maturity was delayed by only 4 days but these factors combined to reduce lint yield by 25%.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	dicamba
Rate:	28 g a.i./ha
% of typical field rate	10%
Date of exposure:	5th Dec (9 weeks post-emergence)
Growth stage at exposure:	11 nodes

Damage key:

Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group:	I
Translocation:	readily absorbed by leaves
Mode of action:	an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production
Residual activity:	limited
Soil half-life:	4 – 14 days

Kamba 500 applied broadcast at 56 ml/ha to 11 node cotton. Photo taken on 11th Dec, 6 days after exposure.

By 6 days, plants were showing some yellowing and cupping of the new leaves, with reddening of the leaf margins.

Kamba 500 applied broadcast at 56 ml/ha to 11 node cotton. Photo taken on 21st Dec, 16 days after exposure.

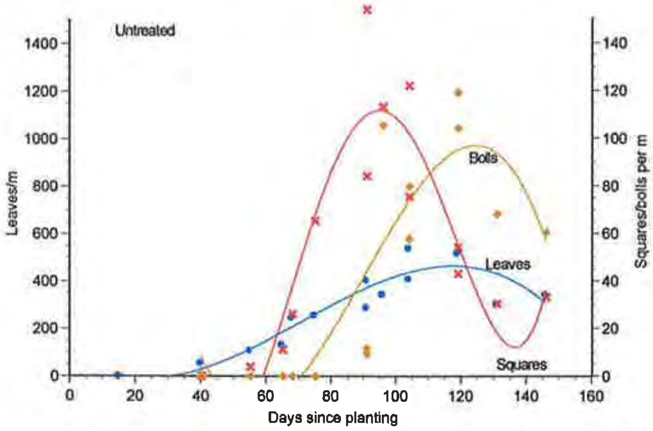
By 16 days, new growth with typical phenoxy damage is obvious. Distortion ranges from almost normal leaves with a leathery appearance and heavy venation, to cupped leaves and more typical "wedge" shaped leaves ending in multiple "fingers".

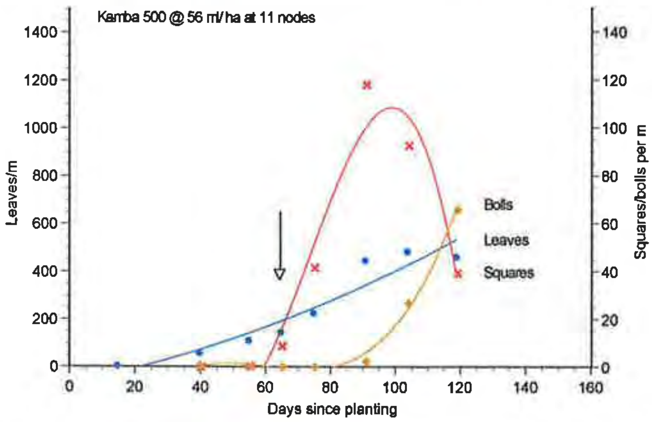
Kamba 500 applied broadcast at 56 ml/ha to 11 node cotton. Photo taken on 2nd Jan, 28 days after exposure.

New growth on these plants is very distorted, with small leaves and long internodes. Distortion ranges from almost normal leaves with a leathery appearance and heavy venation, to cupped leaves and more typical "wedge" shaped leaves ending in multiple "fingers".

Kamba 500 applied broadcast at 56 ml/ha to 11 node cotton. Photo taken on 14th Jan, 40 days after exposure.

Distorted new growth with long internodes continues to top the plant after 40 days. Most of the damage symptoms disappeared by 50 days after exposure.





Impact on plant growth

Leaves: exposure to a 10% rate of dicamba caused distinct yellowing and cupping of young, exposed leaves.

This initial damage was later followed by the production of distorted new leaves, typical of phenoxy damage, with extended inter-nodes. This resulted in a 12% reduction in leaf number and a 16% reduction in mid-season leaf area.

Squares: the dicamba damage had little effect on square production.

Bolls: boll production and retention were both affected by the herbicide. There was a 24% reduction in the number of mature bolls at picking and a 29% reduction in the retention of mature bolls on nodes 10 - 20. Plants only retained mature bolls to node 21, fives nodes fewer than undamaged plants. There was also a 13% reduction in boll weight and 16 day delay in crop maturity.

Final plant count data		
	Untreated	**Dicamba**
Nodes/plant	27.8	27.3
Leaves/m*	517	456
Leaf area (cm²/m)*	10030	8383
Reduction in leaf area*		16%
Bolls/m	176	134
Boll weight (g/boll)	4.8	4.2
Bolls/node (nodes 10-20)#	0.86	0.60
Days to 50% open	183	199
Maturity delay (days)		16
% Open bolls at picking	86%	76%
Lint yield/ha	2147	1034

Exposure to 10% of a typical field rate of dicamba at 11 nodes reduced leaf number and leaf area but had little effect on square production. Boll production and retention were reduced and plants were unable to compensate by setting a late crop.

Crop maturity was delayed and 12% fewer of the retained bolls were mature at picking. This lack of maturity combined with reduced boll weight and boll number to result in a 52% reduction in lint yield in a very long season, with picking delayed till June.

Note* Leaf number and area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by:

Graham Charles
NSW Dept of Primary Industries

Herbicide:	**dicamba**
Rate:	**28 g a.i./ha**
% of typical field rate	**10%**
Date of exposure:	**2^{nd} Jan** (13 weeks post-emergence)
Growth stage at exposure:	**15 nodes**

Damage key:

Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily absorbed by leaves
Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production
Residual activity: limited
Soil half-life: 4 – 14 days

Kamba 500 applied broadcast at 56 ml/ha to 15 node cotton. Photo taken on 4^{th} Jan, 2 days after exposure.

There were no obvious signs of herbicide damage 2 days after exposure to this rate.

Kamba 500 applied broadcast at 56 ml/ha to 15 node cotton. Photo taken on 7^{th} Jan, 5 days after exposure.

By 5 days after exposure, some of the younger leaves were yellowish and distorted. They were often "cupped" or "bubbled", with raised edges and the edges were reddish.

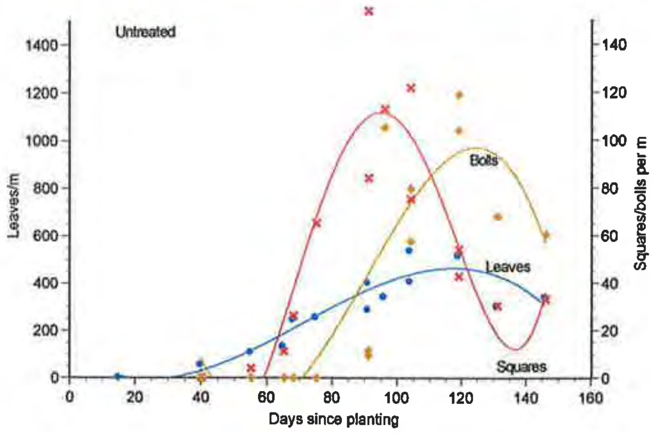
Kamba 500 applied broadcast at 56 ml/ha to 15 node cotton. Photo taken on 14^{th} Jan, 14 days after exposure.

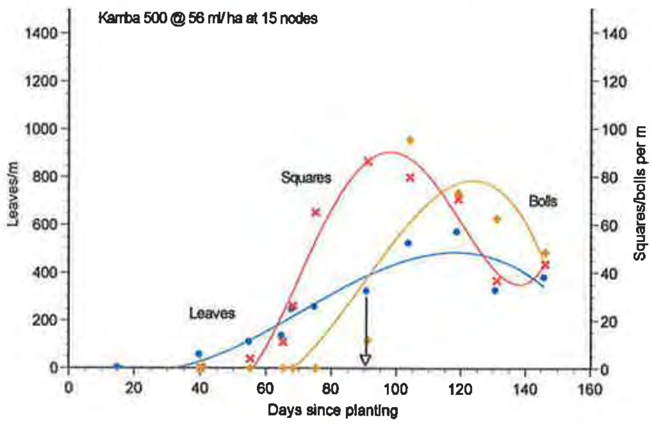
By 14 days the plants were topped with distorted, rank growth with long internodes. Many of the emerging leaves on this top growth were "wedge" shaped, ending in multiple "fingers". Cupping and reddening of the some leaves was also still apparent.

Kamba 500 applied broadcast at 56 ml/ha to 15 node cotton. Photo taken on 31st Jan, 29 days after exposure.

Distorted new growth with long internodes continues to top the plant after 29 days.

Most of the damage symptoms disappeared by 50 days after exposure.





Impact on plant growth

Leaves: exposure to a 10% rate of dicamba caused distinct yellowing and cupping of young, exposed leaves. This effect was apparent within 5 days of exposure.

This initial damage was later followed by the production of distorted new leaves, typical of phenoxy damage, and rank growth with extended inter-nodes. This caused only a small reduction (11%) in leaf area 55 days after exposure.

Squares: the dicamba reduced peak square production, but the plants compensated, increasing square production later in the season.

Bolls: the herbicide exposure reduced peak boll production. The final retention of mature bolls was reduced by 14%, with a 40% reduction in the retention of mature bolls on nodes 10 - 20. A large number of late season bolls were retained, with mature bolls to the top of the plant (node 29). There was a 13% reduction in boll weight and an 8 day delay in crop maturity.

Final plant count data		
	Untreated	**Dicamba**
Nodes/plant	27.8	29.3
Leaves/m*	341	396
Leaf area (cm²/m)*	19630	17471
Reduction in leaf area*		11%
Bolls/m	176	150
Boll weight (g/boll)	4.8	4.1
Bolls/node (nodes 10-20)#	0.86	0.52
Days to 50% open	183	191
Maturity delay (days)		8
% Open bolls at picking	86%	78%
Lint yield/ha	2147	1564

Exposure to 10% of a typical field rate of dicamba at 15 nodes caused little visible damage to the crop, but reduced peak square production, boll production and boll retention.

Crop maturity was delayed and 14% fewer bolls were mature at picking. This lack of maturity combined with reduced boll number and boll weight to give a 27% reduction in lint yield in what was a very long season.

Note* Leaf number and leaf area were last recorded 55 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: **Graham Charles**
NSW Dept of Primary Industries

Herbicide:	**dicamba**
Rate:	**140 g a.i./ha**
% of typical field rate	**50%**
Date of exposure:	**12th Nov** (6 weeks post-emergence)
Growth stage at exposure:	**6 nodes**

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily absorbed by leaves
Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production
Residual activity: limited
Soil half-life: 4 – 14 days

Kamba 500 applied broadcast at 280 ml/ha to 6 node cotton. Photo taken on 15th Nov, 3 days after exposure.

There are few initial symptoms of dicamba damage apparent 3 days after exposure. There is some cupping of new leaves, with reddening around the edges.

Kamba 500 applied broadcast at 280 ml/ha to 6 node cotton. Photo taken on 22nd Nov, 10 days after exposure.

By 10 days, plants are showing elongated petioles on the new leaves and cupping and reddening of the new leaves is more obvious.

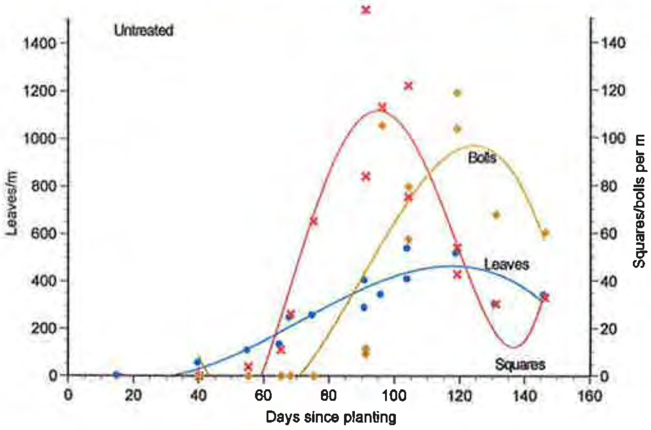
Kamba 500 applied broadcast at 280 ml/ha to 6 node cotton. Photo taken on 11th Dec, 29 days after exposure.

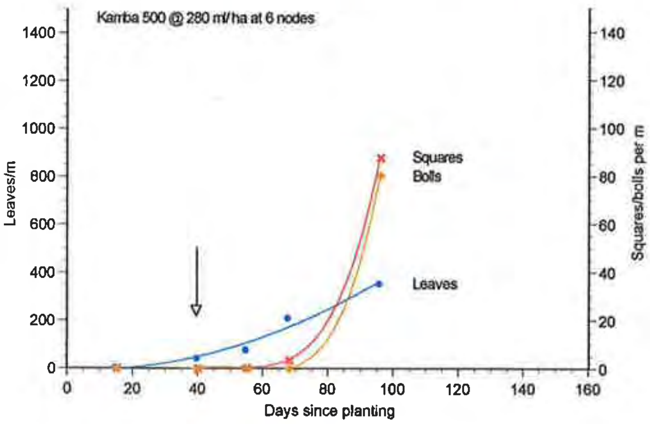
Plants have resumed growth, but new growth is showing typical phenoxy damage. Distortion ranges from almost normal leaves with a leathery appearance and heavy venation, to cupped leaves and more typical “wedge” shaped leaves ending in multiple “fingers”.

Kamba 500 applied broadcast at 280 ml/ha to 6 node cotton. Photo taken on 2nd Jan, 51 days after exposure.

Some distorted leaves with crinkled edges are still apparent, although more normal leaves are emerging on newly developing lateral branches.

Most symptoms of damage have disappeared by 25th Jan, 74 days after exposure.





Impact on plant growth

Leaves: exposure to a 50% rate of dicamba initially caused some reddening and cupping of young leaves.

The main effect was on leaves which emerged following the herbicide exposure, with the production of distorted leaves, with typical symptoms of phenoxy damage. There was an 18% reduction in leaf area mid-season.

Squares: dicamba damage delayed square production by around 15 days.

Bolls: boll production was largely unaffected by the herbicide, but boll retention was more affected than the relatively mild herbicide symptoms might indicate.

There was a 25% reduction in the number of mature bolls at picking and an 11% reduction in boll weight. Fruit retention on nodes 10 - 20 was reduced by 53%, with few mature bolls retained above node 19, seven nodes from the top of the plant.

Final plant count data		
	Untreated	**Dicamba**
Nodes/plant	27.8	26.9
Leaves/m*	342	349
Leaf area (cm²/m)*	16870	13801
Reduction in leaf area*		18%
Bolls/m	176	132
Boll weight (g/boll)	4.8	4.3
Bolls/node (nodes 10-20)#	0.86	0.40
Days to 50% open	183	202
Maturity delay (days)		19
% Open bolls at picking	86%	86%
Lint yield/ha	2147	1198

Exposure to 50% of a typical field rate of dicamba at 6 nodes caused only relatively mild symptoms of herbicide damage, but had a big impact on boll retention, with reduced boll retention on all nodes and no bolls retained at the top of the plant.

Dicamba caused a reduction in boll number and boll weight. This resulted in a 44% reduction in yield, with a 19 day delay in crop maturity.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: dicamba
Rate: 140 g a.i./ha
% of typical field rate 50%
Date of exposure: 5th Dec (9 weeks post-emergence)
Growth stage at exposure: 11 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily absorbed by leaves
Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production
Residual activity: limited
Soil half-life: 4 – 14 days

Kamba 500 applied broadcast at 280 ml/ha to 11 node cotton. Photo taken on 14th Dec, 9 days after exposure.

The only symptoms of dicamba damage apparent 9 days after exposure is cupping of the new leaves, with reddening around the edges.

Kamba 500 applied broadcast at 280 ml/ha to 11 node cotton. Photo taken on 21st Dec, 16 days after exposure.

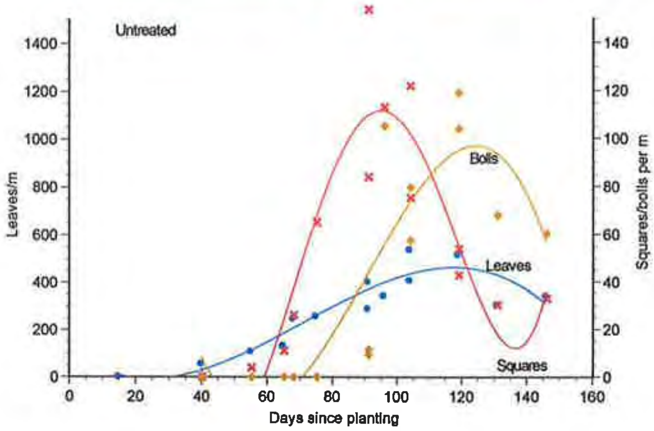
By 16 days, distorted growth, typical of phenoxy damage, is becoming apparent on the new leaves. Many of the emerging new leaves are "wedge" shaped, ending in multiple "fingers". Cupping and reddening of the newer leaves is still apparent.

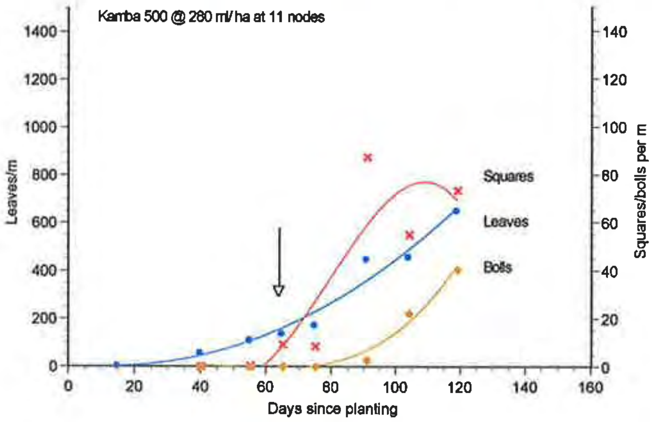
Kamba 500 applied broadcast at 280 ml/ha to 11 node cotton. Photo taken on 2nd Jan, 28 days after exposure.

Plants are beginning to resume normal growth on the laterals, but new growth on the main stem is showing typical phenoxy damage. Distortion ranges from almost normal leaves with a leathery appearance and heavy venation, to cupped leaves and more typical "wedge" shaped leaves ending in multiple "fingers".

Kamba 500 applied broadcast at 280 ml/ha to 11 node cotton. Photo taken on 14th Jan, 40 days after exposure.

Symptoms of damage are disappearing as new 'normal' growth develops. Distorted growth can still be found in the centre of the plant.





Impact on plant growth

Leaves: exposure to a 50% rate of dicamba initially caused some discolouration and cupping of young leaves.

The main effect was on leaves which emerged following the herbicide exposure, with the production of distorted leaves, typical of phenoxy damage. The plant compensated for an initial reduction in leaf area by producing a mass of new growth resulting in an over-all increase in leaf number and leaf area mid-season.

Squares: dicamba damage delayed peak square production by around 30 days and reduced peak squaring by around 30%.

Bolls: boll production was delayed by around 20 days by the herbicide. Final boll retention was down by 44%.

There was also an 18% reduction in boll weight and 22% reduction in fruit retention on nodes 10 - 20. Few mature bolls were retained on nodes 14 and 15, on a plant that was 7 nodes shorter than the undamaged plants.

Final plant count data

	Untreated	Dicamba
Nodes/plant	27.8	20.9
Leaves/m*	517	647
Leaf area (cm²/m)*	10030	15299
Reduction in leaf area*		-
Bolls/m	176	98
Boll weight (g/boll)	4.8	3.9
Bolls/node (nodes 10-20)#	0.86	0.67
Days to 50% open	183	217
Maturity delay (days)		34
% Open bolls at picking	86%	80%
Lint yield/ha	2147	920

Exposure to 50% of a typical field rate of dicamba at 11 nodes caused moderate symptoms of herbicide damage, but caused a big reduction in boll retention and yield.

Dicamba caused a reduction in boll number and a reduction in boll weight, with few bolls retained on the main stem. Lint yield was reduced by 57%, with a 34 day delay in crop maturity. Of the retained bolls, 7% fewer bolls were open at picking.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	dicamba
Rate:	140 g a.i./ha
% of typical field rate	50%
Date of exposure:	2^{nd} Jan (13 weeks post-emergence)
Growth stage at exposure:	15 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily absorbed by leaves
Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production
Residual activity: limited
Soil half-life: 4 – 14 days

Kamba 500 applied broadcast at 280 ml/ha to 15 node cotton. Photo taken on 4 Jan, 2 days after exposure.

The only symptoms of dicamba damage apparent 2 days after exposure is twisting of the petioles on a few of the upper leaves.

Kamba 500 applied broadcast at 280 ml/ha to 15 node cotton. Photo taken on 11 Jan, 9 days after exposure.

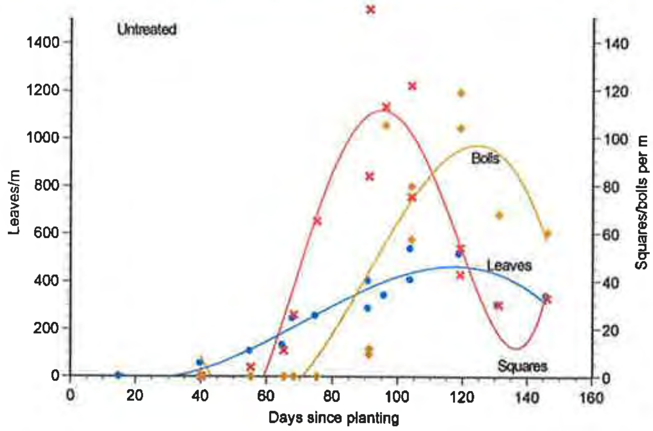
By 9 days after exposure, some of the younger leaves are yellowish and distorted. They are "cupped", with raised edges and the edges are reddish.

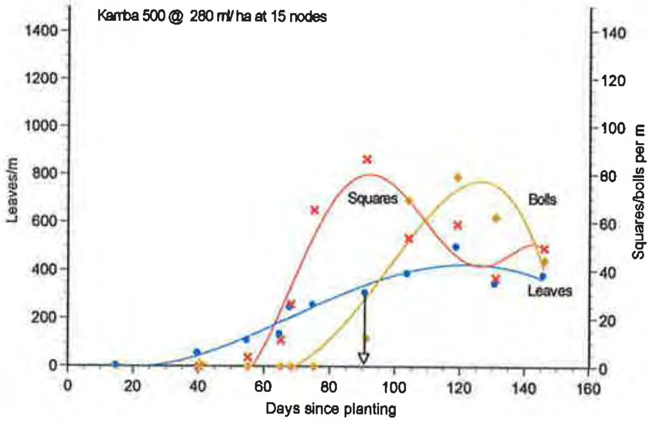
Kamba 500 applied broadcast at 280 ml/ha to 15 node cotton. Photo taken on 31 Jan, 29 days after exposure.

By 29 days, rank new growth is appearing at the top of the plants, with long internodes and distorted growth, typical of phenoxy damage. Many of the emerging leaves are "wedge" shaped, ending in multiple "fingers". Cupping and reddening of the some leaves is also still apparent.

Kamba 500 applied broadcast at 280 ml/ha to 15 node cotton. Photo taken on 11 Feb, 40 days after exposure.

Rank new distorted growth is very obvious at the top of the plants. Most top leaves are "wedge" shaped, ending in multiple "fingers".





Impact on plant growth

Leaves: exposure to a 50% rate of dicamba initially caused some discolouration and cupping of young leaves.

The main effect on the crop was on leaves which emerged from the top of the plant following the herbicide exposure, with the production of distorted leaves, typical of phenoxy damage.

Squares: dicamba damage reduced peak square production, but plants compensated by producing additional squares later in the season.

Bolls: the peak of boll production was delayed by around 10 days by the herbicide.

The final retention of mature boll was reduced by 27%, with few bolls retained above node 23, five nodes from the top of the plant. There were 29% fewer bolls retained on nodes 10 - 20 than on undamaged plants. Boll weight was also reduced by 18% on average.

Final plant count data

	Untreated	Dicamba
Nodes/plant	27.8	28.5
Leaves/m*	341	359
Leaf area (cm²/m)*	19630	21630
Reduction in leaf area*		-
Bolls/m	176	128
Boll weight (g/boll)	4.8	3.9
Bolls/node (nodes 10-20)#	0.86	0.61
Days to 50% open	183	191
Maturity delay (days)		8
% Open bolls at picking	86%	73%
Lint yield/ha	2147	1109

Exposure to 50% of a typical field rate of dicamba initially cause mild damage symptoms, but had a large effect on later leaf development. This combined to cause a reduction in boll weight, boll retention and yield.

Dicamba caused an 8 day delay in average boll maturity, but many of the late bolls were still not fully open at harvest, even though harvest was delayed till late June. Reduced boll number and weight combined to give a 48% reduction in yield.

Note* Leaf number and leaf area were last recorded 55 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: **Graham Charles**
NSW Dept of Primary Industries

Herbicide:	**fluroxypyr**
Rate:	**36 g a.i./ha**
% of typical field rate	**10%**
Date of exposure:	**12th Nov** (6 weeks post-emergence)
Growth stage at exposure:	**6 nodes**

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily moves to the plant growth points
Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production.
Residual activity: limited
Soil half-life: 11 - 38 days in moist soil

Starane® 300 applied broadcast at 120 ml/ha to 6 node cotton. Photo taken on 15th Nov, 3 days after exposure.

There were few symptoms of fluroxypyr damage apparent 3 days after exposure to the 10% rate. There was some reddening of the stems, petiole twisting and bending and leaf cupping but it was difficult to distinguish this damage from background thrip damage.

Starane® 300 applied broadcast at 120 ml/ha to 6 node cotton. Photo taken on 22nd Nov, 10 days after exposure.

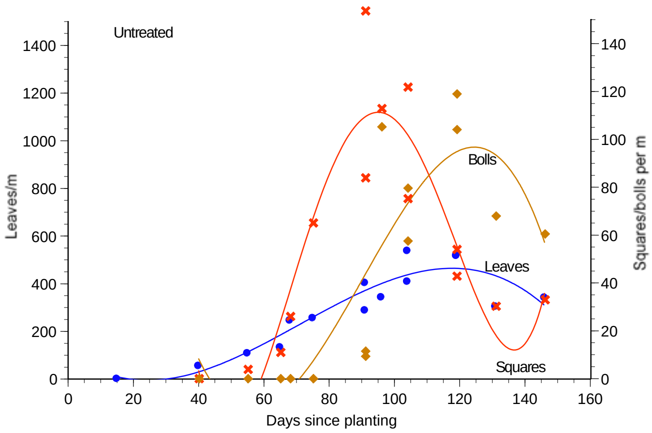
Some initial symptoms of fluroxypyr damage were still apparent 10 days after exposure. New leaves were yellowed, cupped and distorted, with discoloured edges.

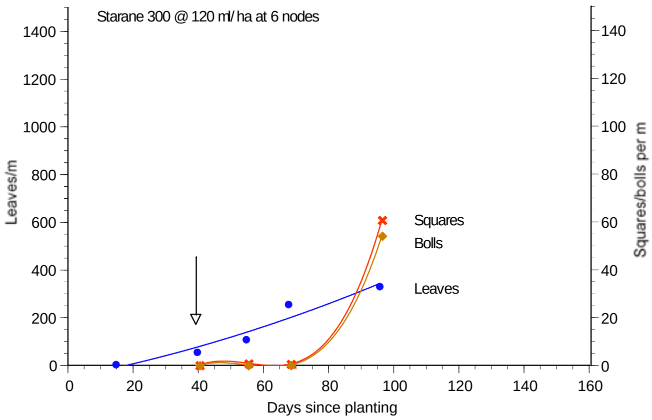
Starane® 300 applied broadcast at 120 ml/ha to 6 node cotton. Photo taken on 11th Dec, 29 days after exposure.

The typical signs of phenoxy damage were readily apparent at this stage. New leaves were twisted and distorted, often “wedge” shaped, ending in a row of short “fingers”.

Starane® 300 applied broadcast at 120 ml/ha to 6 node cotton. Photo taken on 2nd Jan, 51 days after exposure.

Plants had resumed normal growth by 51 days after exposure, although some crinkling of the leaf margins was still apparent on older leaves and distorted leaves could be found under the new outer leaves.





Impact on plant growth

Leaves: exposure to the 10% rate of fluroxypyr caused little initial damage to the crop.

Leaves which emerged after the herbicide exposure showed the typical symptoms of phenoxy damage, with the production of small, distorted, often "wedge" shaped leaves. Leaf area was reduced by 46% during early boll fill.

Squares: square production was delayed by about 30 days by the herbicide exposure, and most early squares were shed.

Bolls: bolls production was largely unaffected by this rate of fluroxypyr, but some early bolls were lost and few mature bolls were retained above node 19, on plants which were 5 nodes shorter than the undamaged plants on average.

Most later bolls were retained on lateral branches which developed after the herbicide exposure. There was an 11% reduction in the number of mature bolls at picking, and a 48% reduction in boll retention at nodes 10 – 20.

Final plant count data		
	Untreated	**Starane**
Nodes/plant	27.8	23.0
Leaves/m*	342	327
Leaf area (cm²/m)*	16870	9107
Reduction in leaf area*		46%
Bolls/m	176	156
Boll weight (g/boll)	4.8	4.1
Bolls/node (nodes 10-20)#	0.86	0.45
Days to 50% open	183	202
Maturity delay (days)		19
% Open bolls at picking	86%	88%
Lint yield/ha	2147	1310

Exposure to 10% of a typical field rate of fluroxypyr at 6 nodes initial caused some leaf yellowing and cupping. More obvious signs of damage became apparent later with extensive deformation on newly emerging leaves. There was a loss of early squares and bolls.

Plants compensated with new growth later in the season, setting a large number of late bolls. Mature bolls were retained to the top of the plant. Boll weight was reduced by 15%. There was a 19 day delay in crop maturity and a 39% yield loss.

Note* Leaf number and area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	**fluroxypyr**	**Damage key:**	
Rate:	**36 g a.i./ha**	**Leaf loss**	
% of typical field rate	**10%**	**Leaf distortion**	**x**
Date of exposure:	**5th Dec** (9 weeks post-emergence)	**Petiole distortion**	**x**
		Plant stunting	**x**
Growth stage at exposure:	**11 nodes**	**Square shedding**	**x**
		Boll shedding	**x**

Herbicidal action

Herbicide group: I
Translocation: readily moves to the plant growth points
Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production.
Residual activity: limited
Soil half-life: 11 - 38 days in moist soil

Starane® 300 applied broadcast at 120 ml/ha to 11 node cotton. Photo taken on 11th Dec, 6 days after exposure.

Initial symptoms of fluroxypyr damage were apparent after only a couple of days, with reddening of the stems, petiole twisting and bending, leaf cupping and some leaf discolouration and burning.

Starane® 300 applied broadcast at 120 ml/ha to 11 node cotton. Photo taken on 21st Dec, 16 days after exposure.

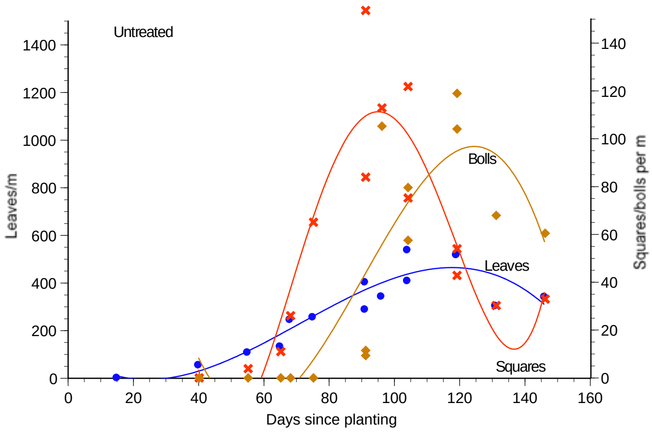
Initial symptoms of fluroxypyr damage were still very apparent 16 days after exposure, with reddening of the stems, petiole twisting and bending and some necrotic spots.

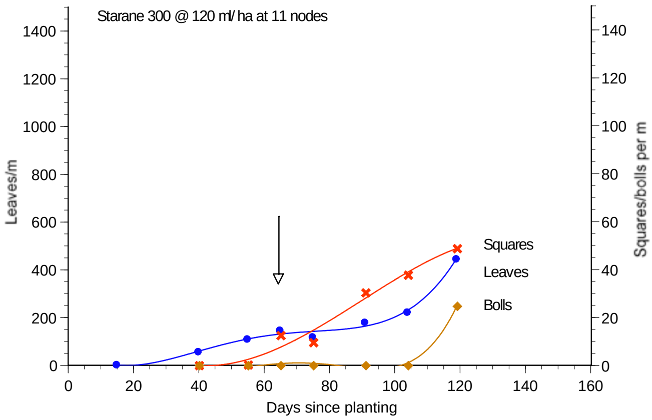
Starane® 300 applied broadcast at 120 ml/ha to 11 node cotton. Photo taken on 2nd Jan, 28 days after exposure.

Plants had resumed 'normal' growth 28 days after exposure. The more typical signs of phenoxy damage with leaf distortion etc. were not apparent at any stage.

Starane® 300 applied broadcast at 120 ml/ha to 11 node cotton. Photo taken on 14th Jan, 40 days after exposure.

Plants were growing normally, although distorted petioles and leaves could still be found at the base of the plant.





Impact on plant growth

Leaves: exposure to the 10% rate of fluroxypyr caused extensive initial damage to the crop, distorting petioles and misaligning the leaves, reducing the plant's effective photosynthetic area.

However, plants recovered relatively rapidly from the damage. By mid-season, leaf number and area were only 14% lower on the damaged plants compared to undamaged plants.

Squares: square production was delayed by over 30 days from the herbicide exposure, with most early squares being shed.

Bolls: damaged plants did not start to retain bolls before about 110 days after planting, a delay of around 40 days.

Final boll number was reduced by 43%, with a 30% reduction in retention of mature bolls on nodes 10 – 20. Mature bolls were retained to the top of the plant, but there was a 32 day delay in crop maturity.

Final plant count data		
	Untreated	**Starane**
Nodes/plant	27.8	23.5
Leaves/m*	517	443
Leaf area (cm²/m)*	10030	8634
Reduction in leaf area*		14%
Bolls/m	176	101
Boll weight (g/boll)	4.8	4.2
Bolls/node (nodes 10-20)#	0.86	0.60
Days to 50% open	183	215
Maturity delay (days)		32
% Open bolls at picking	86%	84%
Lint yield/ha	2147	843

Exposure to 10% of a typical field rate of fluroxypyr at 11 nodes caused extensive petiole distortion and a loss of many early squares. Plants compensated, producing new growth later in the season.

Most early season squares and bolls were shed. Late bolls were retained, but with reduced boll weight, a 32 day delay in crop maturity and a 61% loss in lint yield.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	**fluroxypyr**	
Rate:	**36 g a.i./ha**	
% of typical field rate	**10%**	
Date of exposure:	**2nd Jan** (13 weeks post-emergence)	
Growth stage at exposure:	**15 nodes**	

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily moves to the plant growth points
Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production.
Residual activity: limited
Soil half-life: 11 - 38 days in moist soil

Starane® 300 applied broadcast at 120 ml/ha to 15 node cotton. Photo taken on 4th Jan, 2 days after exposure.

Initial symptoms of fluroxypyr damage were apparent after only a couple of days, with petiole twisting and bending, misaligning many of the leaves.

This gave the plants a wilted appearance.

Starane® 300 applied broadcast at 120 ml/ha to 15 node cotton. Photo taken on 11th Jan, 9 days after exposure.

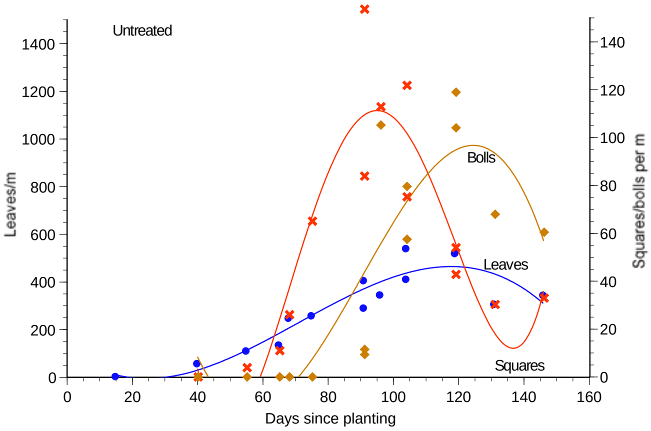
Initial symptoms of fluroxypyr damage were still very apparent, with reddening of the stems, and petiole twisting and bending.

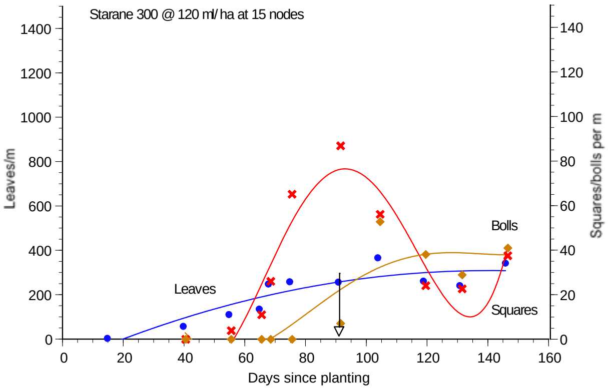
Starane® 300 applied broadcast at 120 ml/ha to 15 node cotton. Photo taken on 31st Jan, 29 days after exposure.

Plants had resumed normal growth 29 days after exposure. The more typical signs of phenoxy damage, including leaf distortion, were not apparent at any stage.

Starane® 300 applied broadcast at 120 ml/ha to 15 node cotton. Photo taken on 11th Feb, 40 days after exposure.

Plants were growing normally, although the last internodes were longer than normal.





Impact on plant growth

Leaves: exposure to the 10% rate of fluroxypyr caused reddening and bending of the stems and petioles, giving a wilted appearance.

The exposure had a relatively mild impact on leaf production, with no reduction in leaf number and a 16% reduction in leaf area due to a delay in crop growth and development.

Squares: plants shed some squares after the herbicide exposure, but compensated with increased square production later in the season.

Bolls: many early season bolls were shed in the weeks following the herbicide exposure, but the plants compensated, setting a late crop, with some mature bolls to the top of the plant. Nevertheless, the number of mature bolls retained at picking was reduced by 43% and average boll weight was reduced by 18%. Boll retention at nodes 10 – 20 was reduced by 40%.

Final plant count data		
	Untreated	**Starane**
Nodes/plant	27.8	32.0
Leaves/m*	341	339
Leaf area (cm²/m)*	19630	16461
Reduction in leaf area*		16%
Bolls/m	176	128
Boll weight (g/boll)	4.8	3.9
Bolls/node (nodes 10-20)#	0.86	0.40
Days to 50% open	183	203
Maturity delay (days)		20
% Open bolls at picking	86%	79%
Lint yield/ha	2147	865

Exposure to 10% of a typical field rate of fluroxypyr at 15 nodes caused petiole distortion and the loss of early squares. Plants compensated with new growth later in the season.

Many early season squares and bolls were shed. More late-season bolls were retained, with mature bolls retained to node 28, but with reduced boll weight, a 20 day delay in crop maturity and a 60% yield loss.

Note* Leaf number and leaf area were last recorded 55 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	**fluroxypyr**	
Rate:	**180 g a.i./ha**	
% of typical field rate	**50%**	
Date of exposure:	**12th Nov** (6 weeks post-emergence)	
Growth stage at exposure:	**6 nodes**	

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily moves to the plant growth points
Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production.
Residual activity: limited
Soil half-life: 11 - 38 days in moist soil

Starane® 300 applied broadcast at 600 ml/ha to 6 node cotton. Photo taken on 15th Nov, 3 days after exposure.

Initial symptoms of fluroxypyr damage were apparent after only 3 days, with reddening of the stems, petiole twisting and bending, leaf cupping and some leaf discolouration and burning.

Starane® 300 applied broadcast at 600 ml/ha to 6 node cotton. Photo taken on 22nd Nov, 10 days after exposure.

Initial symptoms of fluroxypyr damage were still apparent after 10 days, with reddening of the stems and petiole twisting and bending. New leaves were yellowed, cupped and distorted, with discoloured edges.

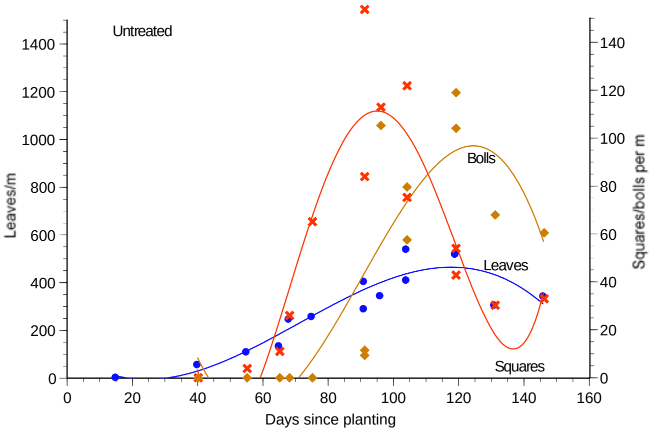
Starane® 300 applied broadcast at 600 ml/ha to 6 node cotton. Photo taken on 11th Dec, 29 days after exposure.

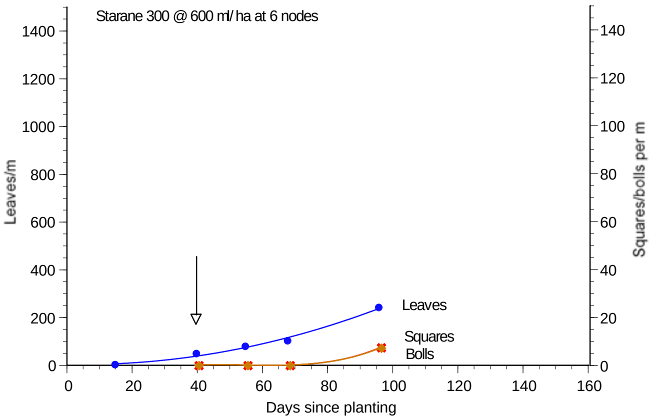
Initial symptoms of fluroxypyr damage were becoming less apparent, but new leaves were emerging, showing the typical signs of phenoxy damage. These leaves were distorted, often "wedge" shaped, ending in a row of short "fingers".

Starane® 300 applied broadcast at 600 ml/ha to 6 node cotton. Photo taken on 2nd Jan, 51 days after exposure.

The fluroxypyr damage was very obvious, with elongated internodes and distorted leaves which were twisted and leathery, with prominent veins.

By 25 Jan, 74 days after exposure, plants had resumed normal growth, although with a big delay in maturity and a reduction in lint yield.





Impact on plant growth

Leaves: exposure to the 50% rate of fluroxypyr initially caused reddening, bending and twisting of the petioles, giving a "crazy", wilted appearance. The damaged petioles remained bent throughout the life of the plant, although they were later overgrown by normal growth.

The secondary effect was on leaves that developed following the exposure, through the production of small, distorted, often "wedge" shaped leaves. Leaf number and leaf area were slow to recover on fluroxypyr damaged plants.

Squares: plants were very slow to recover from fluroxypyr damage with few squares produced in the first 100 days.

Bolls: bolls production was delayed, with most bolls produced on lateral branches and few mature bolls above node 15 on a very stunted plant. Relatively few bolls were retained on the first 3 positions on the main stem. The bolls which were retained were small.

Final plant count data		
	Untreated	**Starane**
Nodes/plant	27.8	18.7
Leaves/m*	342	239
Leaf area (cm²/m)*	16870	1542
Reduction in leaf area*		91%
Bolls/m	176	88
Boll weight (g/boll)	4.8	3.6
Bolls/node (nodes 10-20)#	0.86	0.28
Days to 50% open	183	222
Maturity delay (days)		39
% Open bolls at picking	86%	69%
Lint yield/ha	2147	962

Exposure to a 50% rate of fluroxypyr at 6 nodes caused extensive leaf deformation and a loss of leaves, squares and bolls through the middle of the season. Plants eventually compensated with new growth on lateral branches.

Some bolls were retained on these laterals, but with a 24% reduction in boll size, a 39 day delay in maturity and a 55% reduction in yield in a very long season.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	**fluroxypyr**	**Damage key:**	
Rate:	**180 g a.i./ha**	**Leaf loss**	
% of typical field rate	**50%**	**Leaf distortion**	**x**
Date of exposure:	**5th Dec (9 weeks post-emergence)**	**Petiole distortion**	**x**
		Plant stunting	**x**
Growth stage at exposure:	**11 nodes**	**Square shedding**	**x**
		Boll shedding	**x**

Herbicidal action

Herbicide group: I
Translocation: readily moves to the plant growth points
Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production.
Residual activity: limited
Soil half-life: 11 - 38 days in moist soil

Starane® 300 applied broadcast at 600 ml/ha to 11 node cotton. Photo taken on 11th Dec, 6 days after exposure.

Initial symptoms of fluroxypyr damage were apparent after only a couple of days, with reddening of the stems, petiole twisting and bending, leaf cupping and some leaf discolouration and burning.

Starane® 300 applied broadcast at 600 ml/ha to 11 node cotton. Photo taken on 21st Dec, 16 days after exposure.

Initial symptoms of fluroxypyr damage were still very apparent, with reddening of the stems, petiole twisting and bending and necrotic spots on the leaves.

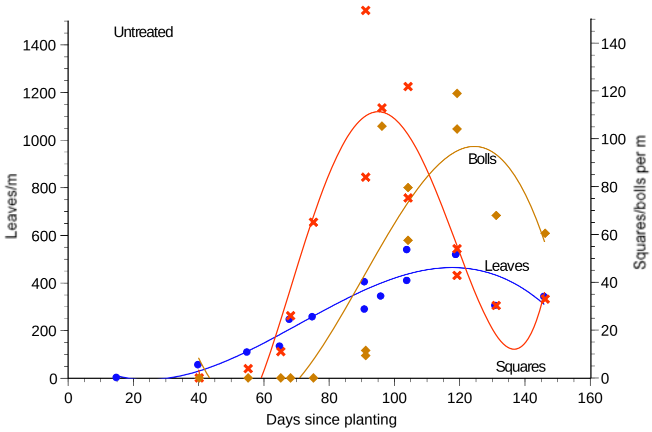
Starane® 300 applied broadcast at 600 ml/ha to 11 node cotton. Photo taken on 2nd Jan, 28 days after exposure.

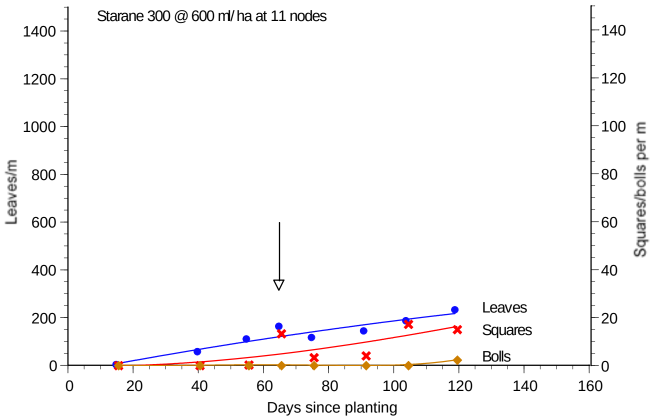
Plants have shown few changes over the time since exposure, with no new growth apparent 28 days after exposure. Fluroxypyr damage was still obvious as reddening of the stems, petiole twisting and bending and necrotic spots on the leaves.

Starane® 300 applied broadcast at 600 ml/ha to 11 node cotton. Photo taken on 14th Jan, 40 days after exposure.

Plants began to resume normal growth by 40 days after exposure, although damage was still readily apparent under the outer leaves. Surprisingly, few signs of typical phenoxy damage were observed.

By 25 Jan, 51 days after exposure, some plants had resumed normal growth, but many remain stunted and severely distorted.





Impact on plant growth

Leaves: exposure to the 50% rate of fluroxypyr caused reddening and extreme bending and twisting of the stems and petioles, giving a "crazy", wilted appearance. Plants were very slow to recover from this damage, which was readily apparent on some plants until around 70 days after exposure.

Leaf number and leaf area were severely affected, with leaf number down 56% and leaf area reduced by 53% compared to undamaged plants mid-season.

Squares: plants were very slow to recover from fluroxypyr damage with few squares produced in the first 120 days.

Bolls: bolls production was delayed, with most bolls produced on late developing lateral branches and few mature bolls retained on the main stem. The final boll count was reduced by 53%. Many of the bolls which were retained were small and immature. Of the boll retained, 30% fewer bolls were open at picking compared to undamaged plants.

Final plant count data

	Untreated	Starane
Nodes/plant	27.8	20.9
Leaves/m*	517	230
Leaf area (cm²/m)*	10030	4677
Reduction in leaf area*		53%
Bolls/m	176	66
Boll weight (g/boll)	4.8	3.6
Bolls/node (nodes 10-20)#	0.86	0.20
Days to 50% open	183	225
Maturity delay (days)		42
% Open bolls at picking	86%	61%
Lint yield/ha	2147	507

Exposure to a 50% rate of fluroxypyr at 11 nodes caused extensive crop damage, stopping plant growth and development for many weeks. Plants eventually compensated with new growth on lateral branches, but retained few bolls on any nodes. Average boll retention on nodes 10-20 was down by 77% and only 61% of bolls were open for a very late harvest.

Average boll weight was reduced by 24% and yield was down 76%, with a 42 day delay in crop maturity.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: fluroxypyr
Rate: 180 g a.i./ha
% of typical field rate 50%
Date of exposure: 2nd Jan (13 weeks post-emergence)
Growth stage at exposure: 15 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily moves to the plant growth points
Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production.
Residual activity: limited
Soil half-life: 11 - 38 days in moist soil

Starane® 300 applied broadcast at 600 ml/ha to 15 node cotton. Photo taken on 4th Jan, 2 days after exposure.

Symptoms of fluroxypyr damage were apparent after only a couple of days, with petiole reddening, twisting and bending. Most exposed leaves were mis-orientated, giving the crop a wilted appearance.

Starane® 300 applied broadcast at 600 ml/ha to 15 node cotton. Photo taken on 11th Jan, 9 days after exposure.

Symptoms of fluroxypyr damage had intensified by 9 days, with twisting and reddening of the stems and petioles, and some reddening of the squares and backs of the leaves.

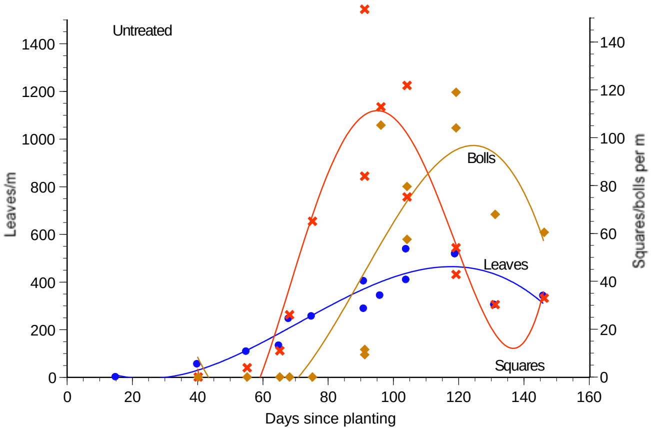
Starane® 300 applied broadcast at 600 ml/ha to 15 node cotton. Photo taken on 31st Jan, 29 days after exposure.

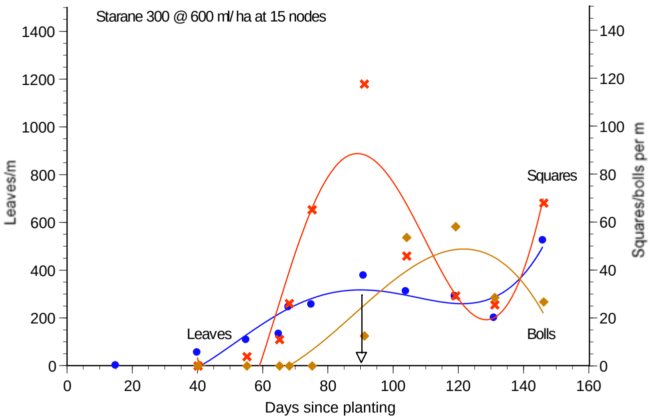
Plants showed few changes over the 29 days since exposure, with no new growth apparent. Fluroxypyr damage was still obvious as reddening of the stems and petiole twisting and bending.

Starane® 300 applied broadcast at 600 ml/ha to 15 node cotton. Photo taken on 11th Feb, 40 days after exposure.

Plants have shown few changes over the time since exposure, with no new growth apparent. Damage was still obvious as reddening of the stems and petiole twisting and bending. Surprisingly, few signs of typical phenoxy damage were observed.

By 3rd Mar, 60 days after exposure, plants have resumed normal growth.





Impact on plant growth

Leaves: exposure to the 50% rate of fluroxypyr caused reddening and extreme bending and twisting of the stems and petioles, giving a "crazy", wilted appearance. Plants were slow to recover from this damage.

Plants had begun to compensate by 55 days after exposure, producing a large number of new, highly distorted, wedge shaped leaves. This resulted in a large increase in leaf number, but not as large an increase in leaf area.

Squares: plants shed a large proportion of squares after the herbicide exposure, but compensated with increased square production later in the season.

Bolls: most bolls were shed in the weeks following the herbicide. Only 56 bolls/m were present at picking, a reduction of 72%, and many of these bolls were small and immature. Average boll weight was reduced by 21%, with only 15 mature bolls/m present at picking, a 92% reduction compared to undamaged plants.

Final plant count data

	Untreated	**Starane**
Nodes/plant	27.8	20.4
Leaves/m*	341	524
Leaf area (cm^2/m)*	19630	15350
Reduction in leaf area*		22%
Bolls/m	176	15
Boll weight (g/boll)	4.8	3.8
Bolls/node (nodes 10-20)#	0.86	0.17
Days to 50% open	183	200
Maturity delay (days)		17
% Open bolls at picking	86%	26%
Lint yield/ha	2147	120

A 50% rate of fluroxypyr at 15 nodes caused extensive damage to exposed plants, causing reddening, bending and twisting of the leaves and petioles.

Plants were unable to compensate for damage at this stage in the season, retaining few late squares and bolls. This lead to a large decrease in the number of mature bolls open at picking. Lint yield was reduced by 94%.

Note* Leaf number and leaf area were last recorded 55 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	glufosinate
Rate:	75 g a.i./ha
% of typical field rate	10%
Date of exposure:	12^{th} Nov (6 weeks post-emergence)
Growth stage at exposure:	6 nodes

Damage key:	
Leaf loss	x
Leaf distortion	
Petiole distortion	
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: N
Translocation: poorly translocated within the plant
Mode of action: inhibits glutamine production, resulting in an accumulation of ammonia which inhibits photosynthesis and destroys cells
Residual activity: almost none due to rapid microbial breakdown in the soil
Soil half-life: 7 days

Liberty 200 applied broadcast at 375 ml/ha to 6 node cotton. Photo taken on 15^{th} Nov, 3 days after exposure.

A few burn marks with necrotic spots on some leaves were the only symptoms of glufosinate damage from the 10% rate.

Liberty 200 applied broadcast at 375 ml/ha to 6 node cotton. Photo taken on 22^{nd} Nov, 10 days after exposure.

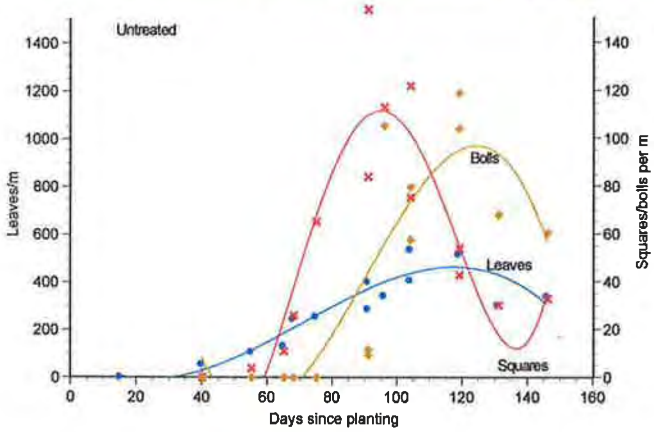
By 10 days, new undamaged leaves had emerged and glufosinate damage was only visible on the older leaves.

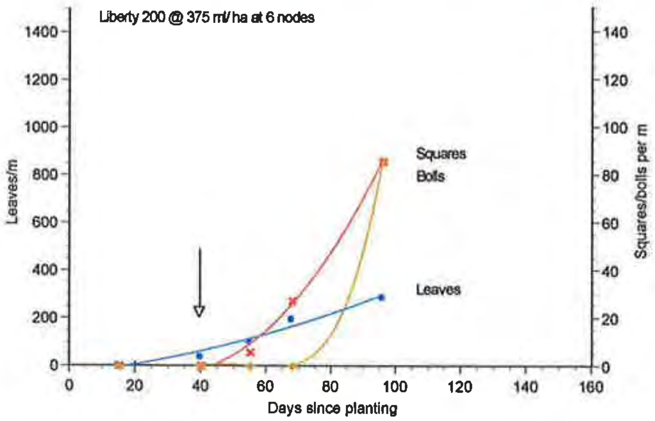
Liberty 200 applied broadcast at 375 ml/ha to 6 node cotton. Photo taken on 11^{th} Dec, 29 days after exposure.

Plants had resumed normal growth by 29 days after exposure and there were no signs of the herbicide damage.

Liberty 200 applied broadcast at 375 ml/ha to 6 node cotton. Photo taken on 2nd Jan, 51 days after exposure.

Plants were growing normally.





Impact on plant growth

Leaves: exposure to a 10% rate of glufosinate caused mild leaf damage, causing a few necrotic spots on the leaves.

Plants were more affected than was indicated by the mild damage symptoms, with a 23% reduction in leaf area 56 days after exposure. Leaves developed normally following the herbicide.

Squares: glufosinate damage caused only a very small delay in early square production. Peak squaring was little affected.

Bolls: boll production and retention were largely unaffected by the herbicide, with mature bolls retained to node 30, five nodes more than the untreated plants.

Final plant count data		
	Untreated	**glufosinate**
Nodes/plant	27.8	29.8
Leaves/m*	342	284
Leaf area (cm²/m)*	16870	13034
Reduction in leaf area*		23%
Bolls/m	176	180
Boll weight (g/boll)	4.8	4.9
Bolls/node (nodes 10-20)#	0.86	1.10
Days to 50% open	183	185
Maturity delay (days)		2
% Open bolls at picking	86%	88%
Lint yield/ha	2147	1967

Exposure to 10% of a typical field rate of glufosinate at 6 nodes resulted in a few necrotic spots on the leaves, but plants quickly recovered from this damage.

Glufosinate caused no reduction in boll number or weight. Boll retention on nodes 10 - 20 was also unaffected.

There was no appreciable delay in crop maturity or loss of yield.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: glufosinate
Rate: 75 g a.i./ha
% of typical field rate 10%
Date of exposure: 5th Dec (9 weeks post-emergence)
Growth stage at exposure: 11 nodes

Damage key:	
Leaf loss	x
Leaf distortion	
Petiole distortion	
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: N
Translocation: poorly translocated within the plant
Mode of action: inhibits glutamine production, resulting in an accumulation of ammonia which inhibits photosynthesis and destroys cells
Residual activity: almost none due to rapid microbial breakdown in the soil
Soil half-life: 7 days

Liberty 200 applied broadcast at 375 ml/ha to 11 node cotton. Photo taken on 11th Dec, 6 days after exposure.

Symptoms of glufosinate damage were readily apparent, with necrotic spots and dead areas on the leaves.

Liberty 200 applied broadcast at 375 ml/ha to 11 node cotton. Photo taken on 14th Dec, 9 days after exposure.

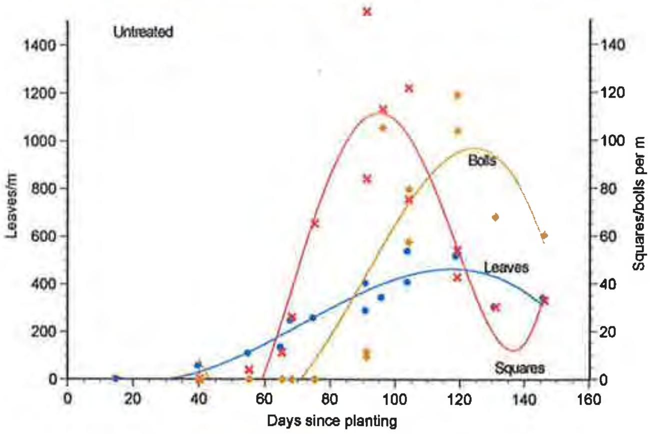
By 9 days, most damaged leaves had died, but new, undamaged leaves were emerging.

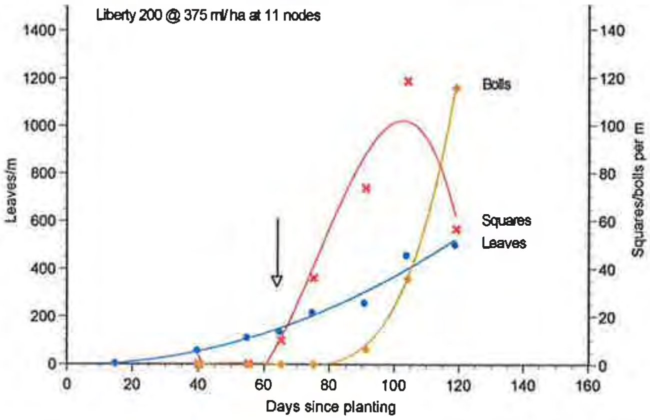
Liberty 200 applied broadcast at 375 ml/ha to 11 node cotton. Photo taken on 21st Dec, 16 days after exposure.

Plants had resumed normal growth.

Liberty 200 applied broadcast at 375 ml/ha to 11 node cotton. Photo taken on 2nd Jan, 28 days after exposure.

Plants were growing normally.





Impact on plant growth

Leaves: exposure to a 10% rate of glufosinate caused moderate leaf damage, killing a small number on exposed leaves.

Surviving plants rapidly recovered with no reduction in leaf number or leaf area mid-season.

Squares: glufosinate damage had almost no impact on early square production and delayed peak squaring by only about 10 days.

Bolls: boll production and retention were largely unaffected by the herbicide, with mature bolls retained to node 25. All aspects of boll production were similar to the undamaged plants.

Final plant count data		
	Untreated	**glufosinate**
Nodes/plant	27.8	28.5
Leaves/m*	517	497
Leaf area (cm²/m)*	10030	10227
Reduction in leaf area*		-2%
Bolls/m	176	185
Boll weight (g/boll)	4.8	4.7
Bolls/node (nodes 10-20)#	0.86	0.83
Days to 50% open	183	187
Maturity delay (days)		4
% Open bolls at picking	86%	84%
Lint yield/ha	2147	1800

Exposure to 10% of a typical field rate of glufosinate at 11 nodes caused some leaf damage and partially defoliated the plants, but they quickly recovered.

Glufosinate at this rate had only a small negative impact on square and boll production.

A 16% reduction in lint yield was recorded.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	glufosinate
Rate:	75 g a.i./ha
% of typical field rate	10%
Date of exposure:	2nd Jan (13 weeks post-emergence)
Growth stage at exposure:	15 nodes

Damage key:	
Leaf loss	x
Leaf distortion	
Petiole distortion	
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: N
Translocation: poorly translocated within the plant
Mode of action: inhibits glutamine production, resulting in an accumulation of ammonia which inhibits photosynthesis and destroys cells
Residual activity: almost none due to rapid microbial breakdown in the soil
Soil half-life: 7 days

Liberty 200 applied broadcast at 375 ml/ha to 15 node cotton. Photo taken on 4th Jan, 2 days after exposure.

Minor symptoms of glufosinate damage were apparent, with some bleached areas visible on the leaves.

Liberty 200 applied broadcast at 375 ml/ha to 15 node cotton. Photo taken on 7th Jan, 5 days after exposure.

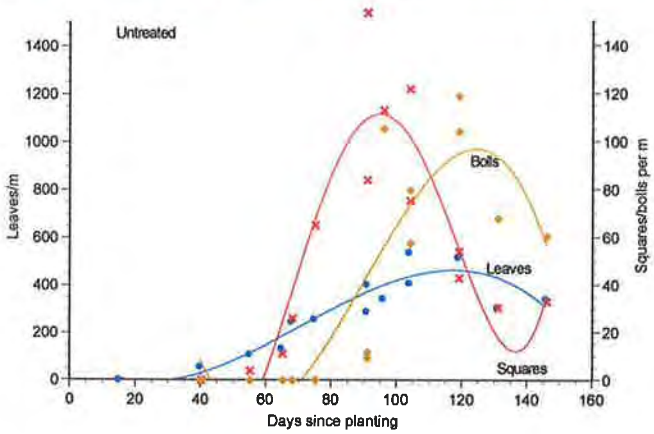
By 5 days, necrotic spots and patches were obvious on some leaves. A few leaves were completely dead.

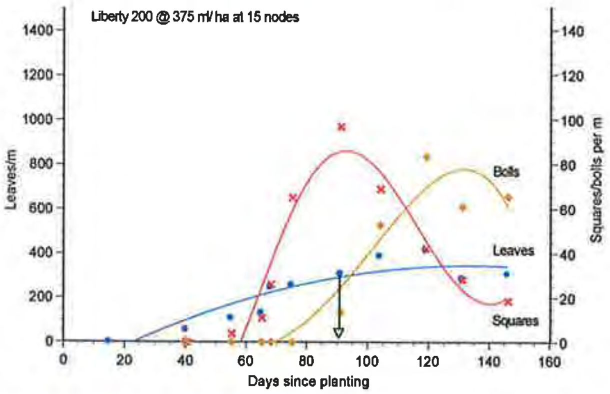
Liberty 200 applied broadcast at 375 ml/ha to 15 node cotton. Photo taken on 14th Jan, 12 days after exposure.

Necrotic spots were still visible on many leaves, but new leaves were emerging and plants were resuming normal growth.

Liberty 200 applied broadcast at 375 ml/ha to 15 node cotton. Photo taken on 31st Jan, 29 days after exposure.

Plants were growing normally, although necrotic spots were present on most lower leaves.





Impact on plant growth

Leaves: exposure to a 10% rate of glufosinate caused some leaf damage, killing a small number on exposed leaves.

Plants appeared to rapidly recover from the damage, but had a 16% reduction in leaf number and a 22% reduction in leaf area 55 days after exposure.

Squares: glufosinate damage caused a small reduction in peak square number.

Bolls: the herbicide also had a small impact on boll production and retention. There was no reduction in the total boll number at the end of the season and only a 9% reduction in the number of mature bolls, with mature bolls retained to node 25. All aspects of boll production were similar to the undamaged plants.

Final plant count data

	Untreated	glufosinate
Nodes/plant	27.8	27.7
Leaves/m*	341	305
Leaf area (cm²/m)*	19630	15261
Reduction in leaf area*		22%
Bolls/m	176	160
Boll weight (g/boll)	4.8	4.7
Bolls/node (nodes 10-20)#	0.86	0.60
Days to 50% open	183	181
Maturity delay (days)		-
% Open bolls at picking	86%	76%
Lint yield/ha	2147	1866

Exposure to 10% of a typical field rate of glufosinate caused some leaf damage and partially defoliated the plants, but they quickly recovered.

Glufosinate at this rate had only a small negative impact on square and boll production. Boll retention on nodes 10 - 20 was reduced by 31%, but the plants compensated by retaining more bolls on the higher branches.

A 13% reduction in lint yield was recorded, with no delay in maturity.

Note* Leaf number and leaf area were last recorded 55 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by:

Graham Charles
NSW Dept of Primary Industries

Herbicide:	**glufosinate**
Rate:	**375 g a.i./ha**
% of typical field rate	**50%**
Date of exposure:	**12th Nov** (6 weeks post-emergence)
Growth stage at exposure:	**6 nodes**

Damage key:

Leaf loss	x
Leaf distortion	
Petiole distortion	
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: N
Translocation: poorly translocated within the plant
Mode of action: inhibits glutamine production, resulting in an accumulation of ammonia which inhibits photosynthesis and destroys cells
Residual activity: almost none due to rapid microbial breakdown in the soil
Soil half-life: 7 days

Liberty 200 applied broadcast at 1.875 L/ha to 6 node cotton. Photo taken on 15th Nov, 3 days after exposure.

Symptoms of glufosinate damage were readily apparent, with necrotic areas on most leaves. Some leaves are completely desiccated.

Liberty 200 applied broadcast at 1.875 L/ha to 6 node cotton. Photo taken on 22nd Nov, 10 days after exposure.

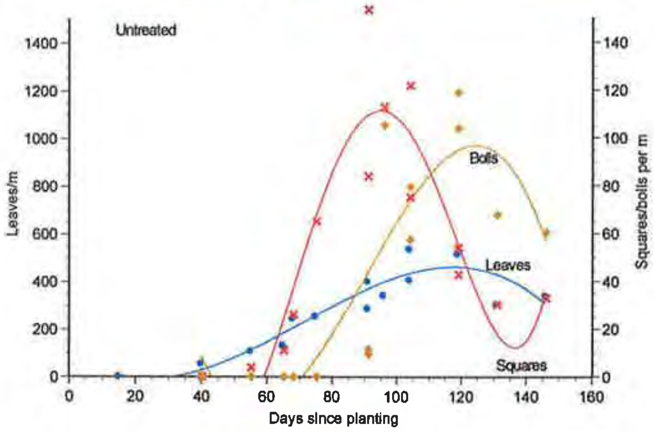
By 10 days, most damaged leaves had died, but a few new undamaged leaves have emerged.

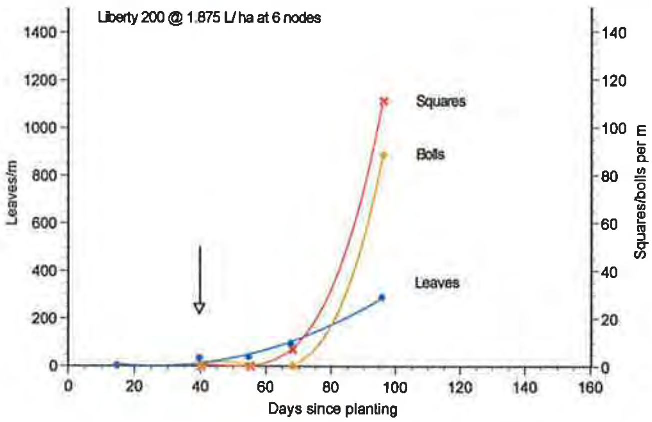
Liberty 200 applied broadcast at 1.875 L/ha to 6 node cotton. Photo taken on 11th Dec, 29 days after exposure.

Plants had resumed normal growth by 29 days after exposure.

Liberty 200 applied broadcast at 1.875 L/ha to 6 node cotton. Photo taken on 2nd Jan, 51 days after exposure.

Plants were growing normally.





Impact on plant growth

Leaves: exposure to a 50% rate of glufosinate caused extensive leaf damage, killing a large proportion on exposed leaves and some plants.

Surviving plants rapidly recovered, but there was still a 16% reduction in leaf number and a 38% reduction in leaf area mid-season.

Squares: glufosinate damage delayed early square production by around 15 days, but peak squaring was little affected.

Bolls: boll production and boll retention was largely unaffected by the herbicide, with mature bolls retained to node 27.

However, many of these bolls were not pickable, resulting in a large yield loss.

Final plant count data		
	Untreated	**glufosinate**
Nodes/plant	27.8	27.5
Leaves/m*	342	287
Leaf area (cm²/m)*	16870	10515
Reduction in leaf area*		38%
Bolls/m	176	155
Boll weight (g/boll)	4.8	5.3
Bolls/node (nodes 10-20)#	0.86	0.94
Days to 50% open	183	195
Maturity delay (days)		12
% Open bolls at picking	86%	74%
Lint yield/ha	2147	919

Exposure to 50% of a typical field rate of glufosinate at 6 nodes defoliated most plants, but they quickly recovered.

Glufosinate caused a 12% reduction in boll number but no reduction in boll size. Boll retention on nodes 10 - 20 was also not reduced.

There was a 12 day delay in crop maturity, with many bolls not fully open at picking. This resulted in a 57% reduction in yield.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: **Graham Charles**
NSW Dept of Primary Industries

Herbicide: glufosinate
Rate: 375 g a.i./ha
% of typical field rate 50%
Date of exposure: 5th Dec
(9 weeks post-emergence)
Growth stage at exposure: 11 nodes

Damage key:	
Leaf loss	x
Leaf distortion	
Petiole distortion	
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: N
Translocation: poorly translocated within the plant
Mode of action: inhibits glutamine production, resulting in an accumulation of ammonia which inhibits photosynthesis and destroys cells
Residual activity: almost none due to rapid microbial breakdown in the soil
Soil half-life: 7 days

Liberty 200 applied broadcast at 1.875 L/ha to 11 node cotton. Photo taken on 11th Dec, 6 days after exposure.

Symptoms of glufosinate damage wre readily apparent, with dead areas on many of the leaves.

Liberty 200 applied broadcast at 1.875 L/ha to 11 node cotton. Photo taken on 14th Dec, 9 days after exposure.

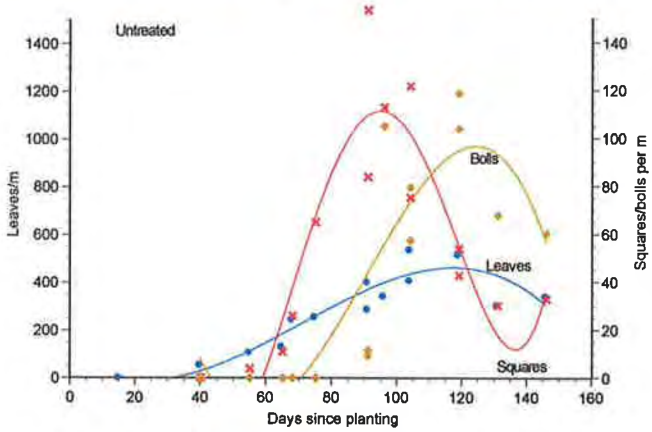
By 9 days, most damaged leaves had died, but new, undamaged leaves were emerging.

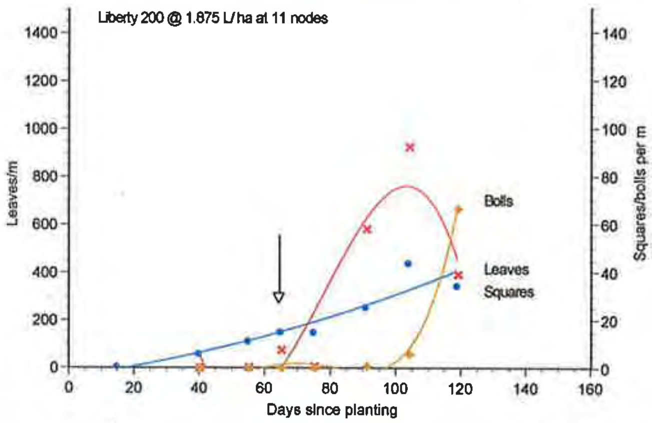
Liberty 200 applied broadcast at 1.875 L/ha to 11 node cotton. Photo taken on 21st Dec, 16 days after exposure.

Plants had resumed normal growth 16 days after exposure.

Liberty 200 applied broadcast at 1.875 L/ha to 11 node cotton. Photo taken on 2nd Jan, 28 days after exposure.

Plants were stunted, compared to undamaged plants, but were growing normally.





Impact on plant growth

Leaves: exposure to a 50% rate of glufosinate caused extensive leaf damage, killing a proportion on exposed leaves.

Surviving plants rapidly recovered. By mid-season plants had 34% fewer leaves than undamaged plants, but had 10% more leaf area.

Squares: glufosinate damage caused little delay to early square production, but caused a big reduction in peak squaring.

Bolls: boll production and retention were delayed by around 20 days by the herbicide. There was a reduction in the final number of mature bolls retained, boll weight and a delay in boll maturity. Mature bolls were retained to node 27, 2 nodes higher than the undamaged plants.

Final plant count data		
	Untreated	**glufosinate**
Nodes/plant	27.8	29.6
Leaves/m*	517	339
Leaf area (cm²/m)*	10030	11077
Reduction in leaf area*		-
Bolls/m	176	142
Boll weight (g/boll)	4.8	4.0
Bolls/node (nodes 10-20)#	0.86	0.61
Days to 50% open	183	203
Maturity delay (days)		20
% Open bolls at picking	86%	88%
Lint yield/ha	2147	1144

Exposure to 50% of a typical field rate of glufosinate at 11 nodes defoliated many plants, but they quickly recovered, developing an increased leaf area.

Glufosinate caused a 19% reduction in boll number and 16% reduction in boll weight. Boll retention on nodes 10 - 20 was also reduced by 29%.

There was a 20 day delay in crop maturity and 47% reduction in yield.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: glufosinate
Rate: 375 g a.i./ha
% of typical field rate 50%
Date of exposure: 2nd Jan (13 weeks post-emergence)
Growth stage at exposure: 15 nodes

Damage key:	
Leaf loss	x
Leaf distortion	
Petiole distortion	
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: N
Translocation: poorly translocated within the plant
Mode of action: inhibits glutamine production, resulting in an accumulation of ammonia which inhibits photosynthesis and destroys cells
Residual activity: almost none due to rapid microbial breakdown in the soil
Soil half-life: 7 days

Liberty 200 applied broadcast at 1.875 L/ha to 15 node cotton. Photo taken on 4th Jan, 2 days after exposure.

Symptoms of glufosinate damage at this stage appear as bleached patches on the leaves.

Liberty 200 applied broadcast at 1.875 L/ha to 15 node cotton. Photo taken on 7th Jan, 5 days after exposure.

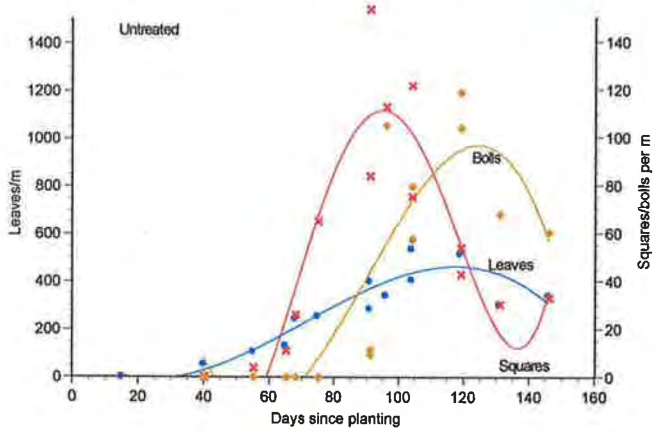
By 5 days, necrotic patches were obvious on most leaves, although few leaves were completely dead.

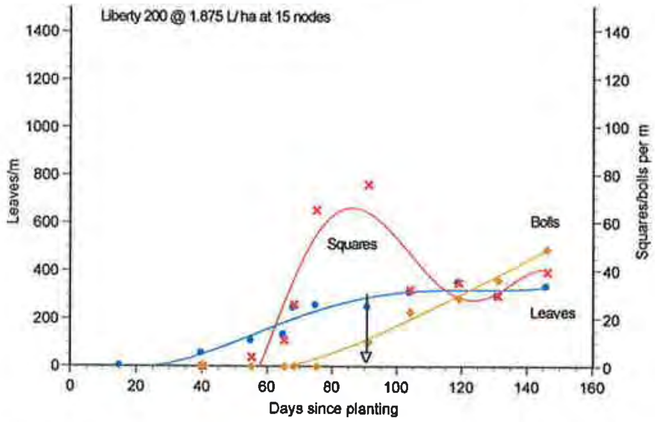
Liberty 200 applied broadcast at 1.875 L/ha to 15 node cotton. Photo taken on 14th Jan, 12 days after exposure.

Most damaged leaves have died by 12 days after exposure, but new leaves are emerging and plants are resuming normal growth.

Liberty 200 applied broadcast at 1.875 L/ha to 15 node cotton. Photo taken on 31st Jan, 29 days after exposure.

Plants are growing normally although dead leaves can still be found under the surface layer of leaves.





Impact on plant growth

Leaves: exposure to a 50% rate of glufosinate at 15 nodes caused some leaf damage, killing a proportion on exposed leaves.

Plants rapidly recover from this damage, but there was a big reduction in leaf number 30 days after exposure. Plants had recovered by 55 days after exposure to have only 3% fewer leaves than undamaged plants, and 14% less leaf area.

Squares: glufosinate damage caused little delay to early square production, but caused a big reduction in peak squaring. Plants compensated, producing more squares later in the season.

Bolls: boll production and retention were greatly delayed by the herbicide. There was a 53% reduction in final boll retention and a 50% reduction in the retention of mature bolls. Mature bolls were retained to node 25, with a uniform reduction in the number of bolls at each node compared to undamaged plants.

Final plant count data

	Untreated	glufosinate
Nodes/plant	27.8	28.7
Leaves/m*	341	332
Leaf area (cm²/m)*	19630	16788
Reduction in leaf area*		14%
Bolls/m	176	88
Boll weight (g/boll)	4.8	4.0
Bolls/node (nodes 10-20)#	0.86	0.43
Days to 50% open	183	211
Maturity delay (days)		28
% Open bolls at picking	86%	91%
Lint yield/ha	2147	1010

Exposure to 50% of a typical field rate of glufosinate caused some defoliation the plants, but they appeared to quickly recover from this damage.

However, glufosinate caused a 50% reduction in boll number and 17% reduction in boll weight. Boll retention on nodes 10 - 20 was reduced by 50%.

There was a 28 day delay in crop maturity and 53% reduction in yield.

Note* Leaf number and leaf area were last recorded 55 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: glyphosate
Rate: 35 g a.i./ha
% of typical field rate 3%
Date of exposure: 12 Dec
(4 weeks post-emergence)
Growth stage at exposure: 6 nodes

Damage key:
Leaf loss
Leaf distortion
Petiole distortion
Plant stunting
Square shedding
Boll shedding

Herbicidal action

Herbicide group: M
Translocation: moves throughout the plant to growth points
Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis.
Residual activity: none
Soil half-life: 47 days in moist soil

Roundup Ready Herbicide applied broadcast at 50 g/ha to 6 node cotton. Photo taken on 5 Jan, 24 days after exposure.

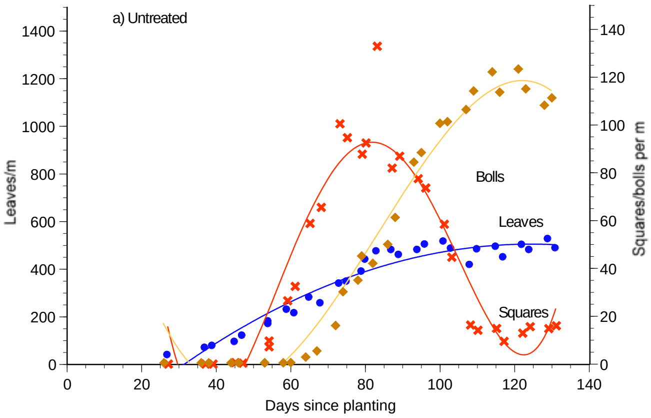
There were no visual symptoms of herbicide damage at this time.

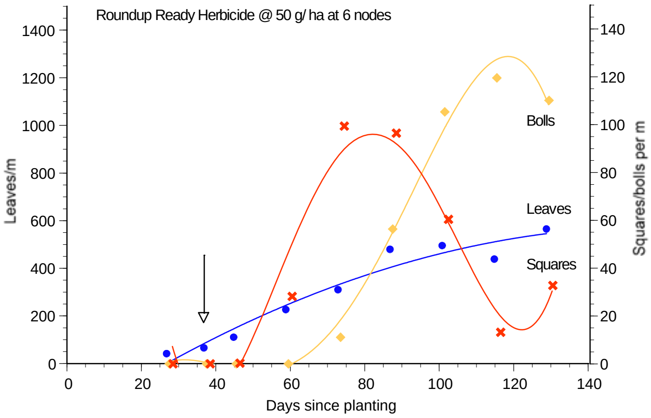
Roundup Ready Herbicide applied broadcast at 50 g/ha to 6 node cotton. Photo taken on 5 Jan, 24 days after exposure.

Roundup Ready Herbicide applied broadcast at 50 g/ha to 6 node cotton. Photo taken on 24 Mar, 102 days after exposure.

There were no visible symptoms of herbicide damage on these plants, which looked identical to the untreated plants.

Roundup Ready Herbicide applied broadcast at 50 g/ha to 6 node cotton. Photo taken on 24 Mar, 102 days after exposure.





Impact on plant growth

Leaves: the herbicide exposure had no effect on leaf shape or orientation, but did result in a 12% increase in leaf number. However, the increased leaf number did not compensate for a decrease in leaf size, resulting in a 15% reduction in total leaf area.

Squares: the herbicide had no measurable effect on square production.

Bolls: the herbicide had no negative effect on boll production.

Final plant count data		
	Untreated	**glyphosate**
Nodes/plant	21.5	22.1
Leaves/m	502	562
Light interception	87%	89%
Leaf area (cm²/m)	22921	19379
Bolls/m	114	110
Boll weight (g/boll)	4.4	4.7
Days to 50% open	154	154
% Open bolls at picking	82%	91%
Lint yield/ha	1649	1684

Exposure of a 6 node cotton plant to Roundup Ready Herbicide at 50 g/ha caused no measurable negative effects. The plant was able to compensate for any negative effects caused by the herbicide, resulting in no delay in maturity or reduction in yield.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: glyphosate
Rate: 35 g a.i./ha
% of typical field rate 3%
Date of exposure: 21st Dec (5½ weeks post-emergence)
Growth stage at exposure: 8 nodes

Damage key:
Leaf loss
Leaf distortion
Petiole distortion
Plant stunting
Square shedding
Boll shedding

Herbicidal action

Herbicide group: M
Translocation: moves throughout the plant to growth points
Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis.
Residual activity: none
Soil half-life: 47 days in moist soil

Roundup Ready Herbicide applied broadcast at 50 g/ha to 8 node cotton. Photo taken on 5th Jan, 15 days after exposure.

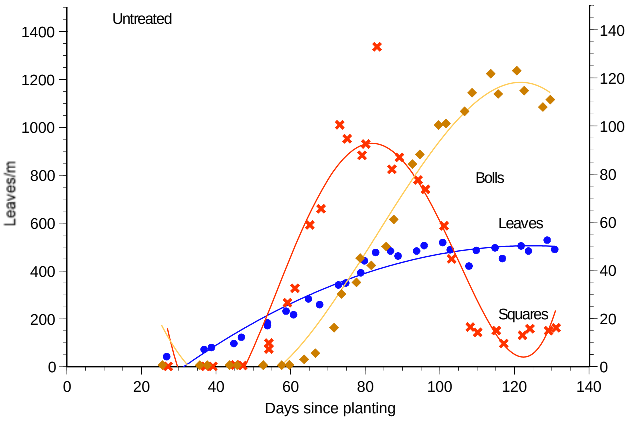
There were no visual symptoms of herbicide damage at this time.

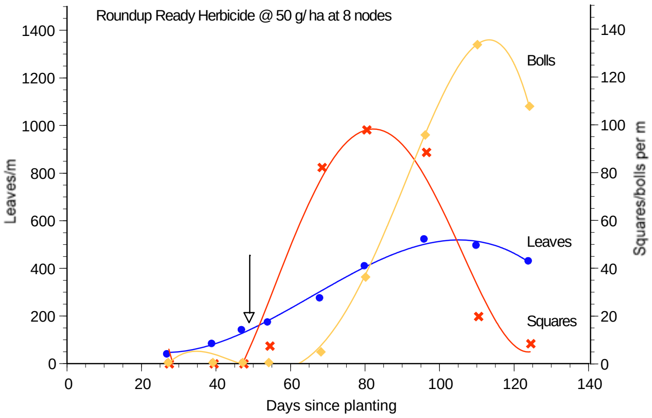
Roundup Ready Herbicide applied broadcast at 50 g/ha to 8 node cotton. Photo taken on 5th Jan, 15 days after exposure.

Roundup Ready Herbicide applied broadcast at 50 g/ha to 8 node cotton. Photo taken on 24th Mar, 93 days after exposure.

There were no visible symptoms of herbicide damage on these plants, which looked identical to the untreated plants.

Roundup Ready Herbicide applied broadcast at 50 g/ha to 8 node cotton. Photo taken on 24th Mar, 93 days after exposure.





Impact on plant growth

Leaves: the herbicide had no effect on leaf shape or orientation, but did reduce leaf number by 17% and leaf area by 12%,.

Squares: the herbicide exposure had no observable impact on squaring.

Bolls: the herbicide exposure had no observable impact on crop yield, although average boll size was reduced by 18%.

Final plant count data		
	Untreated	**glyphosate**
Nodes/plant	21.5	21.3
Leaves/m	502	429
Light interception	87%	86%
Leaf area (cm²/m)	22921	20207
Bolls/m	114	107
Boll weight (g/boll)	4.4	3.6
Days to 50% open	154	156
% Open bolls at picking	82%	83%
Lint yield/ha	1649	1592

Exposure of an 8 node cotton plant to Roundup Ready Herbicide at 50 g/ha caused a small decrease in leaf number and boll size, but didn't delay crop maturity or reduce lint yield.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: glyphosate
Rate: 35 g a.i./ha
% of typical field rate 3%
Date of exposure: 4th Jan (7½ weeks post-emergence)
Growth stage at exposure: 12 nodes

Damage key:
Leaf loss
Leaf distortion
Petiole distortion
Plant stunting
Square shedding
Boll shedding

Herbicidal action

Herbicide group: M
Translocation: moves throughout the plant to growth points
Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis.
Residual activity: none
Soil half-life: 47 days in moist soil

Roundup Ready Herbicide applied broadcast at 50 g/ha to 12 node cotton. Photo taken on 25th Jan, 21 days after exposure.

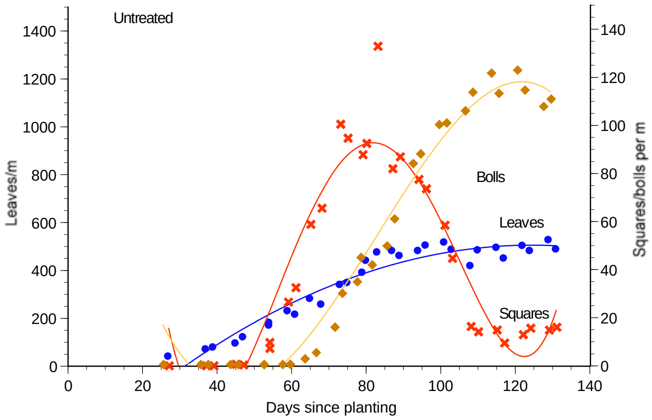
There were no visual symptoms of herbicide damage at this time.

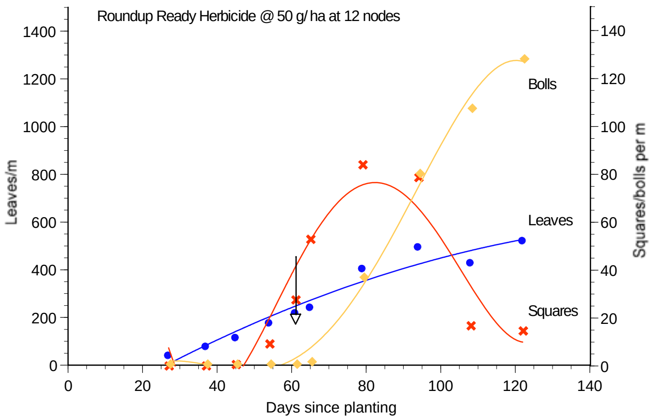
Roundup Ready Herbicide applied broadcast at 50 g/ha to 12 node cotton. Photo taken on 25th Jan, 21 days after exposure.

Roundup Ready Herbicide applied broadcast at 50 g/ha to 12 node cotton. Photo taken on 24th Mar, 79 days after exposure.

There were no visible symptoms of herbicide damage on these plants, which looked identical to the untreated plants.

Roundup Ready Herbicide applied broadcast at 50 g/ha to 12 node cotton. Photo taken on 24th Mar, 79 days after exposure.





Impact on plant growth

Leaves: the glyphosate exposure at 12 nodes had no effect of leaf number, shape, size or orientation.

Squares: the plant shed some squares following the glyphosate exposure, but peak squaring was not delayed.

Bolls: the glyphosate exposure had no effect on boll retention, but did reduce average boll size and delayed crop maturity by 15 days.

Final plant count data		
	Untreated	**glyphosate**
Nodes/plant	21.5	20.9
Leaves/m	502	519
Light interception	87%	89%
Leaf area (cm²/m)	22921	22519
Bolls/m	114	128
Boll weight (g/boll)	4.4	3.7
Days to 50% open	154	169
% Open bolls at picking	82%	67%
Lint yield/ha	1649	1655

Exposure of a 12 node cotton plant to Roundup Ready Herbicide at 50 g/ha had little impact on the plant.

The herbicide exposure reduced average boll size and delaying crop maturity, but did not reduce lint yield.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: glyphosate
Rate: 35 g a.i./ha
% of typical field rate 3%
Date of exposure: 24th Jan
(10½ weeks post-emergence)
Growth stage at exposure: 16 nodes

Damage key:
Leaf loss
Leaf distortion
Petiole distortion
Plant stunting
Square shedding
Boll shedding

Herbicidal action

Herbicide group: M
Translocation: moves throughout the plant to growth points
Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis.
Residual activity: none
Soil half-life: 47 days in moist soil

Roundup Ready Herbicide applied broadcast at 50 g/ha to 16 node cotton. Photo taken on 10th Feb, 17 days after exposure.

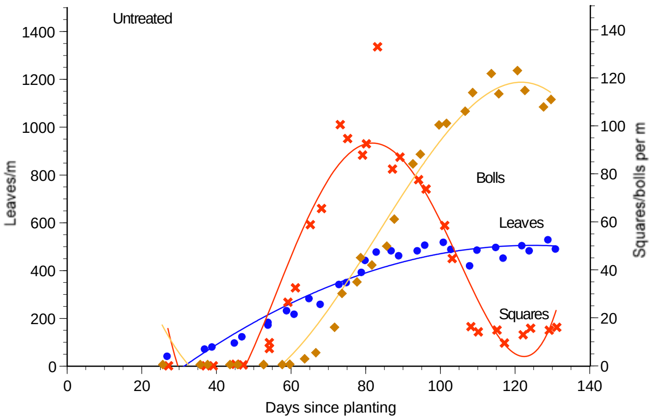
There were no visual symptoms of herbicide damage at this time.

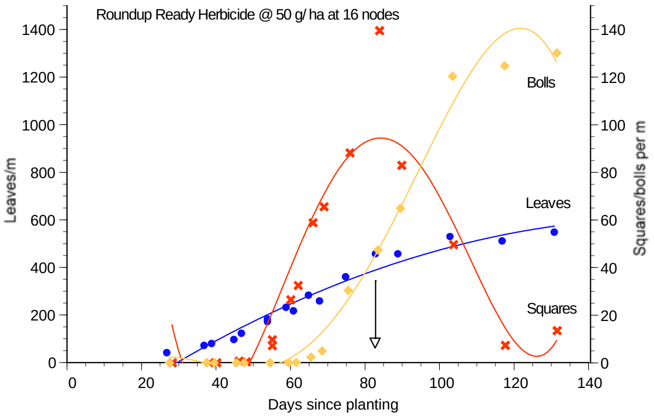
Roundup Ready Herbicide applied broadcast at 250 g/ha to 16 node cotton. Photo taken on 10th Feb, 17 days after exposure.

Roundup Ready Herbicide applied broadcast at 250 g/ha to 16 node cotton. Photo taken on 24th Mar, 59 days after exposure.

There were no visible symptoms of herbicide damage on these plants, which looked identical to the untreated plants.

Roundup Ready Herbicide applied broadcast at 250 g/ha to 16 node cotton. Photo taken on 24th Mar, 59 days after exposure.





Impact on plant growth

Leaves: the glyphosate exposure at 16 nodes had no impact on leaf number, shape or orientation, but did reduce leaf area, resulting in a 13% reduction in leaf area.

Squares: the herbicide had no measurable effect on square production.

Bolls: the herbicide had little impact on boll production, but had a large impact on crop maturity. Crop maturity was delayed by 26 days, with many of the later bolls not reaching maturity before picking.

Final plant count data		
	Untreated	**glyphosate**
Nodes/plant	21.5	21.6
Leaves/m	502	545
Light interception	87%	83%
Leaf area (cm^2/m)	22921	19966
Bolls/m	114	130
Boll weight (g/boll)	4.4	4.0
Days to 50% open	154	170
% Open bolls at picking	82%	65%
Lint yield/ha	1649	1649

Exposure of a 16 node cotton plant to Roundup Ready Herbicide at 50 g/ha had little impact on the plant, except for a decrease in leaf area and a delay in crop maturity.

Average boll size and lint yield were not affected by the herbicide.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: glyphosate
Rate: 173 g a.i./ha
% of typical field rate 17%
Date of exposure: 12th Dec (4 weeks post-emergence)
Growth stage at exposure: 6 nodes

Damage key:
Leaf loss
Leaf distortion
Petiole distortion
Plant stunting
Square shedding
Boll shedding

Herbicidal action

Herbicide group: M
Translocation: moves throughout the plant to growth points
Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis.
Residual activity: none
Soil half-life: 47 days in moist soil

Roundup Ready Herbicide applied broadcast at 250 g/ha to 6 node cotton. Photo taken on 5th Jan, 24 days after exposure.

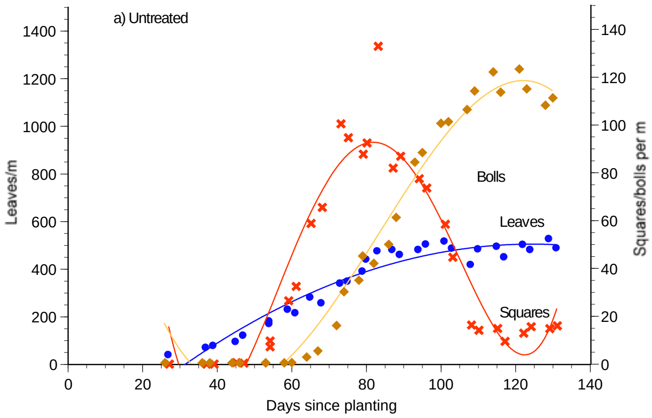
There were no visual symptoms of herbicide damage at this time.

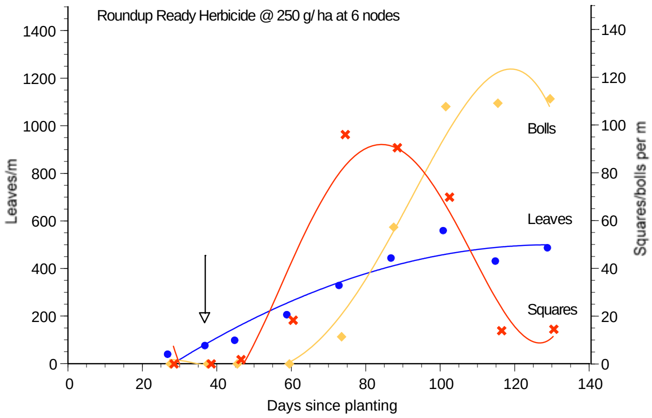
Roundup Ready Herbicide applied broadcast at 250 g/ha to 6 node cotton. Photo taken on 5th Jan, 24 days after exposure.

Roundup Ready Herbicide applied broadcast at 250 g/ha to 6 node cotton. Photo taken on 8th Mar, 86 days after exposure.

There were no visible symptoms of herbicide damage on these plants, which looked identical to the untreated plants.

Roundup Ready Herbicide applied broadcast at 250 g/ha to 6 node cotton. Photo taken on 8th Mar, 86 days after exposure.





Impact on plant growth

Leaves: the herbicide had no effect on leaf number, shape or orientation, but did cause a reduction in leaf size, resulting in a 15% reduction in total leaf area.

Squares: the herbicide had no measurable effect on square production.

Bolls: the herbicide had no measurable effect on boll production.

Final plant count data		
	Untreated	**glyphosate**
Nodes/plant	21.5	21.8
Leaves/m	502	484
Light interception	87%	85%
Leaf area (cm²/m)	22921	19179
Bolls/m	114	111
Boll weight (g/boll)	4.4	4.4
Days to 50% open	154	157
% Open bolls at picking	82%	82%
Lint yield/ha	1649	1684

Exposure of a 6 node cotton plant to Roundup Ready Herbicide at 250 g/ha caused no measurable negative impact.

The plant was able to compensate for any negative effects caused by the herbicide at this early crop stage, resulting in no delay in crop maturity or reduction in yield.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	**glyphosate**	**Damage key:**
Rate:	**173 g a.i./ha**	**Leaf loss**
% of typical field rate	**17%**	**Leaf distortion**
Date of exposure:	**21 Dec** (5½ weeks post-emergence)	**Petiole distortion**
		Plant stunting
Growth stage at exposure:	**8 nodes**	**Square shedding**
		Boll shedding

Herbicidal action

Herbicide group: M
Translocation: moves throughout the plant to growth points
Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis.
Residual activity: none
Soil half-life: 47 days in moist soil

Roundup Ready Herbicide applied broadcast at 250 g/ha to 8 node cotton. Photo taken on 5 Jan, 15 days after exposure.

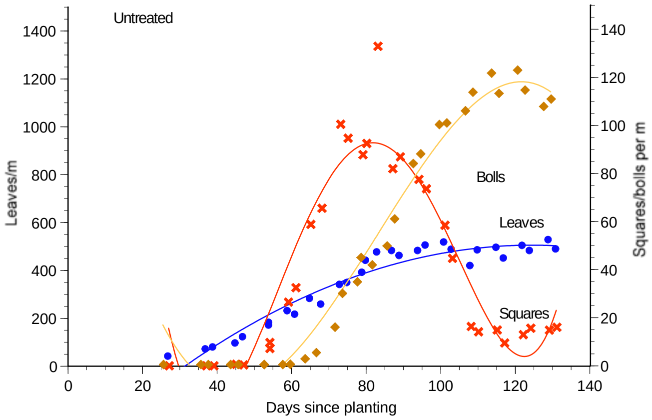
There were no visual symptoms of herbicide damage at this time.

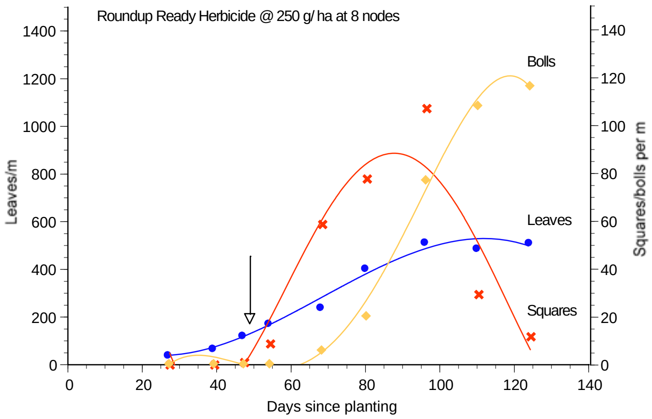
Roundup Ready Herbicide applied broadcast at 250 g/ha to 8 node cotton. Photo taken on 5 Jan, 15 days after exposure.

Roundup Ready Herbicide applied broadcast at 250 g/ha to 8 node cotton. Photo taken on 8 Mar, 77 days after exposure.

There were no visible symptoms of herbicide damage on these plants, which looked identical to the untreated plants.

Roundup Ready Herbicide applied broadcast at 250 g/ha to 8 node cotton. Photo taken on 8 Mar, 77 days after exposure.





Impact on plant growth

Leaves: the herbicide had no effect on leaf number, shape or orientation.

Squares: the plant shed some early squares following the glyphosate exposure. Peak squaring was delayed by 5 days.

Bolls: the plant shed some early bolls following the glyphosate exposure. Crop maturity was delayed by 8 days.

Final plant count data		
	Untreated	**glyphosate**
Nodes/plant	21.5	20.7
Leaves/m	502	509
Light interception	87%	86%
Leaf area (cm²/m)	22921	21731
Bolls/m	114	116
Boll weight (g/boll)	4.4	3.0
Days to 50% open	154	162
% Open bolls at picking	82%	80%
Lint yield/ha	1649	1393

Exposure of an 8 node cotton plant to Roundup Ready Herbicide at 250 g/ha caused no measurable negative effects of leaf production, but did delay peak flowering and crop maturity.

Final boll count was not reduced, but a percentage of bolls were malformed and average boll size was reduced by 32%, resulting in a 16% yield reduction.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	**glyphosate**
Rate:	**173 g a.i./ha**
% of typical field rate	**17%**
Date of exposure:	**4th Jan** (7½ weeks post-emergence)
Growth stage at exposure:	**12 nodes**

Damage key:
- Leaf loss
- Leaf distortion
- Petiole distortion
- Plant stunting
- Square shedding
- Boll shedding

Herbicidal action

Herbicide group: M
Translocation: moves throughout the plant to growth points
Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis.
Residual activity: none
Soil half-life: 47 days in moist soil

Roundup Ready Herbicide applied broadcast at 250 g/ha to 12 node cotton. Photo taken on 25th Jan, 21 days after exposure.

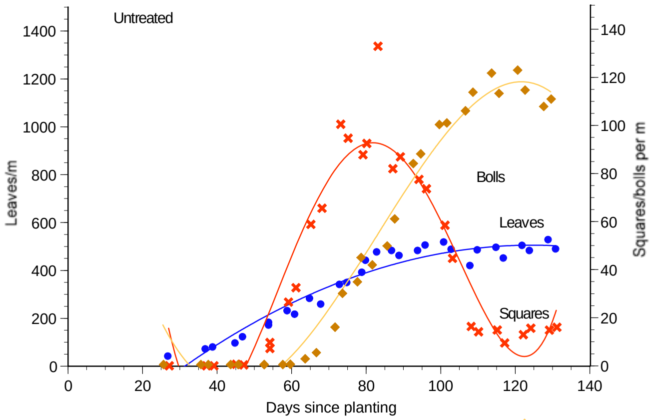
There were no visual symptoms of herbicide damage at this time.

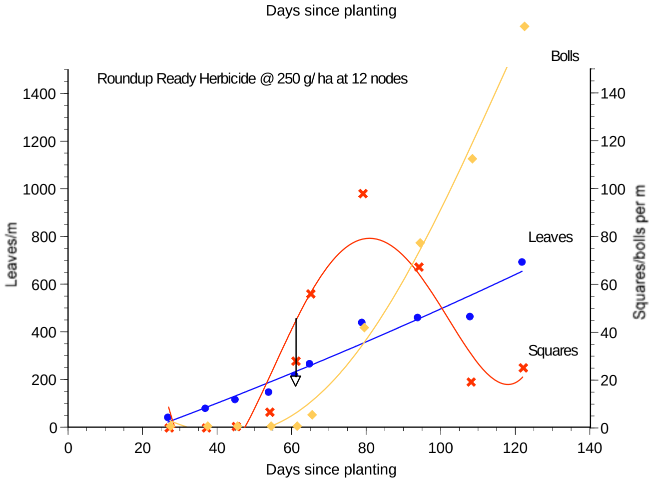
Roundup Ready Herbicide applied broadcast at 250 g/ha to 12 node cotton. Photo taken on 25th Jan, 21 days after exposure.

Roundup Ready Herbicide applied broadcast at 250 g/ha to 12 node cotton. Photo taken on 24th Mar, 79 days after exposure.

There were no visible symptoms of herbicide damage on these plants, which looked identical to the untreated plants.

Roundup Ready Herbicide applied broadcast at 250 g/ha to 12 node cotton. Photo taken on 24th Mar, 79 days after exposure.





Impact on plant growth

Leaves: the glyphosate exposure at 12 nodes caused an increase in leaf production, with 37% more leaves, and a 26% increase in leaf area.

Squares: the plant shed some early squares following the glyphosate exposure. Peak squaring was not delayed.

Bolls: the plant shed some early bolls following the glyphosate exposure and set a large crop of late bolls. Crop maturity was delayed by 25 days, with a large percentage of bolls not reaching maturity before picking.

Final plant count data		
	Untreated	**glyphosate**
Nodes/plant	21.5	22.6
Leaves/m	502	690
Light interception	87%	80%
Leaf area (cm²/m)	22921	28893
Bolls/m	114	167
Boll weight (g/boll)	4.4	3.4
Days to 50% open	154	179
% Open bolls at picking	82%	54%
Lint yield/ha	1649	1427

Exposure of a 12 node cotton plant to Roundup Ready Herbicide at 250 g/ha caused an increase in leaf production and production of a large number of late bolls, delaying crop maturity.

Final boll number was increased by 46%, but many of these bolls were small and didn't reach maturity.

Average boll size was reduced by 23%, and lint yield by 13%.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: glyphosate
Rate: 173 g a.i./ha
% of typical field rate 17%
Date of exposure: 24th Jan (10½ weeks post-emergence)
Growth stage at exposure: 16 nodes

Damage key:
Leaf loss
Leaf distortion
Petiole distortion
Plant stunting
Square shedding
Boll shedding

Herbicidal action

Herbicide group: M
Translocation: moves throughout the plant to growth points
Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis.
Residual activity: none
Soil half-life: 47 days in moist soil

Roundup Ready Herbicide applied broadcast at 250 g/ha to 16 node cotton. Photo taken on 10th Feb, 17 days after exposure.

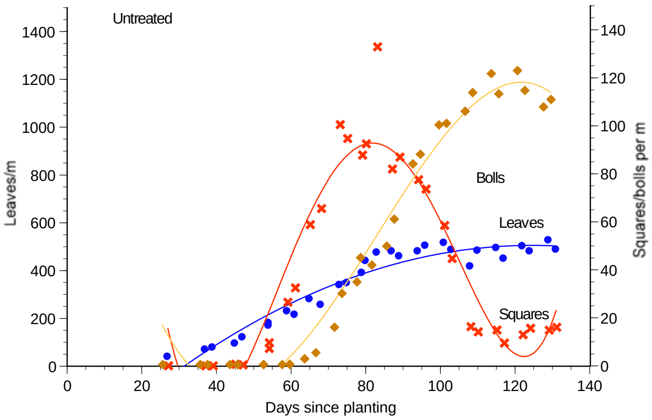
There were no visual symptoms of herbicide damage at this time.

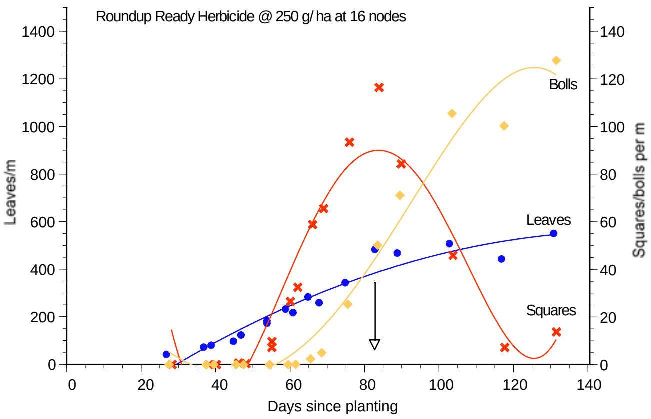
Roundup Ready Herbicide applied broadcast at 250 g/ha to 16 node cotton. Photo taken on 10th Feb, 17 days after exposure.

Roundup Ready Herbicide applied broadcast at 250 g/ha to 16 node cotton. Photo taken on 24th Mar, 59 days after exposure.

There were no visible symptoms of herbicide damage on these plants, which looked identical to the untreated plants.

Roundup Ready Herbicide applied broadcast at 250 g/ha to 16 node cotton. Photo taken on 24th Mar, 59 days after exposure.





Impact on plant growth

Leaves: the glyphosate exposure at 16 nodes had no impact on leaf number, shape or orientation, but did reduce leaf area, resulting in a 23% reduction in leaf area.

Squares: the herbicide had no measurable effect on square production.

Bolls: the herbicide had little impact on boll production, but had a large impact on crop maturity. Crop maturity was delayed by 26 days, with many of the later bolls not reaching maturity before picking.

Final plant count data		
	Untreated	**glyphosate**
Nodes/plant	21.5	22.4
Leaves/m	502	547
Light interception	87%	84%
Leaf area (cm²/m)	22921	17681
Bolls/m	114	127
Boll weight (g/boll)	4.4	4.4
Days to 50% open	154	180
% Open bolls at picking	82%	68%
Lint yield/ha	1649	1606

Exposure of a 16 node cotton plant to Roundup Ready Herbicide at 250 g/ha had little impact on the plant, except for a decrease in leaf area and a delay in crop maturity.

Average boll size and lint yield were not affected.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	MCPA
Rate:	105 g a.i./ha
% of typical field rate	10%
Date of exposure:	12th Nov (6 weeks post-emergence)
Growth stage at exposure:	6 nodes

Damage key:

Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily absorbed by leaves and highly mobile within the plant
Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production
Residual activity: limited, although surface residues can be washed into the soil and are readily absorbed by roots and emerging shoots
Soil half-life: 5 – 6 days, but will persist for up to 6 months in dry soil

MCPA 500 applied broadcast at 210 ml/ha to 6 node cotton. Photo taken on 15th Nov, 3 days after exposure.

Initial symptoms of MCPA damage were apparent after only 3 days, with some twisting of the petioles and main stem.

MCPA 500 applied broadcast at 210 ml/ha to 6 node cotton. Photo taken on 22nd Nov, 10 days after exposure.

The initial symptoms were still apparent 10 days after exposure.

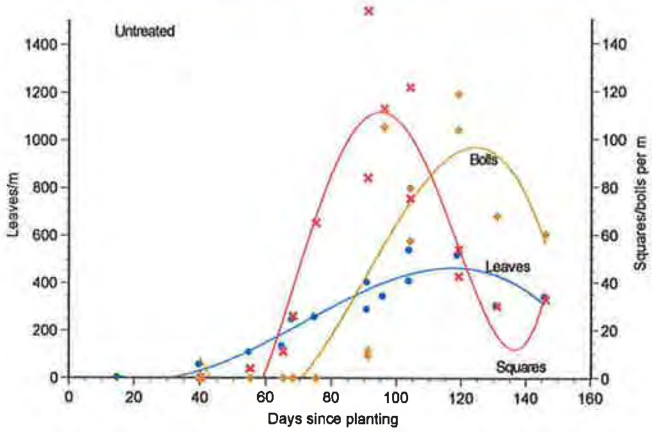
MCPA 500 applied broadcast at 210 ml/ha to 6 node cotton. Photo taken on 11th Dec, 29 days after exposure.

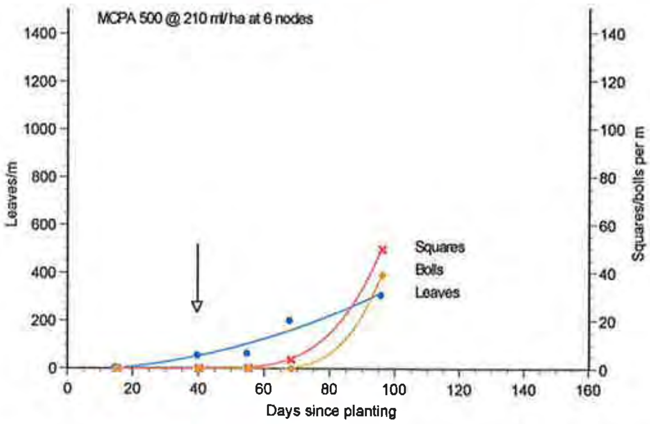
Plants had resumed growth, but new growth was showing typical phenoxy damage. New leaves were distorted, with crinkled edges and ending in a row of short "fingers". Many of the distorted leaves were more square in shape, not as fine as distorted leaves from some of the other phenoxy herbicides.

MCPA 500 applied broadcast at 210 ml/ha to 6 node cotton. Photo taken on 2nd Jan, 51 days after exposure.

Distorted leaves were still very apparent although more normal leaves were emerging on newly developing lateral branches.

Most symptoms of damage disappeared by 25th Jan, 74 days after exposure, although a few abnormal leaves were still apparent. These leaves were heavily veined and leathery in appearance.





Impact on plant growth

Leaves: exposure to the 10% rate of MCPA initially caused some bending of the petioles and main stems.

The main effect was a reduction in mid-season leaf area (down 63%) and distortion of the leaves which emerged following the herbicide exposure, typical of phenoxy damage. Many of the distorted leaves were not as fine as may be the case with some of the other phenoxy herbicides.

Squares: plants were slow to recover from this level of MCPA damage, with square production delayed by around 20 days.

Bolls: boll production and retention was largely unaffected by the herbicide exposure. There was a small reduction in total boll retention, boll weight and fruit retention on nodes 10 to 20.

Mature bolls were retained up to node 23, only 2 nodes fewer than in the undamaged plots.

Final plant count data		
	Untreated	**MCPA**
Nodes/plant	27.8	27.6
Leaves/m*	342	301
Leaf area (cm²/m)*	16870	6263
Reduction in leaf area*		63%
Bolls/m	176	130
Boll weight (g/boll)	4.8	4.4
Bolls/node (nodes 10-20)#	0.86	0.44
Days to 50% open	183	195
Maturity delay (days)		12
% Open bolls at picking	86%	80%
Lint yield/ha	2147	1544

Exposure to 10% of a typical field rate of MCPA at 6 nodes caused a 20 – 30 day delay in plant growth and development and leaf area was greatly reduced mid-season.

There was a 26% reduction in boll retention at picking and a 9% reduction in boll weight. This resulted in a 28% reduction in lint yield with a 12 day delay in crop maturity.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: MCPA
Rate: 105 g a.i./ha
% of typical field rate 10%
Date of exposure: 5th Dec (9 weeks post-emergence)
Growth stage at exposure: 11 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily absorbed by leaves and highly mobile within the plant
Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production
Residual activity: limited, although surface residues can be washed into the soil and are readily absorbed by roots and emerging shoots
Soil half-life: 5 – 6 days, but will persist for up to 6 months in dry soil

MCPA 500 applied broadcast at 210 ml/ha to 11 node cotton. Photo taken on 11th Dec, 6 days after exposure.

Mild symptoms of MCPA damage were apparent, with some reddening of the leaves and petioles and twisting of the petioles and main stem, causing mis-orientation of the leaves.

MCPA 500 applied broadcast at 210 ml/ha to 11 node cotton. Photo taken on 21st Dec, 16 days after exposure.

The initial symptoms had largely disappeared, although some necrotic spots and discolouration of the leaves were still apparent. New leaves were yellowish.

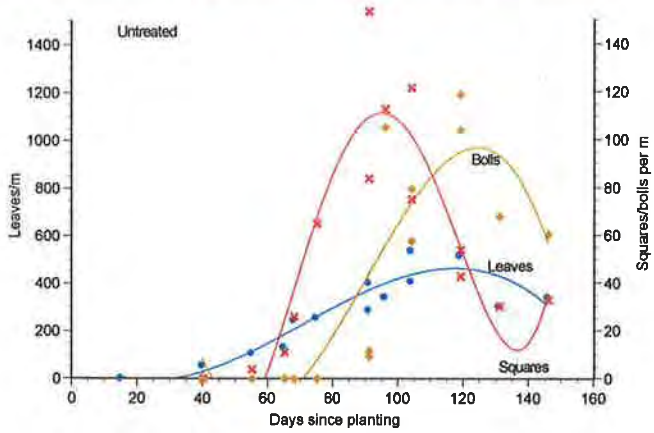
MCPA 500 applied broadcast at 210 ml/ha to 11 node cotton. Photo taken on 2nd Jan, 28 days after exposure.

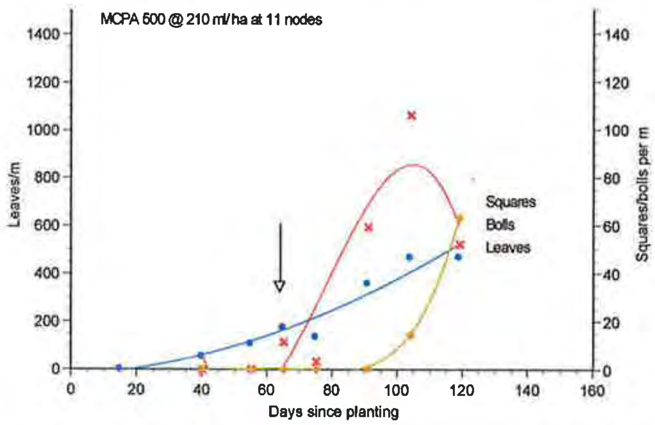
Plants had resumed growth, but new growth was showing typical phenoxy damage. New leaves were distorted, with crinkled edges and ending in a row of short “fingers”.

MCPA 500 applied broadcast at 210 ml/ha to 11 node cotton. Photo taken on 14th Jan, 40 days after exposure.

Distorted leaves were still very apparent at the top of the plant although more normal leaves were emerging on newly developing lateral branches.

Most symptoms of damage disappeared by 31 Jan, 57 days after exposure, although a few abnormal leaves were still apparent.





Impact on plant growth

Leaves: exposure to the 10% rate of MCPA initially caused some loss of leaf area and bending of the petioles and main stems, reducing leaf efficiency. This effect was relatively mild.

The main effect was a reduction in mid-season leaf area (down by 39%) and distortion of leaves which emerged following the herbicide exposure, typical of phenoxy damage.

Squares: square production was delayed by around 10 days and the rate of square production was reduced. The total number of squares produced on damaged plants was also much lower than on undamaged plants.

Bolls: boll production was delayed by around 20 days. There was a reduction in the retention of mature bolls, boll weight and fruit retention on nodes 10 - 20.

Mature bolls were retained up to node 26, but with a number of gaps in retention on lower branches.

Final plant count data		
	Untreated	**MCPA**
Nodes/plant	27.8	27.6
Leaves/m*	517	467
Leaf area (cm²/m)*	10030	6149
Reduction in leaf area*		39%
Bolls/m	176	107
Boll weight (g/boll)	4.8	4.2
Bolls/node (nodes 10-20)#	0.86	0.44
Days to 50% open	183	210
Maturity delay (days)		27
% Open bolls at picking	86%	80%
Lint yield/ha	2147	1197

Exposure to 10% of a typical field rate of MCPA at 11 nodes caused a 10 – 30 day delay in plant development and leaf area was greatly reduced mid-season.

There was a 39% reduction in boll retention and a 12% reduction in boll weight. This resulted in a 44% reduction in yield, with a 27 day delay in crop maturity.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	MCPA
Rate:	105 g a.i./ha
% of typical field rate	10%
Date of exposure:	2nd Jan (13 weeks post-emergence)
Growth stage at exposure:	15 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily absorbed by leaves and highly mobile within the plant
Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production
Residual activity: limited, although surface residues can be washed into the soil and are readily absorbed by roots and emerging shoots
Soil half-life: 5 – 6 days, but will persist for up to 6 months in dry soil

MCPA 500 applied broadcast at 210 ml/ha to 15 node cotton. Photo taken on 4th Jan, 2 days after exposure.

Initial symptoms of MCPA damage were apparent. Plants had a wilted appearance, with twisting of the petioles and main stem, causing mis-orientation of most of the outer leaves.

MCPA 500 applied broadcast at 210 ml/ha to 15 node cotton. Photo taken on 14th Jan, 12 days after exposure.

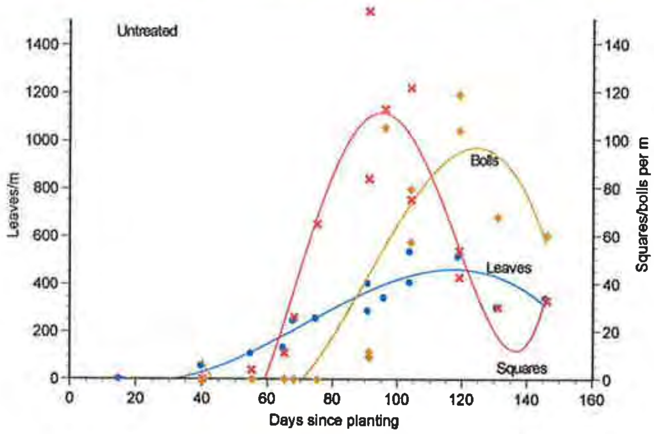
The initial symptoms of MCPA damage were still apparent, with twisting of the petioles and main stem. A reddish discolouration had developed on many of the leaves and was particularly prominent on the veins.

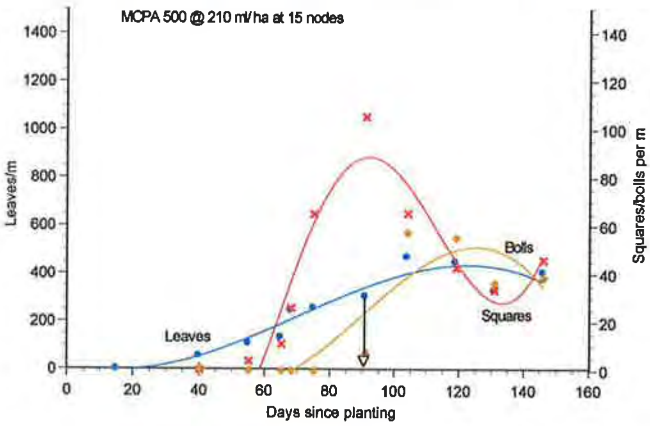
MCPA 500 applied broadcast at 210 ml/ha to 15 node cotton. Photo taken on 25th Jan, 23 days after exposure.

Many of the petioles remain twisted, although most leaves had resumed a more normal orientation. The stems and petioles were still distinctly reddish, with discoloured remaining on some leaves. New leaves were starting to emerge at the top of the plant, but these were showing some signs of phenoxy damage. These leaves were distorted, with crinkled edges and ended in a row of short “fingers”.

MCPA 500 applied broadcast at 210 ml/ha to 15 node cotton. Photo taken on 11th Feb, 40 days after exposure.

Long internodes and distorted leaves were apparent at the top of the plant. New leaves were distorted, with crinkled edges and ended in a row of short "fingers", typical of phenoxy damage.





Impact on plant growth

Leaves: exposure to the 10% rate of MCPA initially caused bending and twisting of the petioles and stems. Reddening of the stems, petioles and leaves became apparent some days later.

Leaf growth and development was initially delayed, but plants compensated and developed more leaves and leaf area later in the season.

The main effect was on leaves which emerged following the herbicide exposure, with the production of distorted leaves, showing typical phenoxy damage.

Squares: the herbicide exposure reduced peak square production, but plants compensated, producing more late-season squares.

Bolls: peak boll production was also reduced. Mature bolls were retained to node 24, but there were few bolls on nodes 10 – 12. Average boll retention on nodes 10 – 20 was reduced by 45%, and boll weight was down by 16%.

Final plant count data		
	Untreated	**MCPA**
Nodes/plant	27.8	28.3
Leaves/m*	341	403
Leaf area (cm²/m)*	19630	20325
Reduction in leaf area*		-
Bolls/m	176	120
Boll weight (g/boll)	4.8	4.0
Bolls/node (nodes 10-20)#	0.86	0.47
Days to 50% open	183	207
Maturity delay (days)		24
% Open bolls at picking	86%	75%
Lint yield/ha	2147	1303

Exposure to 10% of a typical field rate of MCPA at 15 nodes appeared to cause relatively little damage to the plants, with some leaf damage and distortion, but plants compensated for this.

However, many early season bolls were shed and plants were not able to fully compensate with late season bolls. There was a 31% reduction in the number of mature bolls at picking and a 24 day delay in crop maturity. Lint yield was reduced by 39%.

Note* Leaf number and leaf area were last recorded 55 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 to 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: MCPA
Rate: 525 g a.i./ha
% of typical field rate 50%
Date of exposure: 12th Nov (6 weeks post-emergence)
Growth stage at exposure: 6 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily absorbed by leaves and highly mobile within the plant
Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production
Residual activity: limited, although surface residues can be washed into the soil and are readily absorbed by roots and emerging shoots
Soil half-life: 5 – 6 days, but will persist for up to 6 months in dry soil

MCPA 500 applied broadcast at 1.05 L/ha to 6 node cotton. Photo taken on 15th Nov, 3 days after exposure.

Initial symptoms of MCPA damage were apparent after only 3 days, with twisting of the petioles and main stem. Some leaf burning was also apparent with necrotic spots on the leaves.

MCPA 500 applied broadcast at 1.05 L/ha to 6 node cotton. Photo taken on 22nd Nov, 10 days after exposure.

The initial symptoms had largely disappeared, although there was still some twisting of the petioles and main stem. Necrotic spots were still obvious on the leaves.

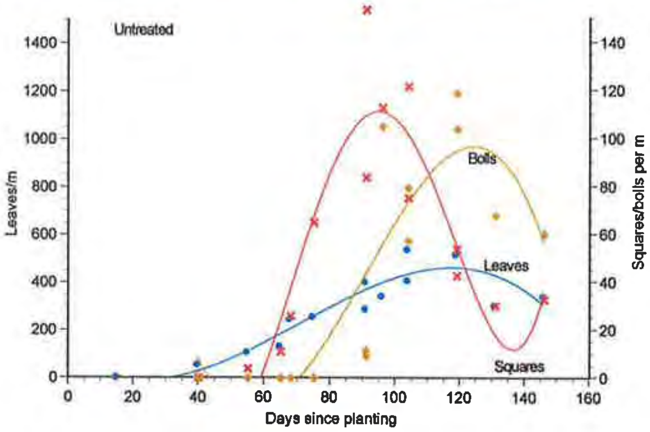
MCPA 500 applied broadcast at 1.05 L/ha to 6 node cotton. Photo taken on 11th Dec, 29 days after exposure.

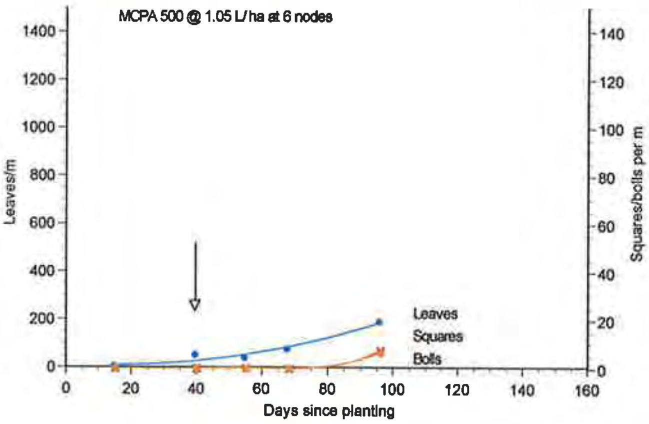
Plants had resumed growth, but new growth was showing typical phenoxy damage. New leaves were distorted, with crinkled edges and ending in a row of short "fingers". Many of the distorted leaves were more square in shape, not as fine as distorted leaves from some of the other phenoxy herbicides.

MCPA 500 applied broadcast at 1.05 L/ha to 6 node cotton. Photo taken on 2nd Jan, 51 days after exposure.

Distorted leaves were still very apparent although more normal leaves were emerging on newly developing lateral branches.

Most symptoms of damage had disappeared by 25th Jan, 74 days after exposure, although a few abnormal leaves were still apparent. These leaves were heavily veined and leathery in appearance.





Impact on plant growth

Leaves: exposure to a 50% rate of MCPA initially caused some bending of the petioles and main stems, and some leaf burn with necrotic spots.

The main effect was on leaves which emerged following the herbicide exposure, with the production of distorted leaves, typical of phenoxy damage. The distorted leaves were not as fine as is commonly the case with the other phenoxy herbicides.

Squares: plants were slow to recover from MCPA damage, with square production delayed by around 20 days.

Bolls: boll production and retention were largely unaffected by the herbicide exposure. There was a small reduction in fruit retention on nodes 10 to 20.

Mature bolls were retained up to node 22, 3 nodes fewer than on undamaged plants.

Final plant count data		
	Untreated	**MCPA**
Nodes/plant	27.8	24.4
Leaves/m*	342	187
Leaf area (cm²/m)*	16870	3600
Reduction in leaf area*		79%
Bolls/m	176	93
Boll weight (g/boll)	4.8	3.9
Bolls/node (nodes 10-20)#	0.86	0.55
Days to 50% open	183	221
Maturity delay (days)		38
% Open bolls at picking	86%	82%
Lint yield/ha	2147	828

Exposure to a 50% of a typical field rate of MCPA caused less damage to 6 node cotton than was seen with comparable rates of the other phenoxy herbicides.

MCPA caused a 20 – 30 day delay in plant development. Leaf number and leaf area were greatly reduced mid-season.

There was a 47% reduction in boll retention and an 18% reduction in boll weight. This resulted in a 61% reduction in yield, with a 38 day delay in crop maturity.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	**MCPA**
Rate:	**525 g a.i./ha**
% of typical field rate	**50%**
Date of exposure:	**5th Dec** (9 weeks post-emergence)
Growth stage at exposure:	**11 nodes**

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily absorbed by leaves and highly mobile within the plant
Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production
Residual activity: limited, although surface residues can be washed into the soil and are readily absorbed by roots and emerging shoots
Soil half-life: 5 – 6 days, but will persist for up to 6 months in dry soil

MCPA 500 applied broadcast at 1.05 L/ha to 11 node cotton. Photo taken on 11th Dec, 6 days after exposure.

Initial symptoms of MCPA damage were apparent, with twisting of the petioles and main stem. Some leaf burning could also be seen, with necrotic spots on the leaves.

MCPA 500 applied broadcast at 1.05 L/ha to 11 node cotton. Photo taken on 21st Dec, 16 days after exposure.

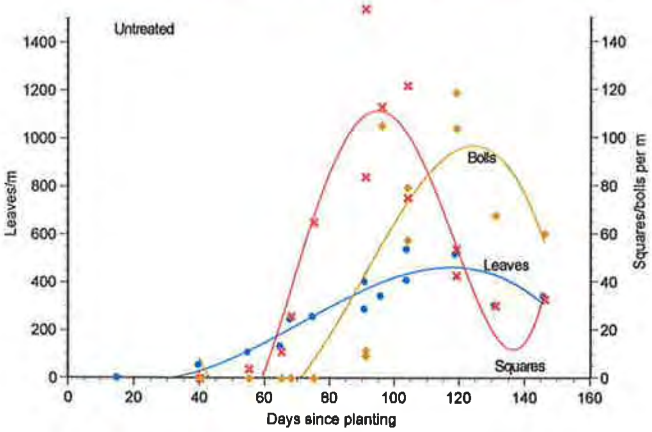
The initial symptoms of MCPA damage were still apparent, with twisting of the petioles and main stem. Some leaf burning could also be seen, with necrotic spots and patches on the leaves.

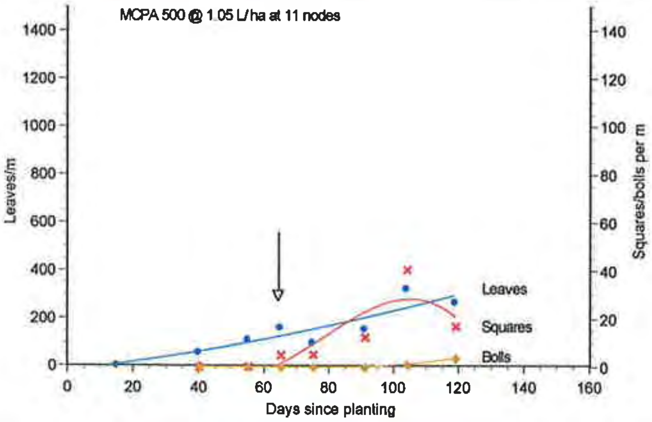
MCPA 500 applied broadcast at 1.05 L/ha to 11 node cotton. Photo taken on 14th Jan, 40 days after exposure.

Plants had resumed growth, but new growth was showing typical signs of phenoxy damage. New leaves were distorted, with crinkled edges and ending in a row of short "fingers". Many of the distorted leaves were more square in shape, and not as fine as distorted leaves from some of the other phenoxy herbicides.

MCPA 500 applied broadcast at 1.05 L/ha to 11 node cotton. Photo taken on 31st Jan, 57 days after exposure.

Long internodes and distorted leaves were still apparent, although more normal leaves were emerging on newly developing lateral branches.





Impact on plant growth

Leaves: exposure to a 50% rate of MCPA initially caused some bending of the petioles and main stems, and some leaf burning with necrotic spots. Some leaves were killed. Leaf number 56 days after exposure were reduced by 46% and leaf area by 54%.

The main effect was on leaves which emerged following the herbicide exposure, with the production of distorted leaves, typical of phenoxy damage. The distorted leaves were not as fine as is commonly the case with the other phenoxy herbicides.

Squares: the herbicide damage had a large effect on square retention, delaying square production and retention.

Bolls: boll production and retention were also severely reduced by the herbicide exposure. The final count of mature bolls/m was down by 59% and the boll weight was reduced by 26% on average. There was a 69% reduction in mature boll retention on nodes 10 to 20, with few mature bolls retained above node 9.

Final plant count data		
	Untreated	**MCPA**
Nodes/plant	27.8	25.7
Leaves/m*	517	265
Leaf area (cm²/m)*	10030	4593
Reduction in leaf area*		54%
Bolls/m	176	72
Boll weight (g/boll)	4.8	3.5
Bolls/node (nodes 10-20)#	0.86	0.27
Days to 50% open	183	218
Maturity delay (days)		35
% Open bolls at picking	86%	67%
Lint yield/ha	2147	745

Exposure to a 50% MCPA rate caused severe damage to 11 node cotton.

MCPA caused a big reduction in leaf number and leaf area mid-season.

There was a big reduction in the number of retained squares mid-season and a 59% reduction in boll retention. This, combined with a 26% reduction in boll weight and a 35 day delay in crop maturity combined to result in a 65% reduction in yield.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by:

Graham Charles
NSW Dept of Primary Industries

Herbicide:	MCPA
Rate:	525 g a.i./ha
% of typical field rate	50%
Date of exposure:	2nd Jan (13 weeks post-emergence)
Growth stage at exposure:	15 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I

Translocation: readily absorbed by leaves and highly mobile within the plant

Mode of action: an auxin-type herbicide that affects plant growth, nitrogen metabolism and enzyme production

Residual activity: limited, although surface residues can be washed into the soil and are readily absorbed by roots and emerging shoots

Soil half-life: 5 – 6 days, but will persist for up to 6 months in dry soil

MCPA 500 applied broadcast at 1.05 L/ha to 15 node cotton. Photo taken on 4th Jan, 2 days after exposure.

Initial symptoms of MCPA damage were apparent. Plants had a wilted appearance, with twisting of the petioles and main stem.

MCPA 500 applied broadcast at 1.05 L/ha to 15 node cotton. Photo taken on 11th Jan, 9 days after exposure.

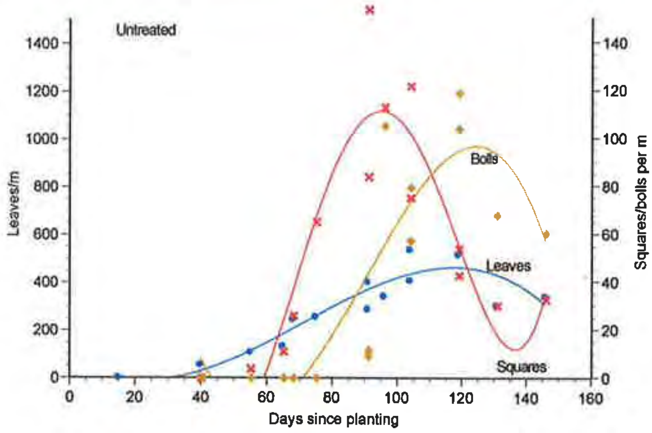
The initial symptoms of MCPA damage were still apparent, with twisting of the petioles and main stem. A red discolouration had developed on many of the leaves, suggesting light burning of the leaves. The veins of these leaves were deeper red in colour.

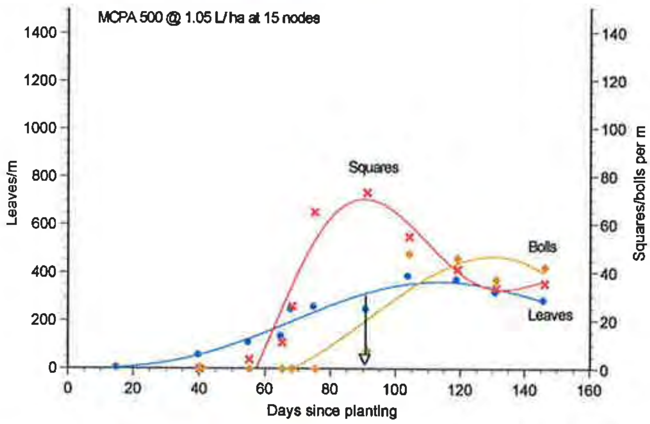
MCPA 500 applied broadcast at 1.05 L/ha to 15 node cotton. Photo taken on 25th Jan, 23 days after exposure.

Many of the petioles remain twisted, although most leaves had resumed a more normal orientation. The stems, veins and some leaves were discoloured. New leaves were starting to emerge at the top of the plant and these were showing symptoms typical of phenoxy damage.

MCPA 500 applied broadcast at 1.05 L/ha to 15 node cotton. Photo taken on 11th Feb, 40 days after exposure.

Long internodes and distorted leaves were apparent at the top of the plants 40 days after exposure. New leaves were distorted, with crinkled edges and ended in a row of short "fingers", as is typical with phenoxy damage.





Impact on plant growth

Leaves: exposure to a 50% rate of MCPA initially caused some bending of the petioles and main stems. Further damage became apparent on many leaves as a red discolouration with some burning.

Leaf growth and development were delayed by the herbicide. Leaf number was reduced by 17% and leaf area by 32% compared to undamaged plants 55 days after exposure.

Leaves which emerged later in the season were distorted, showing symptoms typical of phenoxy damage.

Squares: the herbicide damage reduced peak squaring, but plants compensated, setting more late squares.

Bolls: peak boll production and retention were also reduced by the herbicide exposure. The number of mature bolls retained at picking was reduced by 33% and the average boll weight was reduced by 28%. There was a 38% reduction in mature boll retention on nodes 10 to 20, although a few mature bolls were retained to the top of the plant.

Final plant count data		
	Untreated	**MCPA**
Nodes/plant	27.8	28.3
Leaves/m*	341	282
Leaf area (cm^2/m)*	19630	13274
Reduction in leaf area*		32%
Bolls/m	176	118
Boll weight (g/boll)	4.8	3.4
Bolls/node (nodes 10-20)#	0.86	0.53
Days to 50% open	183	208
Maturity delay (days)		25
% Open bolls at picking	86%	90%
Lint yield/ha	2147	861

Exposure to 50% of a typical field rate of MCPA at 15 nodes delayed plant growth and development for several weeks. Leaf number and area 55 days after exposure were reduced by 17% and 32% respectively. There was a big reduction in peak square and peak boll production.

Many early season squares and bolls were shed. Additional late season bolls were retained, but with a reduction in boll weight, a 25 day delay in crop maturity and a 60% reduction in yield.

Note* Leaf number and leaf area were last recorded 55 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 to 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: glyphosate + 2,4-D
Rate: 35 + 8 g a.i./ha
Date of exposure: 12th Dec (4 weeks post-emergence)
Growth stage at exposure: 6 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide groups: M + I

Glyphosate

Translocation: moves throughout the plant to growth points
Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis.
Residual activity: none
Soil half-life: 47 days in moist soil

2,4-D

Translocation: readily moves to the plant growth points
Mode of action: An auxin-type (phenoxy) herbicide that affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause uncontrolled cell division & growth, leading to plant death.
Residual activity: limited
Soil half-life: 10 days in moist soil

Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 50 + 10 g/ha to 6 node cotton. Photo taken on 5th Jan, 24 days after exposure.

New leaves on the main stem were severely affected by the 2,4-D, with severe leaf distortion on all subsequent growth.

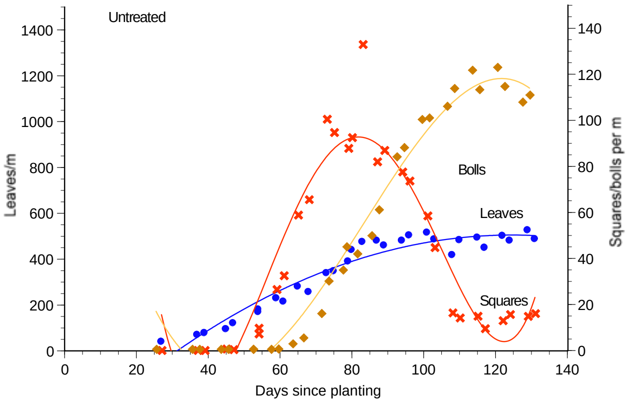
Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 50 + 10 g/ha to 6 node cotton. Photo taken on 5th Jan, 24 days after exposure.

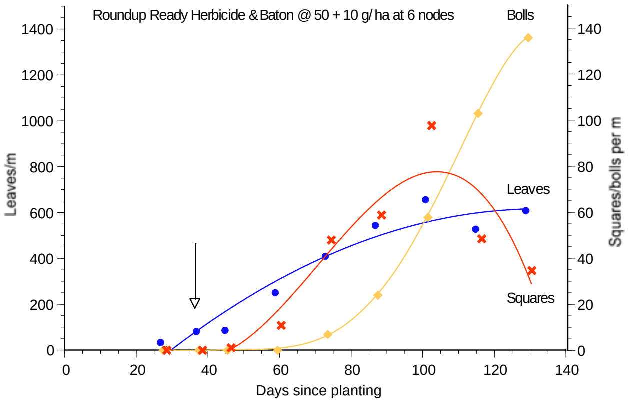
The new leaves on the main stem were severely distorted by the herbicide. Leaves were narrow, cupped, twisted and leathery, with prominent veins. These symptoms are typical of 2,4-D damage.

There were no signs of glyphosate damage.

Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 50 + 10 g/ha to 6 node cotton. Photo taken on 24th Mar, 102 days after exposure.

This plate shows a close-up of a boll distorted by the herbicides. The herbicides affected not only the leaves, but also squares, flowers and bolls.





Impact on plant growth

Leaves: the primary effect of the herbicide was on the leaves that developed following the exposure, causing an increase in leaf production, mainly through the production of small, distorted leaves on the main stem.

Leaves which developed on the vegetative branches were not affected by the herbicides.

Squares: many of the early squares were shed following the herbicide exposure and peak squaring was delayed by 23 days. Later squares were retained and developed.

Bolls: most early bolls were shed, but later bolls on the vegetative branches were retained and developed. The plant produced a large number of late bolls, many of which didn't reach maturity.

Plant: growth on the main stem responded vegetatively, with the plant producing an additional 1.5 nodes.

Final plant count data		
	Untreated	**Gly + 2,4-D**
Height (cm)	73.9	78.9
Nodes/plant	21.5	22.9
Internode length (post-spray)	4.1	3.9
Leaves/m	502	605
Light interception	87%	87%
Leaf area (cm²/m)	22921	21765
Reduction in leaf area		5%
Bolls/m	114	136
Boll weight (g/boll)	4.4	3.1
Days to 50% open	154	-
Maturity delay (days)		-
% Open bolls at picking	82%	48%
Lint yield/ha	1649	1572

Glyphosate + 2,4-D exposure at 6 nodes caused extensive leaf deformation on the main stem and a loss of fruit from the main stem.

The plant compensated for this damage, setting the crop on the vegetative branches, producing a late crop, with a delay in crop maturity. Many of the late bolls were small and still green at harvest.

The herbicide damage did not cause a yield loss.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: glyphosate + 2,4-D
Rate: 35 + 8 g a.i./ha
Date of exposure: 21st Dec (5½ weeks post-emergence)
Growth stage at exposure: 8 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide groups: M + I

Glyphosate

Translocation: moves throughout the plant to growth points
Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis.
Residual activity: none
Soil half-life: 47 days in moist soil

2,4-D

Translocation: readily moves to the plant growth points
Mode of action: An auxin-type (phenoxy) herbicide. 2,4-D affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause abnormal increases in RNA, DNA & protein biosynthesis, resulting in uncontrolled cell division & growth, leading to plant death.
Residual activity: limited
Soil half-life: 10 days in moist soil

Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 50 + 10 g/ha to 8 node cotton. Photo taken on 5th Jan, 15 days after exposure.

New leaves on the main stem were severely affected by the 2,4-D, with severe leaf distortion on all subsequent growth.

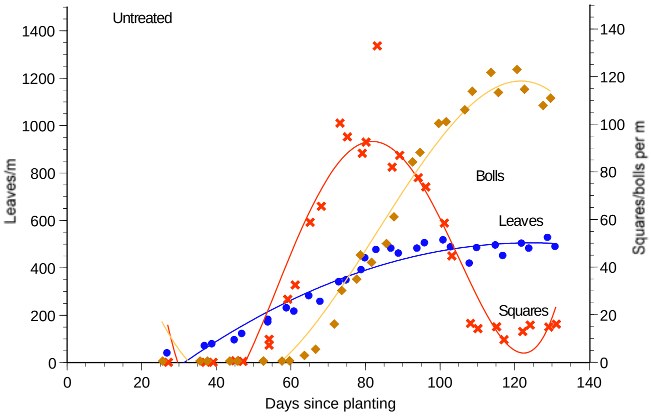
Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 50 + 10 g/ha to 8 node cotton. Photo taken on 25th Jan, 35 days after exposure.

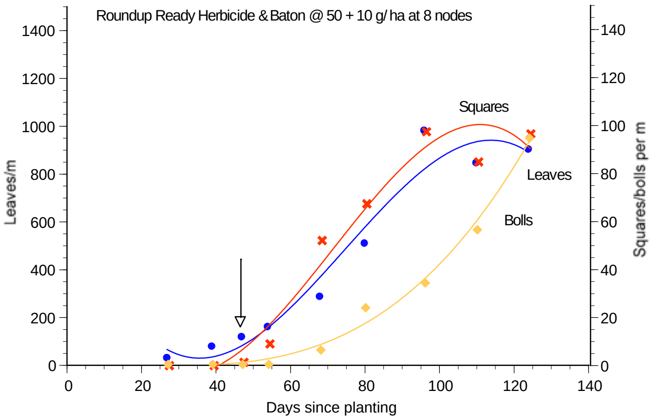
All new leaves were severely distorted by the herbicide. Leaves were narrow, cupped, twisted and leathery, with prominent veins. These symptoms are typical of 2,4-D damage.

No obvious signs of glyphosate damage were apparent.

Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 50 + 10 g/ha to 8 node cotton. Photo taken on 24th Mar, 93 days after exposure.

The plant produced distorted growth on the main stem and most vegetative branches throughout the season. Leaves, squares, flowers and bolls were all distorted by the herbicides.





Impact on plant growth

Leaves: the primary effect of the herbicide was on the leaves which developed following the exposure, causing an 80% increase in leaf production, mainly through the production of small, distorted leaves. Total leaf area and light interception were not affected.

Normal leaves developed on some of the later vegetative branches.

Squares: many of the early squares were shed following the herbicide exposure, but later squares were retained and developed. Peak squaring was delayed by 40 days.

Bolls: most early bolls were shed. Many later bolls were retained and developed, but these bolls were small and few reached maturity.

Plant: growth responded vegetatively to the herbicide damage, producing an additional 4 nodes, and 20 cm in height.

Final plant count data		
	Untreated	**Gly + 2,4-D**
Height (cm)	73.9	93.9
Nodes/plant	21.5	25.3
Internode length (post-spray)	4.2	4.3
Leaves/m	502	902
Light interception	87%	91%
Leaf area (cm²/m)	22921	22485
Reduction in leaf area		2%
Bolls/m	114	94
Boll weight (g/boll)	4.4	1.6
Days to 50% open	154	-
Maturity delay (days)		-
% Open bolls at picking	82%	35%
Lint yield/ha	1649	1256

Glyphosate + 2,4-D exposure at 8 nodes caused extensive leaf deformation on the main stem and most vegetative branches, and a loss of many early fruit.

The plant compensated for this damage by setting a late crop. Most of these bolls were small and green at harvest.

The damage caused a 24% reduction in lint yield, with only 35% of bolls mature at picking.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	**Glyphosate + 2,4-D**	**Damage key:**	
Rate:	**35 + 8 g a.i./ha**	**Leaf loss**	
Date of exposure:	**4th Jan (7½ weeks post-emergence)**	**Leaf distortion**	**x**
		Petiole distortion	**x**
Growth stage at exposure:	**12 nodes**	**Plant stunting**	
		Square shedding	**x**
		Boll shedding	**x**

Herbicidal action

Herbicide groups: **M + I**

Glyphosate

Translocation: moves throughout the plant to growth points
Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis.
Residual activity: none
Soil half-life: 47 days in moist soil

2,4-D

Translocation: readily moves to the plant growth points
Mode of action: An auxin-type (phenoxy) herbicide that affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause uncontrolled cell division & growth, leading to plant death.
Residual activity: limited
Soil half-life: 10 days in moist soil

Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 50 + 10 g/ha to 12 node cotton. Photo taken on 25th Jan, 21 days after exposure.

All new leaves were severely distorted. Leaves were narrow, cupped, twisted and leathery, with prominent veins. These symptoms are typical of 2,4-D damage.

Glyphosate damage was not apparent on these plants.

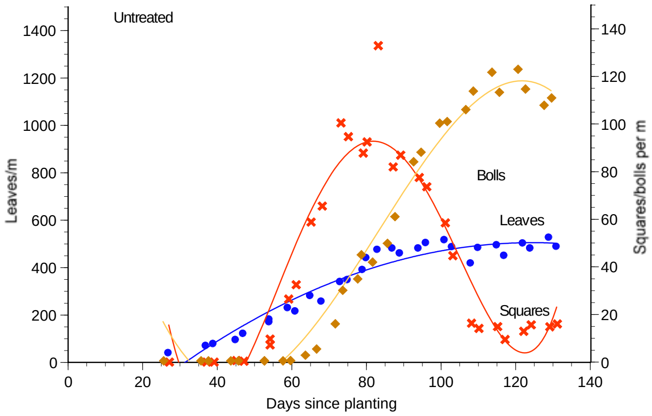
Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 50 + 10 g/ha to 12 node cotton. Photo taken on 25th Jan, 21 days after exposure.

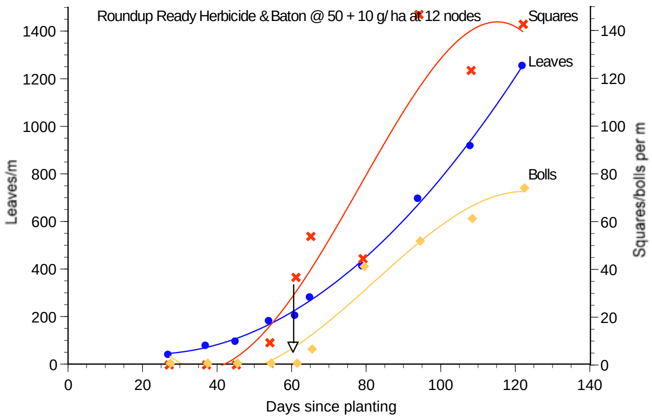
A close-up of the plants in the previous photo.

Older leaves showed some damage, with cupping and distorted edges. Newly emerging leaves were severely distorted. Leaves were narrow, cupped, twisted and leathery, with prominent veins.

Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 50 + 10 g/ha to 12 node cotton. Photo taken on 8th Mar, 63 days after exposure.

The plant continued to produce distorted growth throughout the remainder of the season. This growth was still obvious at picking.





Impact on plant growth

Leaves: the primary effect of the herbicide was on the leaves that developed following the exposure, causing a 150% increase in leaf production, mainly through the production of small, distorted leaves. The increase in leaf number compensated for the reduction in leaf size.

Squares: many early squares were shed following the herbicide exposure. The plant produced masses of later squares, but many of these were distorted and failed to develop normally.

Bolls: many of the early bolls were shed following the herbicide exposure. A large number of later bolls were retained, but these were small and few reached maturity.

Plant: growth responded vegetatively to the herbicide exposure, producing an additional 4.5 nodes and 20 cm in height.

Final plant count data		
	Untreated	**Gly + 2,4-D**
Height (cm)	73.9	93.4
Nodes/plant	21.5	25.9
Internode length (post-spray)	4.5	4.5
Leaves/m	502	1252
Light interception	87%	85%
Leaf area (cm^2/m)	22921	24422
Reduction in leaf area		-
Bolls/m	114	73
Boll weight (g/boll)	4.4	1.6
Days to 50% open	154	174
Maturity delay (days)		20
% Open bolls at picking	82%	64%
Lint yield/ha	1649	708

Glyphosate + 2,4-D exposure at 12 nodes caused extensive deformation of new growth and a loss of early fruit.

The plant compensated for the damage by producing a mass of late square, but few of these developed. Many of the bolls which were retained were small and green at harvest.

The damage caused an 57% reduction in lint yield and 20 day delay in crop maturity.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	**Glyphosate + 2,4-D**	**Damage key:**	
Rate:	**35 + 8 g a.i./ha**	**Leaf loss**	
Date of exposure:	**24th Jan (10 weeks post-emergence)**	**Leaf distortion**	**x**
		Petiole distortion	**x**
Growth stage at exposure:	**16 nodes**	**Plant stunting**	
		Square shedding	**x**
		Boll shedding	**x**

Herbicidal action

Herbicide groups: **M + I**

Glyphosate

Translocation: moves throughout the plant to growth points

Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis.

Residual activity: none

Soil half-life: 47 days in moist soil

2,4-D

Translocation: readily moves to the plant growth points

Mode of action: An auxin-type (phenoxy) herbicide. 2,4-D affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause abnormal increases in RNA, DNA & protein biosynthesis, resulting in uncontrolled cell division & growth, leading to plant death.

Residual activity: limited

Soil half-life: 10 days in moist soil

Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 50 + 10 g/ha to 16 node cotton. Photo taken on 6th Feb, 13 days after the exposure.

Plants appeared to be undamaged but closer examination revealed that the new leaves which had emerged after the herbicide exposure were severely distorted. Leaves were narrow, cupped, twisted and leathery.

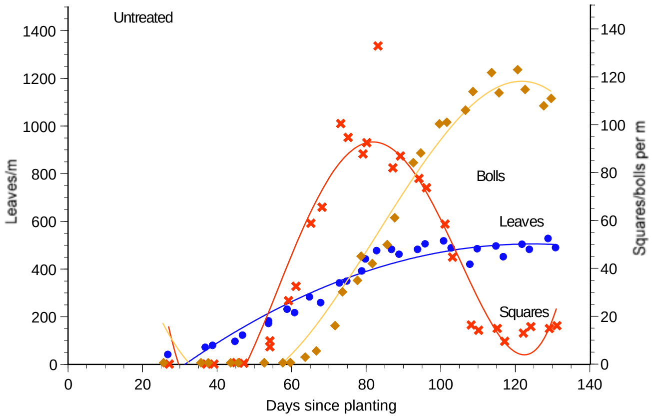
No glyphosate damage was apparent on these plants.

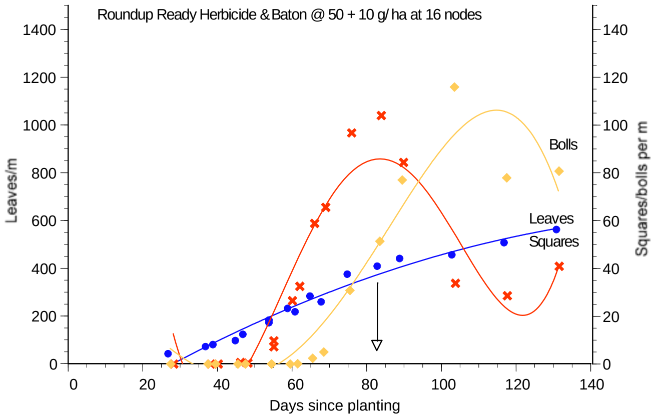
Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 50 + 10 g/ha to 16 node cotton. Photo taken on 22nd Feb, 29 days after the exposure.

The plant produce distorted growth and retained few new bolls above 16 nodes. Leaves were narrow, cupped, twisted and leathery, symptoms typical of phenoxy damage.

Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 50 + 10 g/ha to 16 node cotton. Photo taken on 5th April, 72 days after the exposure.

The plant continued to produce distorted growth, although by 72 days some normal leaves had emerged at the top of the plant. Few fruit were retained above 16 nodes.





Impact on plant growth

Leaves: the primary effect of the herbicide was on the leaves that developed following the exposure, causing an increase in leaf production, mainly through the production of small, distorted leaves. Total leaf area and light interception were not seriously affected.

Squares: most squares initiated before the herbicide exposure were retained and developed normally. The plant produced a few additional late squares.

Bolls: most bolls were retained, although there was some loss of later bolls, resulting in an increase in average boll size.

Plant: the plant responded to the herbicide exposure with some additional vegetative growth, producing an additional 1.5 nodes and 1.5 cm in height. Internode length was reduced slightly following the exposure.

Final plant count data

	Untreated	Gly + 2,4-D
Height (cm)	73.9	75.2
Nodes/plant	21.5	23.9
Internode length (post-spray)	2.5	2.1
Leaves/m	502	559
Light interception	87%	83%
Leaf area (cm²/m)	22921	18760
Reduction in leaf area		18%
Bolls/m	114	80
Boll weight (g/boll)	4.4	5.5
Days to 50% open	154	179
Maturity delay (days)		25
% Open bolls at picking	82%	62%
Lint yield/ha	1649	1377

Glyphosate + 2,4-D exposure at 16 nodes caused deformation of all new growth and a loss of some fruit.

The plant compensated for the damage by producing some late square, but none of these developed to produce harvestable bolls.

Most early bolls were retained.

The damage caused a 16% lint yield loss and a 25 day delay in crop maturity.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: Glyphosate + 2,4-D
Rate: 173 + 80 g a.i./ha
Date of exposure: 12th Dec (4 weeks post-emergence)
Growth stage at exposure: 6 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide groups: M + I

Glyphosate

Translocation: moves throughout the plant to growth points
Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis.
Residual activity: none
Soil half-life: 47 days in moist soil

2,4-D

Translocation: readily moves to the plant growth points
Mode of action: An auxin-type (phenoxy) herbicide that affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause uncontrolled cell division & growth, leading to plant death.
Residual activity: limited
Soil half-life: 10 days in moist soil

Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 250 + 100 g/ha to 6 node cotton. Photo taken on 5th Jan, 24 days after exposure.

Leaves on the main stem were severely affected by the 2,4-D, with severe leaf distortion on all subsequent growth.

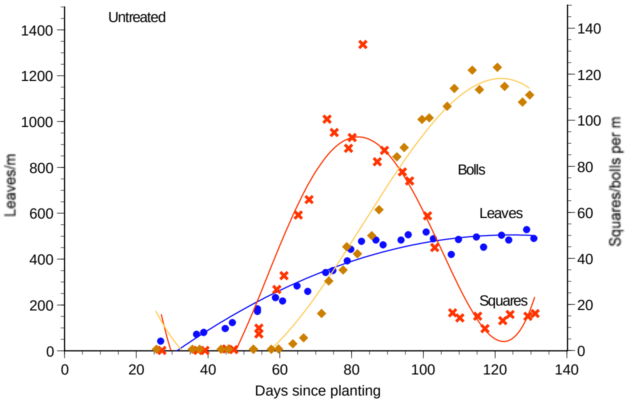
Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 250 + 100 g/ha to 6 node cotton. Photo taken on 5th Jan, 24 days after exposure.

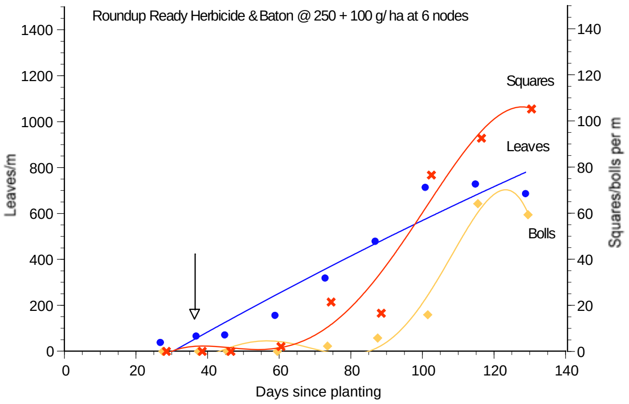
The new leaves on the main stem were severely distorted by the herbicide. Leaves were narrow, cupped, twisted and leathery, with prominent veins. These symptoms are typical of 2,4-D damage.

There were no obvious signs of glyphosate damage.

Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 250 + 100 g/ha to 6 node cotton. Photo taken on 24th Mar, 102 days after exposure.

This plate shows a close-up of the main stem of the plant which continued to produce distorted leaves throughout the season The growth on the vegetative branches was largely unaffected by the herbicides.





Impact on plant growth

Leaves: the 2,4-D exposure initially caused bending and twisting of the petioles (leaf stems), giving a wilted appearance. This effect was transitory.

The primary effect was on leaves that developed following the exposure, causing an increase in leaf production, mainly through the production of small, distorted leaves on the main stem.

Leaves which developed on the vegetative branches were not affected by the herbicides.

Squares: most of the early squares were shed following the herbicide exposure, but later squares were retained and developed.

Bolls: most early bolls were shed, but later bolls were retained and developed. The plant produced a large number of these late bolls, but most didn't reach maturity.

Plant: growth on the main stem responded vegetatively, producing an additional 2 nodes, but plant height was reduced due to a decrease in internode length.

Final plant count data		
	Untreated	**Gly + 2,4-D**
Height (cm)	73.9	71.7
Nodes/plant	21.5	23.2
Internode length (post-spray)	4.1	3.4
Leaves/m	502	683
Light interception	87%	87%
Leaf area (cm²/m)	22921	11741
Reduction in leaf area		49%
Bolls/m	114	60
Boll weight (g/boll)	4.4	1.3
Days to 50% open	154	-
Maturity delay (days)		-
% Open bolls at picking	82%	27%
Lint yield/ha	1649	747

Heavy glyphosate + 2,4-D exposure at 6 nodes caused extensive leaf deformation on the main stem and a loss of fruit from the main stem.

The plant compensated for this damage, setting the crop on the vegetative branches, producing a late crop, with a delay in crop maturity. Most of these bolls were small and still green at harvest.

The damage caused a 55% reduction in lint yield, with only 27% of bolls mature at picking.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: Glyphosate + 2,4-D
Rate: 173 + 80 g a.i./ha
Date of exposure: 21st Dec
(5½ weeks post-emergence)
Growth stage at exposure: 8 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide groups: M + I

Glyphosate

Translocation: moves throughout the plant to growth points
Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis.
Residual activity: none
Soil half-life: 47 days in moist soil

2,4-D

Translocation: readily moves to the plant growth points
Mode of action: An auxin-type (phenoxy) herbicide. 2,4-D affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause uncontrolled cell division & growth, leading to plant death.
Residual activity: limited
Soil half-life: 10 days in moist soil

Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 250 + 100 g/ha to 8 node cotton. Photo taken on 5th Jan, 15 days after exposure.

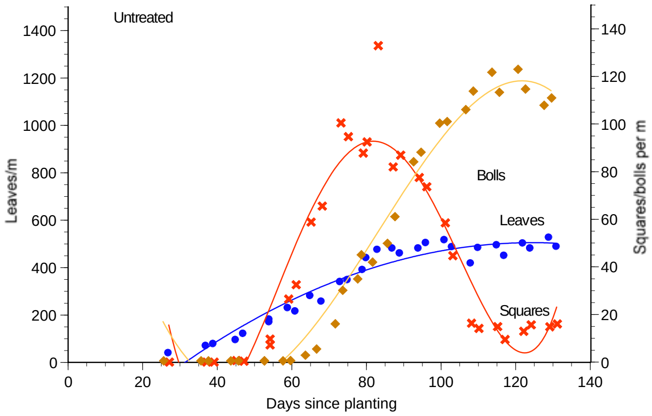
New leaves were severely affected by the 2,4-D, with severe leaf distortion on all subsequent growth. The stems and petioles were bent and distorted.

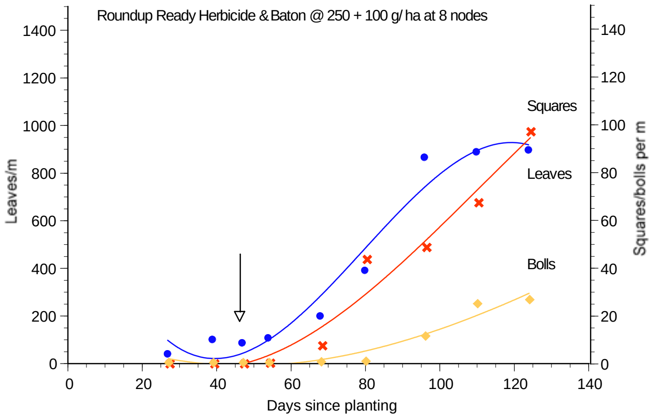
Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 250 + 100 g/ha to 8 node cotton. Photo taken on 25th Jan, 35 days after exposure.

All new leaves were severely distorted by the herbicide. Leaves were narrow, cupped, twisted and leathery, with prominent veins. These symptoms are typical of 2,4-D damage. Glyphosate damage was not apparent.

Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 250 + 100 g/ha to 8 node cotton. Photo taken on 24th Mar, 93 days after exposure.

The plant produced distorted growth on the main stem and most vegetative branches throughout the season, but the growth on the later vegetative branches was largely unaffected by the herbicides.





Impact on plant growth

Leaves: the 2,4-D exposure initially caused bending and twisting of the petioles (leaf stems), giving a wilted appearance. This effect was transitory.

The primary effect was on leaves that developed following the exposure, causing an increase in leaf production, mainly through the production of small, distorted leaves. Total leaf area was reduced by 43%.

Normal leaves developed on some of the later vegetative branches.

Squares: most of the early squares were shed following the herbicide exposure, but later squares were retained and developed.

Bolls: most early bolls were shed. Some later bolls were retained and developed, but these bolls were very small and few reached maturity.

Plant: growth responded vegetatively, producing an additional 2.5 nodes, and an additional 4.5 cm in height.

Final plant count data		
	Untreated	**Gly + 2,4-D**
Height (cm)	73.9	78.4
Nodes/plant	21.5	23.9
Internode length (post-spray)	4.2	3.8
Leaves/m	502	895
Light interception	87%	73%
Leaf area (cm²/m)	22921	13132
Reduction in leaf area		43%
Bolls/m	114	26
Boll weight (g/boll)	4.4	0.6
Days to 50% open	154	-
Maturity delay (days)		-
% Open bolls at picking	82%	10%
Lint yield/ha	1649	453

Heavy glyphosate + 2,4-D exposure at 8 nodes caused extensive leaf deformation on the main stem and most vegetative branches, and a loss of fruit.

The plant compensated for this damage by setting a very late crop. Most of these bolls were very small and green at harvest.

The damage caused a 73% reduction in lint yield, with only 10% of bolls mature at picking.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

		Damage key:	
Herbicide:	**Glyphosate + 2,4-D**	Leaf loss	
Rate:	**173 + 80 g a.i./ha**	Leaf distortion	x
Date of exposure:	**4th Jan** (7½ weeks post-emergence)	Petiole distortion	x
Growth stage at exposure:	**12 nodes**	Plant stunting	
		Square shedding	x
		Boll shedding	x

Herbicidal action

Herbicide groups: M + I

Glyphosate

Translocation: moves throughout the plant to growth points
Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis.
Residual activity: none
Soil half-life: 47 days in moist soil

2,4-D

Translocation: readily moves to the plant growth points
Mode of action: An auxin-type (phenoxy) herbicide. 2,4-D affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause uncontrolled cell division & growth, leading to plant death.
Residual activity: limited
Soil half-life: 10 days in moist soil

Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 250 + 100 g/ha to 12 node cotton. Photo taken on 25th Jan, 21 days after exposure.

All new leaves were severely distorted. Leaves were narrow, cupped, twisted and leathery, with prominent veins. These symptoms are typical of 2,4-D damage. Glyphosate damage was not apparent on these plants.

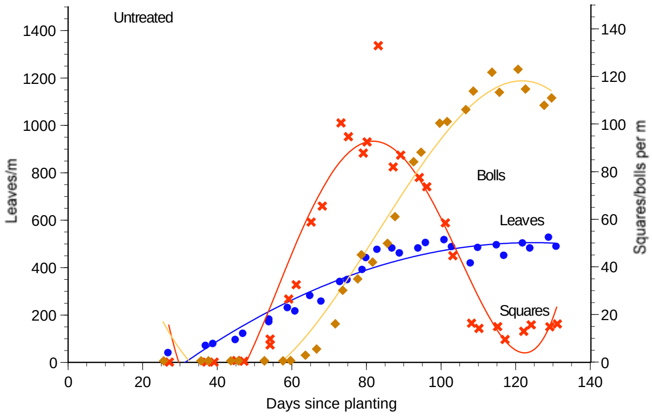
Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 250 + 100 g/ha to 12 node cotton. Photo taken on 25th Jan, 21 days after exposure.

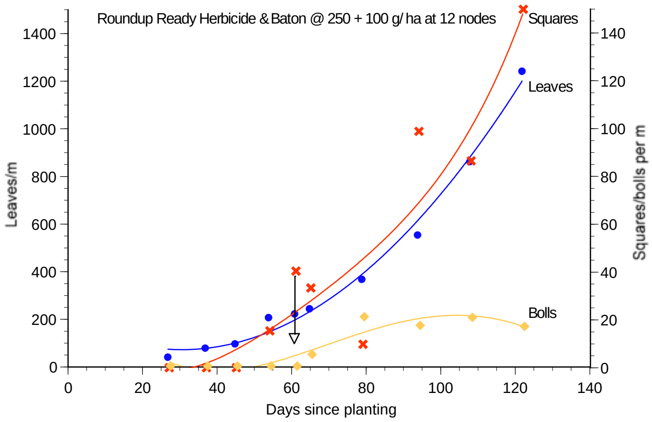
A close-up of the plants in the previous photo.

Older leaves showed some damage, with cupping and distorted edges. Newly emerging leaves were severely distorted. Leaves were narrow, cupped, twisted and leathery, with prominent veins.

Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 250 + 100 g/ha to 12 node cotton. Photo taken on 8th Mar, 63 days after exposure.

The plant continued to produce distorted growth throughout the remainder of the season. This growth was still obvious at picking.





Impact on plant growth

Leaves: the 2,4-D exposure initially caused bending and twisting of the petioles (leaf stems), giving a wilted appearance. This effect was transitory.

The primary effect was on leaves that developed following the exposure, causing an increase in leaf production, mainly through the production of small, distorted leaves. Total leaf area was reduced by 41%.

Squares: most early squares were shed following the herbicide exposure. The plant produced masses of later squares, but many of these were distorted and failed to develop normally.

Bolls: most bolls were shed thoughout the season. Bolls which were retained were very small and few reached maturity.

Plant: growth responded vegetatively, producing an additional 3.5 nodes, but these nodes were very short, giving a 8 cm reduction in final plant height.

Final plant count data		
	Untreated	**Gly + 2,4-D**
Height (cm)	73.9	66.0
Nodes/plant	21.5	25.0
Internode length (post-spray)	4.5	2.5
Leaves/m	502	1239
Light interception	87%	67%
Leaf area (cm^2/m)	22921	13609
Reduction in leaf area		41%
Bolls/m	114	17
Boll weight (g/boll)	4.4	0.9
Days to 50% open	154	-
Maturity delay (days)		-
% Open bolls at picking	82%	31%
Lint yield/ha	1649	190

Heavy glyphosate + 2,4-D exposure at 12 nodes caused extensive deformation of all new growth and a loss of fruit.

The plant compensated for the damage by producing a mass of late square, but almost none of these developed. Most of the bolls which were retained were very small and green at harvest.

The damage caused an 88% reduction in lint yield, with only 5 bolls/m mature at picking.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: glyphosate + 2,4-D
Rate: 173 + 80 g a.i./ha
Date of exposure: 24th Jan (10 weeks post-emergence)
Growth stage at exposure: 16 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide groups: M + I

Glyphosate

Translocation: moves throughout the plant to growth points
Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis
Residual activity: none
Soil half-life: 47 days in moist soil

2,4-D

Translocation: readily moves to the plant growth points
Mode of action: An auxin-type (phenoxy) herbicide that affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause uncontrolled cell division & growth, leading to plant death.
Residual activity: limited
Soil half-life: 10 days in moist soil

Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 250 + 100 g/ha to 16 node cotton. Photo taken on 10th Feb, 17 days after exposure.

All new leaves were severely distorted. Leaves were narrow, cupped, twisted and leathery, with prominent veins. These symptoms are typical of 2,4-D damage. Glyphosate damage was not apparent on these plants.

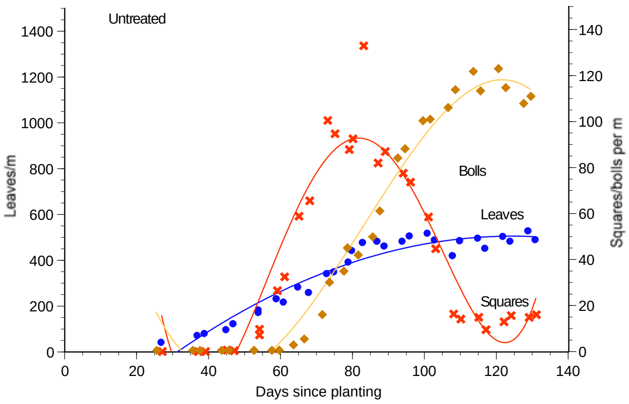
Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 250 + 100 g/ha to 16 node cotton. Photo taken on 10th Feb, 17 days after exposure.

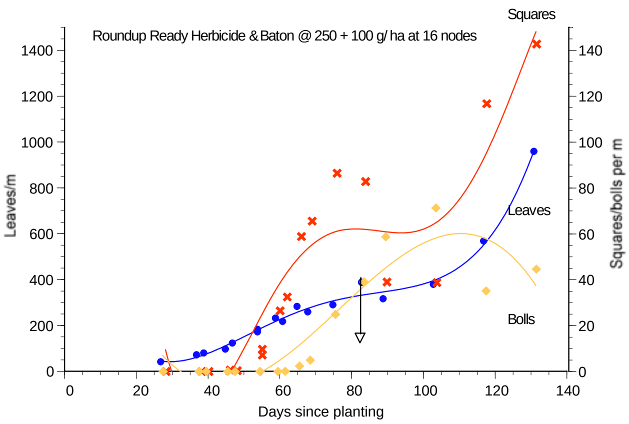
A close-up of the plants in the previous photo.

Some older leaves showed damage, with cupping and distorted edges. Newly emerging leaves were severely distorted. Leaves were narrow, cupped, twisted and leathery, with prominent veins. Petioles and stems at the top of the plant were twisted.

Roundup Ready Herbicide (glyphosate) and Baton (2,4-D amine) applied in combination broadcast at 250 + 100 g/ha to 16 node cotton. Photo taken on 24th Mar, 59 days after exposure.

The plant continued to produce distorted growth throughout the remainder of the season. This growth was still obvious at picking.





Impact on plant growth

Leaves: the 2,4-D exposure initially caused bending and twisting of the petioles (leaf stems), giving a wilted appearance. This effect was transitory.

The primary effect was on leaves that developed following the exposure, causing an increase in leaf production, mainly through the production of small, distorted leaves. Total leaf area was not affected, but light interception was reduced.

Squares: most squares were shed following the herbicide exposure. The plant produced masses of later squares, but many of these were distorted and failed to develop normally.

Bolls: most bolls set before the herbicide exposure were retained. The plant retained few later bolls. The bolls which were retained were small and few reached maturity.

Plant: growth responded vegetatively to the herbicide exposure, producing an additional 4 nodes and 8 cm in height.

Final plant count data		
	Untreated	**Gly + 2,4-D**
Height (cm)	73.9	82.2
Nodes/plant	21.5	25.3
Internode length (post-spray)	2.5	2.8
Leaves/m	502	956
Light interception	87%	74%
Leaf area (cm^2/m)	22921	20155
Reduction in leaf area		12%
Bolls/m	114	45
Boll weight (g/boll)	4.4	2.3
Days to 50% open	154	164
Maturity delay (days)		10
% Open bolls at picking	82%	70%
Lint yield/ha	1649	780

Heavy glyphosate + 2,4-D exposure at 16 nodes caused extensive deformation of all new growth and a loss of fruit.

The plant compensated for the damage by producing a mass of late square, but none of these developed to produce harvestable bolls. The bolls which were retained were small and green at harvest.

The damage caused a 10 days delay in crop maturity and a 53% reduction in lint yield.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	**paraquat + diquat**
Rate:	**43 + 37 g a.i./ha**
% of typical field rate	**10%**
Date of exposure:	**12th Nov** (6 weeks post-emergence)
Growth stage at exposure:	**6 nodes**

Damage key:	
Leaf loss	x
Leaf distortion	
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: L
Translocation: paraquat & diquat are contact herbicides with minimal translocation
Mode of action: inhibit photosynthesis at photosystem 1 and react to destroy unsaturated lips, fatty acids and chlorophyll
Residual activity: none
Soil half-life: 1000 days, but are strongly adsorbed to soil and are biologically inactive

Spray.Seed® (paraquat + diquat) applied broadcast at 320 ml/ha to 6 node cotton. Photo taken on 15th Nov, 3 days after exposure.

Symptoms of paraquat & diquat damage were apparent soon after exposure, with dead spots on the leaves. Paraquat & diquat are not translocated within the plant. Some leaves were completely unaffected, as they were shielded by other plant material and not exposed to the herbicides.

Spray.Seed® (paraquat + diquat) applied broadcast at 320 ml/ha to 6 node cotton. Photo taken on 22nd Nov, 10 days after exposure.

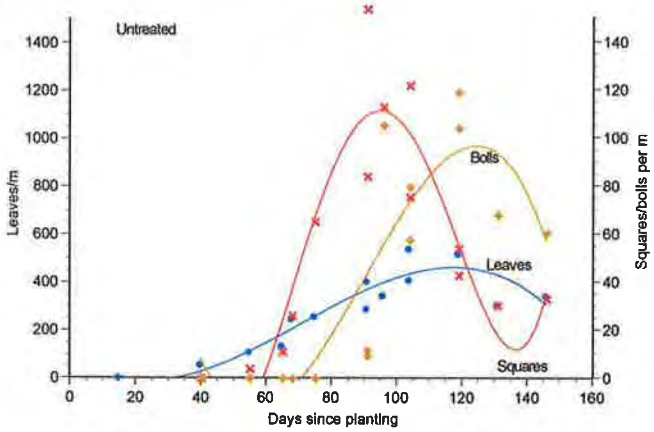
Plants had resumed normal growth. Some herbicide damage (dead spots) was still apparent on older leaves.

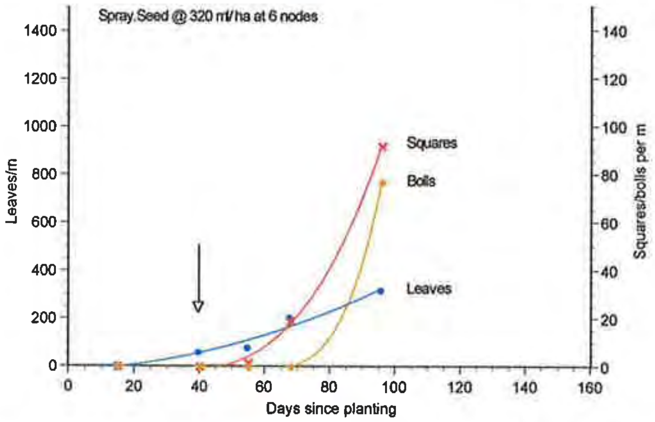
Spray.Seed® (paraquat + diquat) applied broadcast at 320 ml/ha to 6 node cotton. Photo taken on 11th Dec, 29 days after exposure.

Plants were growing normally with little delay in crop development.

Spray.Seed® (paraquat + diquat) applied broadcast at 320 ml/ha to 6 node cotton. Photo taken on 2nd Jan, 51 days after exposure.

Plants were growing normally.





Impact on plant growth

Leaves: exposure to the 10% rate of Spray.Seed caused minor damage to leaves and delayed growth and development, reducing leaf area by 26% at 56 days after exposure. Leaf number was only down 9% at this time.

Squares: square production was delayed by about 10 days by the herbicide.

Bolls: boll production and retention were largely unaffected.

There was a 17% reduction in the retention of mature bolls at picking and a 13% reduction in fruit retention on nodes 10 - 20. Mature bolls were retained up to node 26, a similar retention pattern to the undamaged plants.

Final plant count data		
	Untreated	**Spray.Seed**
Nodes/plant	27.8	27.3
Leaves/m*	342	313
Leaf area (cm²/m)*	16870	12502
Reduction in leaf area*		26%
Bolls/m	176	145
Boll weight (g/boll)	4.8	4.8
Bolls/node (nodes 10-20)#	0.86	0.75
Days to 50% open	183	187
Maturity delay (days)		4
% Open bolls at picking	86%	80%
Lint yield/ha	2147	2068

Exposure to 10% of a typical field rate of Spray.Seed at 6 nodes damaged many leaves but did not defoliate or kill the plants. Plants quickly recovered from this damage.

The herbicide exposure had little impact on square and boll production and retention. Crop maturity was also little affected and lint yield was not reduced.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 to 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: paraquat + diquat
Rate: 43 + 37 g a.i./ha
% of typical field rate 10%
Date of exposure: 5th Dec (9 weeks post-emergence)
Growth stage at exposure: 11 nodes

Damage key:	
Leaf loss	x
Leaf distortion	
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: L
Translocation: paraquat & diquat are contact herbicides with minimal translocation
Mode of action: inhibit photosynthesis at photosystem 1 and react to destroy unsaturated lips, fatty acids and chlorophyll
Residual activity: none
Soil half-life: 1000 days, but are strongly adsorbed to soil and are biologically inactive

Spray.Seed® (paraquat + diquat) applied broadcast at 320 ml/ha to 11 node cotton. Photo taken on 11th Dec, 6 days after exposure.

Symptoms of paraquat & diquat damage were apparent soon after exposure, with necrotic spots on many leaves and many completely dead leaves. Some leaves were unaffected as they were shielded by other plant material and not exposed to the herbicide.

Spray.Seed® (paraquat + diquat) applied broadcast at 320 ml/ha to 11 node cotton. Photo taken on 21st Dec, 16 days after exposure.

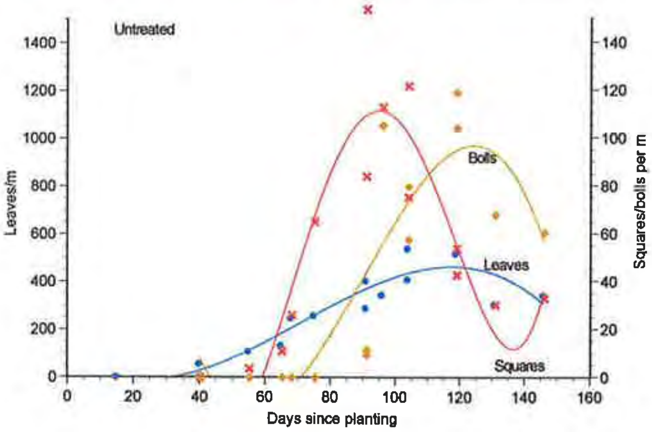
Plants had resumed normal growth. Some herbicide damage, necrotic spots and dead leaves were still apparent.

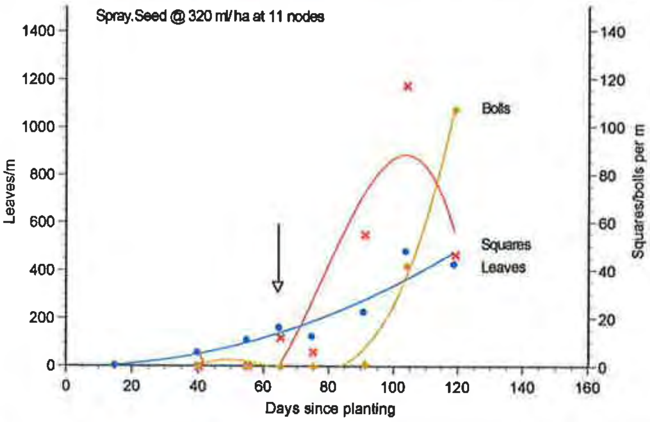
Spray.Seed® (paraquat + diquat) applied broadcast at 320 ml/ha to 11 node cotton. Photo taken on 2nd Jan, 28 days after exposure.

Plants were growing normally, with little delay in crop development.

Spray.Seed® (paraquat + diquat) applied broadcast at 320 ml/ha to 11 node cotton. Photo taken on 14th Jan, 40 days after exposure.

Plants were growing normally.





Impact on plant growth

Leaves: the 10% rate of Spray.Seed desiccated many of the exposed leaves and delayed growth and development. However, plants rapidly recovered and by 56 days after exposure had a 25% greater leaf area than undamaged plants.

Squares: square production was delayed by about 10 days, with many squares shed in the first 20 days after exposure.

Bolls: initial boll production was delayed about 20 days and final boll retention was reduced by 14%. There was a 9% reduction in boll weight and a 28% reduction in fruit retention on nodes 10 to 20.

Mature bolls were retained up to node 20, six nodes fewer than on undamaged plants.

Final plant count data		
	Untreated	**Spray.Seed**
Nodes/plant	27.8	27.3
Leaves/m*	517	424
Leaf area (cm²/m)*	10030	12573
Reduction in leaf area*		-
Bolls/m	176	151
Boll weight (g/boll)	4.8	4.4
Bolls/node (nodes 10-20)#	0.86	0.62
Days to 50% open	183	192
Maturity delay (days)		9
% Open bolls at picking	86%	78%
Lint yield/ha	2147	1173

Plants recovered quickly from exposure to 10% of a typical field rate of Spray.Seed.

There was an initial reduction in leaf number and leaf area, but plants quickly compensated for this damage. There were small reductions in fruit retention and boll weight and a 9 day delay in crop maturity. 10% fewer bolls were open at picking. These small delays and reductions combined to give a 45% yield reduction compared to the untreated plots.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide:	paraquat + diquat
Rate:	43 + 37 g a.i./ha
% of typical field rate	10%
Date of exposure:	2nd Jan (13 weeks post-emergence)
Growth stage at exposure:	15 nodes

Damage key:	
Leaf loss	x
Leaf distortion	
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: L
Translocation: paraquat & diquat are contact herbicides with minimal translocation
Mode of action: they inhibit photosynthesis at photosystem 1 and react to destroy unsaturated lips, fatty acids and chlorophyll
Residual activity: none
Soil half-life: 1000 days, but are strongly adsorbed to soil and are biologically inactive

Spray.Seed® (paraquat + diquat) applied broadcast at 320 ml/ha to 15 node cotton. Photo taken on 4th Jan, 2 days after exposure.

Symptoms of paraquat & diquat damage become apparent soon after exposure, with necrotic spots on most leaves and some completely dead leaves. Some leaves remained unaffected as they were shielded by other plant material and not exposed to the herbicide.

Spray.Seed® (paraquat + diquat) applied broadcast at 320 ml/ha to 15 node cotton. Photo taken on 7th Jan, 5 days after exposure.

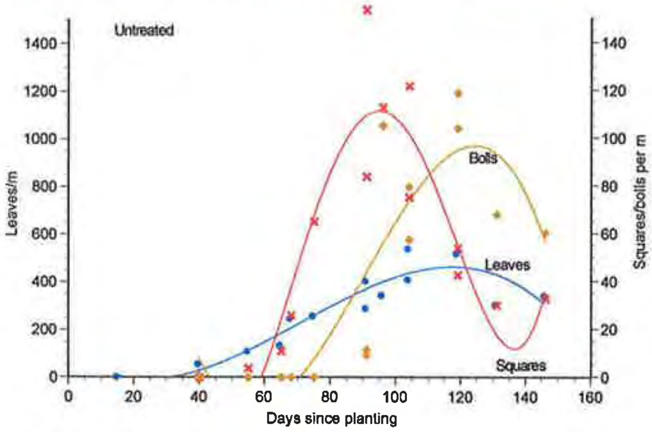
Many of the worst affected leaves had died and some had fallen from the plants. Most remaining leaves had necrotic spots.

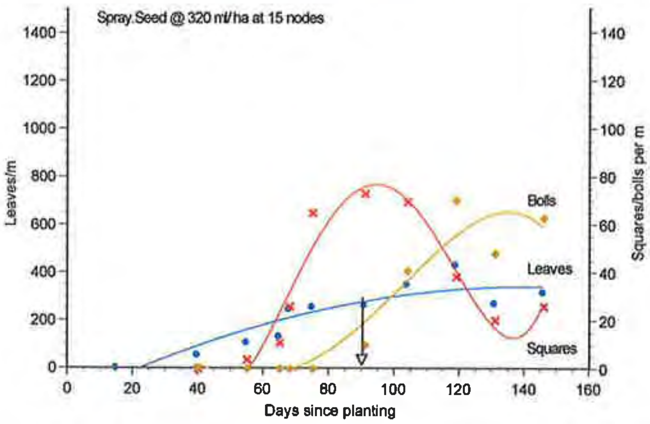
Spray.Seed® (paraquat + diquat) applied broadcast at 320 ml/ha to 15 node cotton. Photo taken on 14th Jan, 12 days after exposure.

Plants had largely resumed normal growth within 2 weeks of herbicide exposure. Some dead leaves and necrotic spots were still evident.

Spray.Seed® (paraquat + diquat) applied broadcast at 320 ml/ha to 15 node cotton. Photo taken on 25th Jan, 23 days after exposure.

Plants were growing normally, although necrotic spots were still obvious on some of the lower leaves.





Impact on plant growth

Leaves: the 10% rate of Spray.Seed desiccated many of the exposed leaves and delayed crop growth and development. However, plants rapidly recovered and by 55 days after exposure had only an 8% reduction in leaf number and 16% reduction in leaf area.

Squares: peak square production was reduced by the exposure.

Bolls: peak boll production was also reduced and delayed by about 10 days. The final retention of mature bolls was reduced by 33%. There was a 16% reduction in boll weight and a 25% reduction in fruit retention on nodes 10 - 20.

Mature bolls were retained to node 26, similar to the retention on undamaged plants.

Final plant count data		
	Untreated	**Spray.Seed**
Nodes/plant	27.8	29.4
Leaves/m*	341	314
Leaf area (cm²/m)*	19630	16450
Reduction in leaf area*		16%
Bolls/m	176	119
Boll weight (g/boll)	4.8	4.0
Bolls/node (nodes 10-20)#	0.86	0.65
Days to 50% open	183	192
Maturity delay (days)		9
% Open bolls at picking	86%	78%
Lint yield/ha	2147	1594

Exposure to 10% of a typical field rate of Spray.Seed at 15 nodes caused necrotic spots on most leaves and killed some leaves. However, plants recovered quickly from this damage.

Some early-season squares and bolls were shed. The plants did partially compensate, retaining additional late-season fruit, but with reduced boll weight, a 9 day delay in crop maturity and a 26% reduction in lint yield.

Note* Leaf number and leaf area were last recorded 55 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: paraquat + diquat
Rate: 216 + 184 g a.i./ha
% of typical field rate 50%
Date of exposure: 12th Nov (6 weeks post-emergence)
Growth stage at exposure: 6 nodes

Damage key:	
Leaf loss	x
Leaf distortion	
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: L
Translocation: paraquat & diquat are contact herbicides with minimal translocation
Mode of action: they inhibit photosynthesis at photosystem 1 and react to destroy unsaturated lips, fatty acids and chlorophyll
Residual activity: none
Soil half-life: 1000 days, but are strongly adsorbed to soil and are biologically inactive

Spray.Seed® (paraquat + diquat) applied broadcast at 1.6 L/ha to 6 node cotton. Photo taken on 15th Nov, 3 days after exposure.

Symptoms of paraquat & diquat damage became apparent almost immediately after exposure, with rapid burning of the leaf and stem tissues. There was some petiole twisting and death of most leaves at this relatively high rate. However, paraquat & diquat are not translocated within the plant. Some leaves were completely unaffected as they were shielded by other plant material and not directly exposed to the herbicide.

Spray.Seed® (paraquat + diquat) applied broadcast at 1.6 L/ha to 6 node cotton. Photo taken on 22nd Nov, 10 days after exposure.

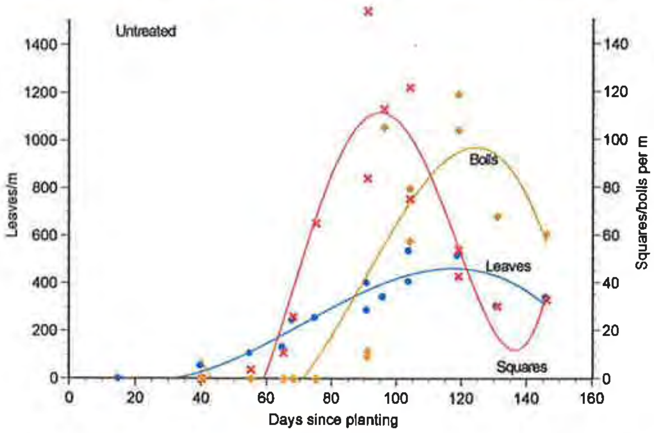
Surviving plants had resumed normal growth, although herbicide damage (dead leaves) was still obvious.

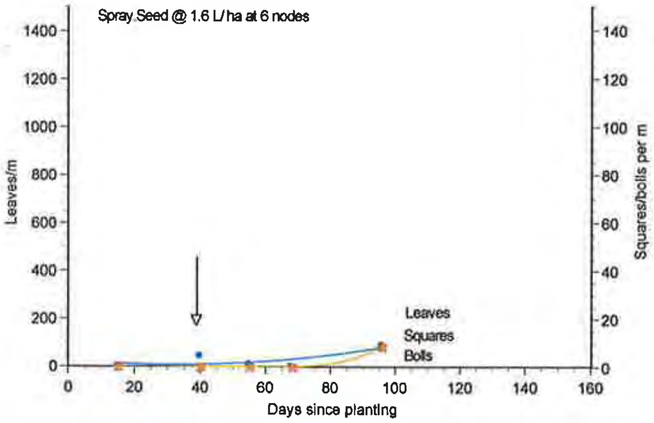
Spray.Seed® (paraquat + diquat) applied broadcast at 1.6 L/ha to 6 node cotton.. Photo taken on 11th Dec, 29 days after exposure.

Plants where all leaf material was killed died soon after exposure. Plants which had some unaffected leaf material generally survived and were growing normally.

Spray.Seed® (paraquat + diquat) applied broadcast at 1.6 L/ha to 6 node cotton. Photo taken on 2nd Jan, 51 days after exposure.

Plants were growing completely normally.





Impact on plant growth

Leaves: the 50% Spray.Seed exposure killed most plants and plant material, causing about 70% plant mortality, with large gaps in the plant stand and a delay in growth of surviving plants of around 60 days. Leaf number was reduced by 74% mid-season and leaf area by 89%.

There was no ongoing effect on surviving plants beyond the initially large reduction in leaf number and area.

Squares: square production was delayed by about 30 days.

Bolls: boll production was also delayed, but surviving plants developed a good load of large bolls.

Mature bolls were retained up to node 25, a similar retention pattern to the undamaged plants.

Final plant count data		
	Untreated	**Spray.Seed**
Nodes/plant	27.8	29.7
Leaves/m*	342	89
Leaf area (cm²/m)*	16870	1840
Reduction in leaf area*		89%
Bolls/m	176	126
Boll weight (g/boll)	4.8	4.2
Bolls/node (nodes 10-20)#	0.86	1.58
Days to 50% open	183	211
Maturity delay (days)		28
% Open bolls at picking	86%	89%
Lint yield/ha	2147	607

Exposure to 50% of a typical field rate of Spray.Seed at 6 nodes defoliated and killed a high proportion of plants.

Surviving plants grew normally, with a high retention of mature bolls in nodes 10 - 20.

Nevertheless, lint yield was reduced by 72% and crop maturity delayed by 28 days. The large reduction in yield from this herbicide exposure was mostly due to the large reduction in the plant stand, with large gaps between some plants.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: paraquat + diquat
Rate: 216 + 184 g a.i./ha
% of typical field rate 50%
Date of exposure: 5th Dec (9 weeks post-emergence)
Growth stage at exposure: 11 nodes

Damage key:	
Leaf loss	x
Leaf distortion	
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: L
Translocation: paraquat & diquat are contact herbicides with minimal translocation
Mode of action: they inhibit photosynthesis at photosystem 1 and react to destroy unsaturated lips, fatty acids and chlorophyll
Residual activity: none
Soil half-life: 1000 days, but are strongly adsorbed to soil and are biologically inactive

Spray.Seed® (paraquat + diquat) applied broadcast at 1.6 L/ha to 11 node cotton. Photo on 11th Dec, 6 days after exposure.

Symptoms of spray damage become apparent almost immediately after exposure, with rapid burning of the leaf and stem tissues. Most leaves were killed at this rate. However, paraquat & diquat were not translocated within the plant. Some leaves were unaffected as they were shielded by other plant material and not exposed to the herbicide.

Spray.Seed® (paraquat + diquat) applied broadcast at 1.6 L/ha to 11 node cotton. Photo taken on 21st Dec, 16 days after exposure.

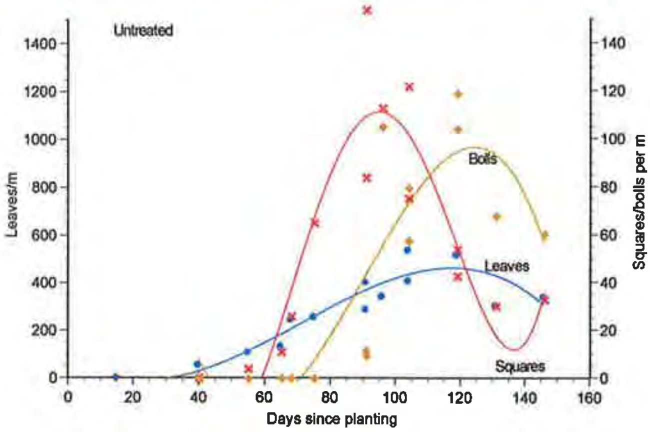
Many plants were killed by the herbicide. Surviving plants were resuming normal growth, although herbicide damage (dead leaves) was still obvious. Growth was generally coming from the lower nodes, which were less affected by the herbicide.

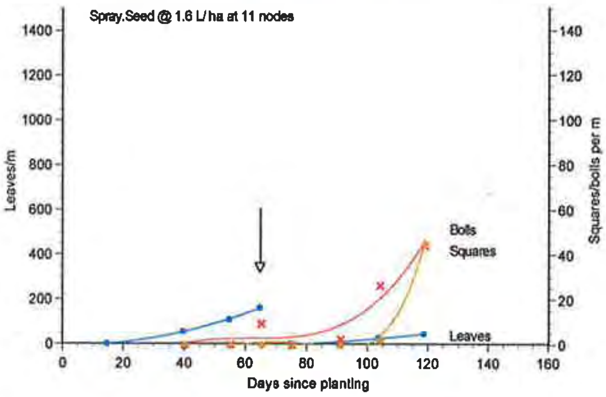
Spray.Seed® (paraquat + diquat) applied broadcast at 1.6 L/ha to 11 node cotton. Photo taken on 2nd Jan, 28 days after exposure.

Plants where all leaf material was killed died soon after exposure. Plants which had some unaffected leaf material generally survived and were beginning to grow normally 28 days after exposure.

Spray.Seed® (paraquat + diquat) applied broadcast at 1.6 L/ha to 11 node cotton. Photo taken on 14th Jan, 40 days after exposure.

Surviving plants were growing normally.





Impact on plant growth

Leaves: the 50% Spray.Seed exposure killed most leaf material and many plants, causing about 60% plant mortality, with large gaps in the plant stand and a delay in growth of surviving plants of around 80 days.

There was no ongoing effect on surviving plants beyond the initially large reduction in leaf number and leaf area. Leaf number was still down by 46% mid-season and leaf area by 72%.

Squares: square production was delayed by about 50 days, with few squares retained before 90 days after planting.

Bolls: boll production was also delayed by about 30 days, but surviving plants developed a reasonable load of large bolls. Mature bolls were retained up to node 22.

Final plant count data

	Untreated	Spray.Seed
Nodes/plant	27.8	22.4
Leaves/m*	517	278
Leaf area (cm²/m)*	10030	2771
Reduction in leaf area*		72%
Bolls/m	176	81
Boll weight (g/boll)	4.8	4.9
Bolls/node (nodes 10-20)#	0.86	0.60
Days to 50% open	183	214
Maturity delay (days)		31
% Open bolls at picking	86%	71%
Lint yield/ha	2147	380

Exposure to 50% of a typical field rate of Spray.Seed at 11 nodes defoliated and killed a high proportion of plants. Surviving plants recovered and grew normally, but with a big reduction in bolls/m due to the reduced plant stand.

Crop maturity was delayed by 31 days and there was a reduction in the percentage of mature bolls at harvest, resulting in a large (82%) reduction in yield in what was a very long season. Yield would have been much lower in a shorter season.

Note* Leaf number and leaf area were last recorded 56 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

Herbicide damage guide for cotton

Photographs & material by: Graham Charles
NSW Dept of Primary Industries

Herbicide: paraquat + diquat
Rate: 216 + 184 g a.i./ha
% of typical field rate 50%
Date of exposure: 2nd Jan
(13 weeks post-emergence)
Growth stage at exposure: 15 nodes

Damage key:	
Leaf loss	x
Leaf distortion	
Petiole distortion	x
Plant stunting	x
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: L
Translocation: paraquat & diquat are contact herbicides with minimal translocation
Mode of action: they inhibit photosynthesis at photosystem 1 and react to destroy unsaturated lips, fatty acids and chlorophyll
Residual activity: none
Soil half-life: 1000 days, but are strongly adsorbed to soil and are biologically inactive

Spray.Seed® (paraquat + diquat) applied broadcast at 1.6 L/ha to 16 node cotton. Photo on 4th Jan, 2 days after exposure.

Symptoms of spray damage become apparent almost immediately after exposure, with rapid burning of the leaves and stem tips. Most leaves had necrotic spots or patches and some leaves were killed. However, paraquat & diquat were not translocated within the plant. Some leaves remained largely unaffected if they were shielded by other plant material and not exposed to the herbicide.

Spray.Seed® (paraquat + diquat) applied broadcast at 1.6 L/ha to 15 node cotton. Photo taken on 7th Jan, 5 days after exposure.

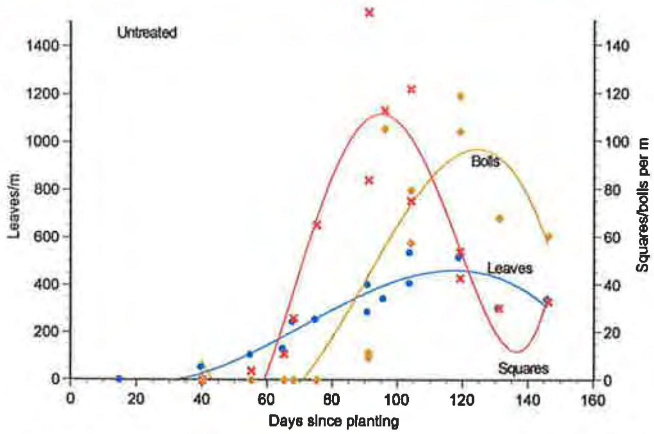
Most leaves and squares had been killed and many have fallen. Some stem tips were also killed. A few green leaves remained, often on the surviving stem tips.

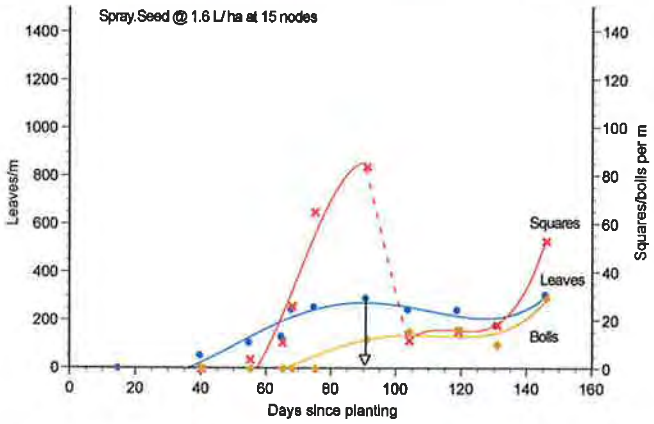
Spray.Seed® (paraquat + diquat) applied broadcast at 1.6 L/ha to 15 node cotton.. Photo taken on 14th Jan, 12 days after exposure.

Plants were beginning to produce new leaves from the stem tips. These leaves were completely normal and showed no symptoms of herbicide damage.

Spray.Seed® (paraquat + diquat) applied broadcast at 1.6 L/ha to 15 node cotton. Photo taken on 11th Feb, 40 days after exposure.

Surviving plants were growing normally, although many "twigs" were still apparent poking through the canopy. These were the ends of the stems which were killed by the herbicide. Necrotic spots remained on many of the lower leaves.





Impact on plant growth

Leaves: the 50% Spray.Seed exposure killed most leaves and some stem tips.

There was no ongoing effect on surviving plants beyond the initially large reduction in leaf number and area. By 55 days after exposure, leaf number was back to 90% and leaf area to 75% of the undamaged plants.

Squares: most squares were killed by the herbicide. Square production was delayed by at least 50 days, with few squares retained before 150 days after planting.

Bolls: boll production was also delayed by several weeks. Plants compensated, setting a very late crop, but the final boll number was well down. At picking, plants retained 48% fewer bolls than comparable undamaged plants and 63% fewer mature bolls. Damaged plants were on average 6 nodes shorter and retained mature boll to node 15, ten nodes fewer than undamaged plants. Boll retention on nodes 10 – 20 was reduced by 25%.

Final plant count data		
	Untreated	**Spray.Seed**
Nodes/plant	27.8	21.5
Leaves/m*	341	306
Leaf area (cm²/m)*	19630	14644
Reduction in leaf area*		25%
Bolls/m	176	64
Boll weight (g/boll)	4.8	3.8
Bolls/node (nodes 10-20)#	0.86	0.31
Days to 50% open	183	219
Maturity delay (days)		36
% Open bolls at picking	86%	60%
Lint yield/ha	2147	461

Exposure to 50% of a typical field rate of Spray.Seed at 15 nodes defoliated most plants and killed most squares. Plants were relatively slow to resume normal growth, with square and boll production delayed by up to 50 days.

Plants did set a late crop, but average maturity was delayed by 36 days and many bolls were still immature at picking. Boll weight was reduced by 21% and yield by 79%, even though picking was delayed till June.

Note* Leaf number and leaf area were last recorded 55 days after exposure.

Note#. Average number of retained mature bolls on nodes 10 - 20.

HERBICIDE DAMAGE SYMPTOMS GUIDE

Graham Charles
(NSW Dept of Primary Industries)

Introduction

This guide shows some of the more typical damage symptoms seen in Australian cotton from exposure to a range of herbicides. Images were obtained from experiments where known rates of herbicide were applied to irrigated cotton at specific growth stages. The symptoms of herbicide damage displayed by cotton plants are affected by the type of herbicide, the herbicide rate, the crop growth stage, and environmental factors such as soil moisture, temperature and humidity. Under different conditions, crops may not display the symptoms of damage indicated in these photos.

Herbicide Damage Symptoms

Phenoxy Herbicides

A range of herbicides, collectively known as the phenoxy herbicides, affect the plant in a manner similar to endogenous auxin (IAA), a natural plant growth hormone. At low rates they can distort plant growth. At higher concentrations they affect cell walls and nucleic acid metabolism and inhibit cell division and growth, leading to plant death. They are effective in controlling a wide range of broad-leaf weeds.

2,4-D – (symptoms from plants exposed to 8 g a.i./ha at 12 nodes) Group I - Phenoxy


15 days after exposure


28 days after exposure

Dicamba – (symptoms from plants exposed to 28 g a.i./ha at 11 nodes) Group I - Phenoxy


6 days after exposure


28 days after exposure

Fluroxypyr – (symptoms from plants exposed to 36 g a.i./ha at 11 nodes) Group I - Phenoxy

6 days after exposure

28 days after exposure

MCPA – (symptoms from plants exposed to 105 g a.i./ha at 11 nodes) Group I - Phenoxy

6 days after exposure

28 days after exposure

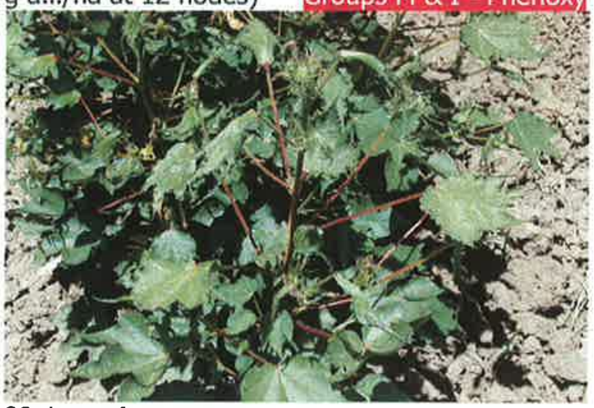
2,4-D plus picloram – (plants exposed to 30 + 7.5 g a.i./ha at 8 nodes) Group I - Phenoxys

7 days after exposure

28 days after exposure

Glyphosate & 2,4-D – (plants exposed to 35 + 8 g a.i./ha at 12 nodes) Groups M & I - Phenoxy

15 days after exposure



28 days after exposure

MCPA plus picloram – (plants exposed to 42 + 2.6 g a.i./ha at 8 nodes)

Group I - Phenoxys

9 days after exposure

28 days after exposure

Triclopyr plus picloram – (plants exposed to 15 + 0.5 g a.i./ha at 8 nodes)

Group I - Phenoxys

7 days after exposure

37 days after exposure

Other Herbicides - Bleachers

A wide range of herbicides other than the phenoxys are commonly used in agriculture and can cause mild to severe damage to cotton. Damaged plants can display a wide range of symptoms, but as with the phenoxys, some symptoms may be fairly general, over a number of herbicides. An example is the Group C herbicides, which disrupt photosynthesis and at lower rates cause leaf bleaching. At higher rates, they can cause necrosis and leaf death.

Atrazine – (symptoms from plants exposed to 200 g a.i./ha at 8 nodes) Group C - Bleacher

15 days after exposure

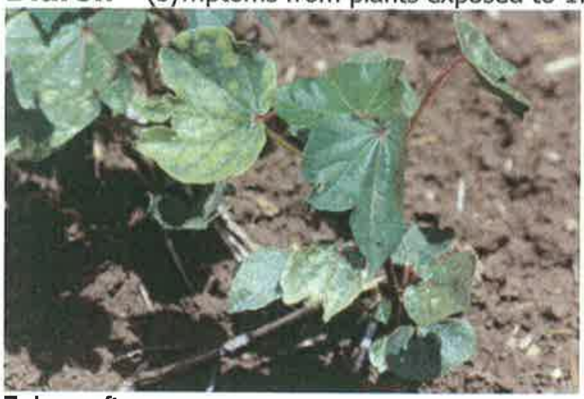
28 days after exposure

Cyanazine – (symptoms from plants exposed to 1.3 kg a.i./ha at 5 nodes) Group C - Bleacher

7 days after exposure

7 days after exposure

Diuron – (symptoms from plants exposed to 1.8 kg a.i./ha at 5 nodes) Group C - Bleacher



7 days after exposure

7 days after exposure

Fluometuron – (symptoms from plants exposed to 1 kg a.i./ha pre-planting)

Group C - Bleacher

Prometryn – (plants exposed to 2.3 kg a.i./ha at 5 nodes and 15 nodes)

Group C - Bleacher

7 days after exposure

Simazine – (symptoms from plants exposed to 1.5 kg a.i./ha at 8 nodes)

Group C - Bleacher

15 days after exposure

28 days after exposure

Glyphosate – (symptoms from plants exposed to glyphosate drift)

Group M - Bleacher

Other Herbicides that may Damage Cotton

Glufosinate – (symptoms from plants exposed to 75 g a.i./ha at 11 nodes) Group N - Desiccant

6 days after exposure

16 days after exposure

Glyphosate – (plants exposed to 35 g a.i./ha at 12 nodes) Group M - Minimal symptoms

6 days after exposure

28 days after exposure

Imazapyr – (symptoms from seedlings exposed to soil residues) Group B

Metsulfuron-methyl – (symptoms from seedlings exposed to soil residues) Group B

Paraquat plus diquat – (plants exposed to 43 + 37 g a.i./ha at 11 nodes) Group Ls - Desiccants

6 days after exposure

16 days after exposure

WEED GROWTH & DEVELOPMENT GUIDE

Graham Charles
(NSW Dept of Primary Industries)

Introduction

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

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

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

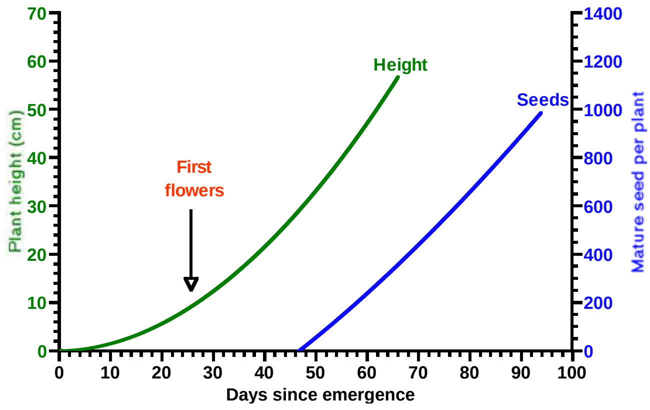
Plant height may often be a better indicator of weed maturity than the time since weed emergence. However, stressed weeds may flower and set seeds while much smaller than is indicated in this guide. If in doubt, check some plants to determine their stage of growth.

Acknowledgement

I gratefully acknowledge the input of Dr. Stephen Johnson (NSW DPI), whose research produced much of the data used to develop this guide.

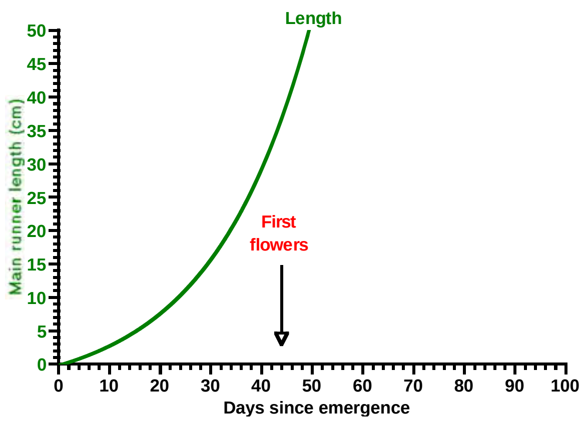
Contents	Page

Anoda (*Anoda cristata*)



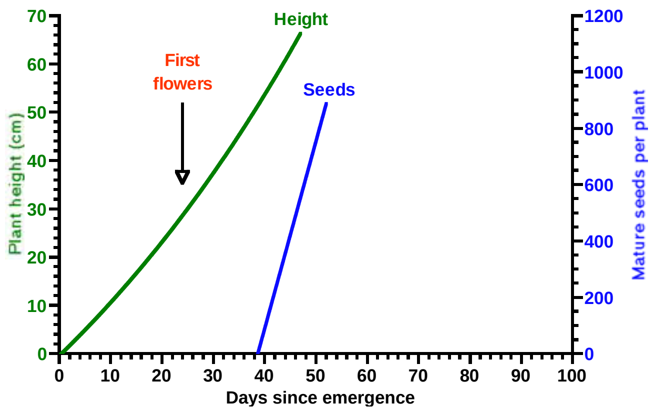
Annual N	
Frost sensitive N	
Emergence	Spring - autumn
Days to emerge	4 - 12
Typical emergence	20%
Depth of emergence	
First flowers	25 days
Mature pods	41 days
Seeds per pod	11 - 14
Seeds per medium plant	4000
Mature plant height	2 m
An introduced weed N	

Australian bindweed (*Convolvulus erubescens*)



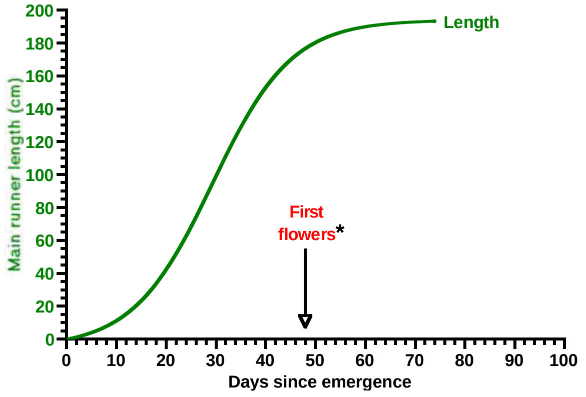
Perennial N	
Frost tolerant N	
Emergence	Autumn - spring
Days to emerge	4 - 9
Typical emergence	2%
Depth of emergence	
First flowers	44 days
Mature pods	
Seeds per pod	4
Seeds per medium plant	100
Mature plant diameter	2 m
A native plant N	

Awnless barnyard grass (*Echinochloa colona*)



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

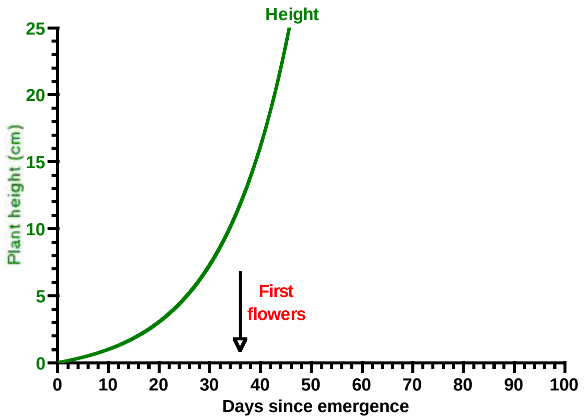
Bellvine (*Ipomoea plebeia*)



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

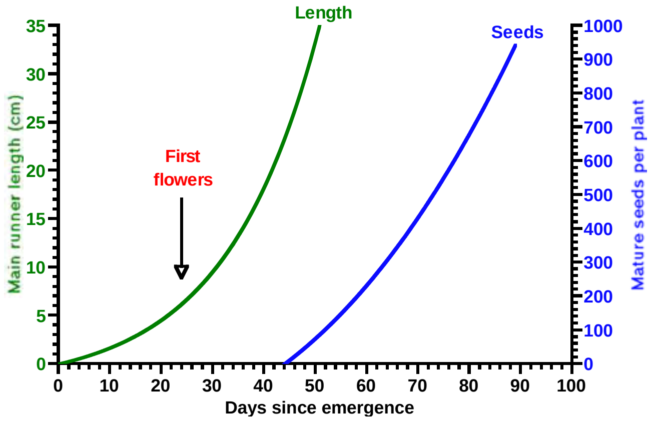
Note* Plants respond to day length and mostly flower in autumn, regardless of plant size.

Blackberry nightshade (*Solanum nigrum*)



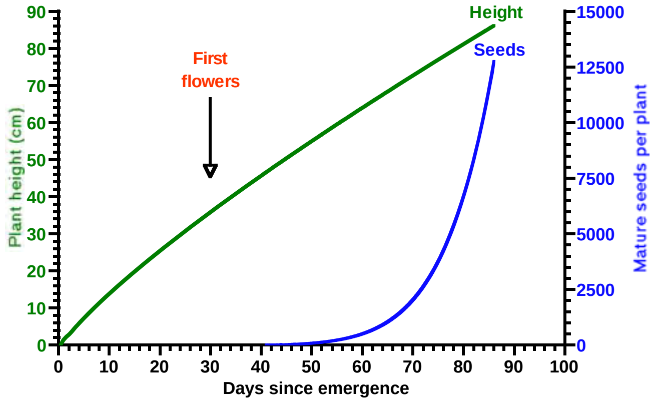
Annual N or short-lived perennial N	
Frost tolerant N	
Emergence	Winter - summer
Days to emerge	6 - 7
Typical emergence	30 - 90%
Depth of emergence	
First flowers	36 days
Mature pods	
Seeds per stem	
Seeds per medium plant	
Mature plant height	0.6 - 1.2 m
An introduced weed N	

Black pigweed (*Trianthema portulactastrum*)



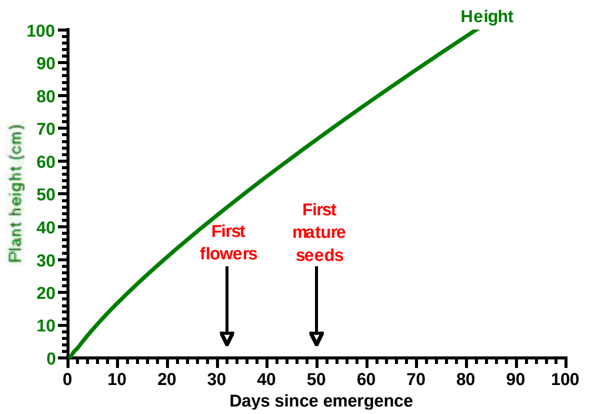
Annual N	
Frost sensitive N	
Emergence	Spring - summer
Days to emerge	4 - 8
Typical emergence	30 - 50%
Depth of emergence	to 7 cm
First flowers	24 days
Mature pods	43 days
Seeds per pod	3 - 15
Seeds per medium plant	7000
Mature plant diameter	0.6 - 1 m
An introduced weed N	

Bladder ketmia – narrow leaf type (*Hibiscus trionum*)



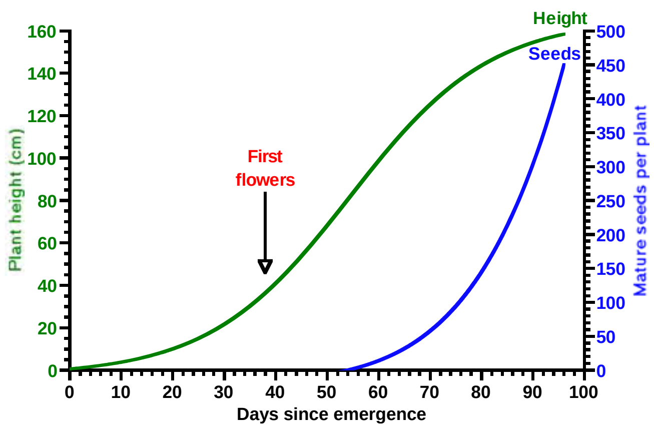
Annual N	
Frost sensitive N	
Emergence	Spring - autumn
Days to emerge	3 - 6
Typical emergence	1 - 10%
Depth of emergence	
First flowers	30 days
Mature seed pods	40 days
Seeds per pod	33
Seeds per medium plant	15 000
Mature plant height	1.3 m

Bladder ketmia – wide leaf type (*Hibiscus trionum*)



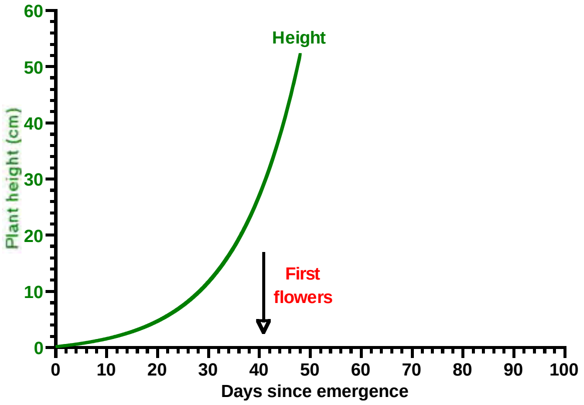
Annual N	
Frost sensitive N	
Emergence	Spring - autumn
Days to emerge	4 - 7
Typical emergence	1 - 10%
Depth of emergence	
First flowers	32 days
Mature seed pods	50 days
Seeds per pod	33
Seeds per medium plant	8000
Mature plant height	1.5 m

Budda pea (*Aeschynomene indica*)



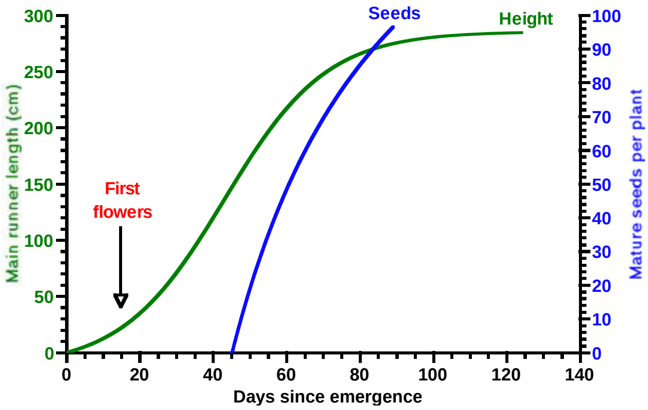
Annual N or short-lived perennial N	
Frost sensitive N	
Emergence	Spring & summer
Days to emerge	11
Typical emergence	20%
Depth of emergence	
First flowers	40 days
Mature seed pods	55 days
Seeds per pod	3 - 9
Seeds per medium plant	1000
Mature plant height	2 m
A native plant N	

Cobbler's pegs (*Bidens pilosa*)



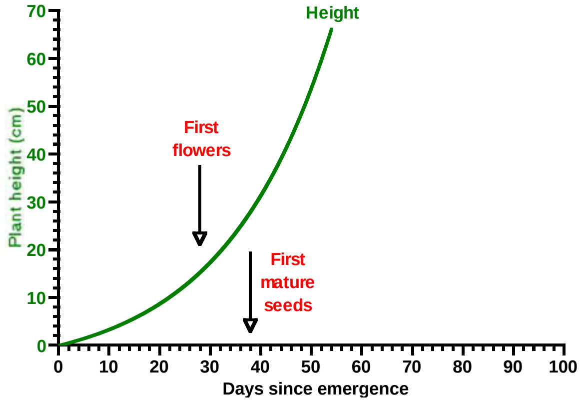
Annual N	
Frost sensitive N	
Emergence	Spring - autumn
Days to emerge	3 - 6
Typical emergence	70 %
Depth of emergence	
First flowers	41 days
Mature seeds	
Seeds per head	
Seeds per medium plant	
Mature plant height	1 m
An introduced weed N	

Cowvine - peachvine (*Ipomoea lonchophylla*)



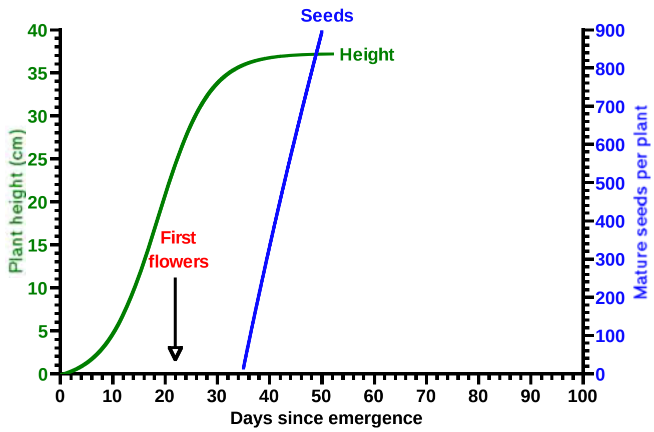
Annual N or short-lived perennial N	
Frost sensitive N	
Emergence	Spring - autumn
Days to emerge	4
Typical emergence	1 - 10%
Depth of emergence	5 cm
First flowers	16 days
Mature seed pods	50 days
Seeds per pod	3 - 4
Seeds per medium plant	1000
Mature plant diameter	2 - 3 m
A native plant N	

Dwarf amaranth (*Amaranthus macrocarpus*)



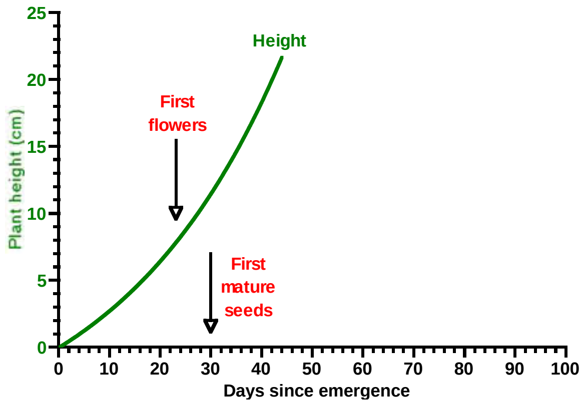
Annual N	
Frost sensitive N	
Emergence	Spring - autumn
Days to emerge	3 - 7
Typical emergence	10 - 50%
Depth of emergence	
First flowers	28 days
Mature seed pods	35 days
Seeds per pod	
Seeds per medium plant	
Mature plant height	0.3 m
A native plant N	

Liverseed grass (*Urochloa panicoides*)



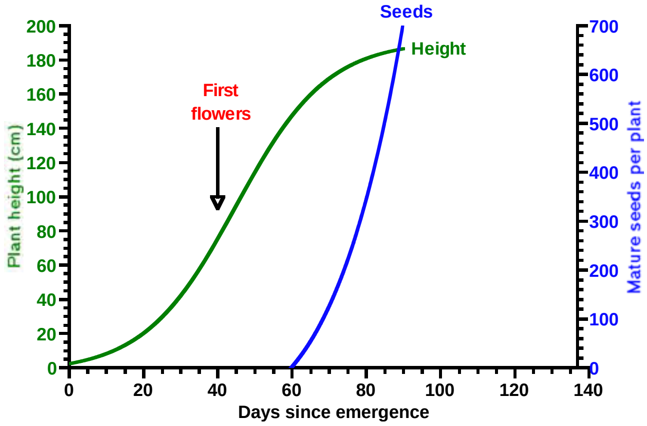
Annual N	
Frost sensitive N	
Emergence	Spring
Days to emerge	5 - 7
Typical emergence	1 - 40%
Depth of emergence	
First flowers	22 days
Mature seeds	38 days
Seeds per stem	20 - 30
Seeds per medium plant	
Mature plant height	0.6 m
An introduced grass N	

Mintweed (*Salvia reflexa*)



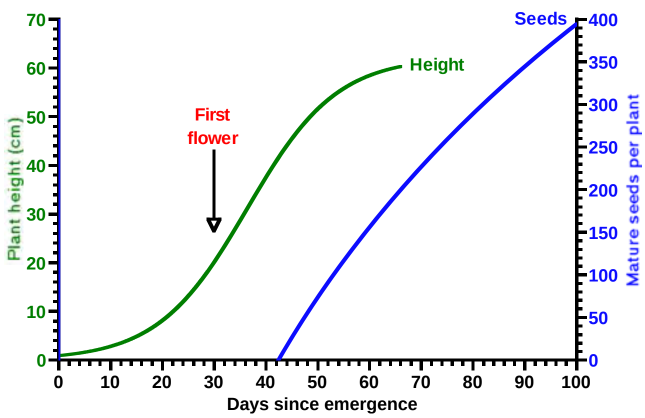
Annual N	
Frost tolerant N	
Emergence	Winter - summer
Days to emerge	7 - 15
Typical emergence	6%
Depth of emergence	
First flowers	23 days
Mature seed pods	30 days
Seeds per pod	2 - 4
Seeds per medium plant	
Mature plant height	0.7 m
An introduced weed N	

Sesbania (*Sesbania canabina*)



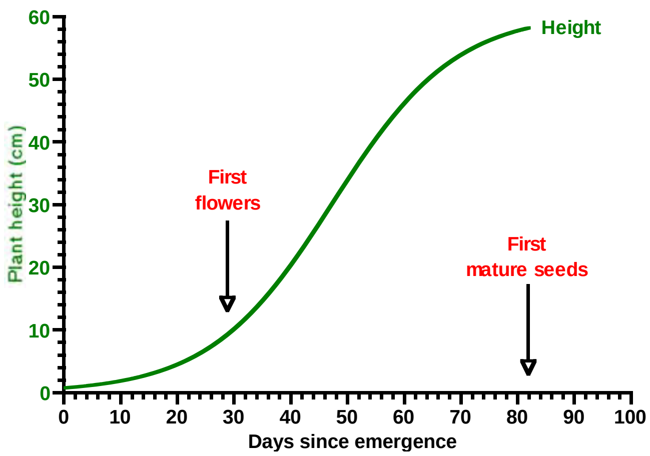
Annual N	
Frost sensitive N	
Emergence	Spring - autumn
Days to emerge	4 - 9
Typical emergence	5%
Depth of emergence	
First flowers	40 days
Mature seed pods	60 days
Seeds per pod	20 - 30
Seeds per medium plant	10 000 - 20 000
Mature plant height	2 - 3.5 m
A native plant N	

Velvet leaf (*Abutilon theophrasti*)



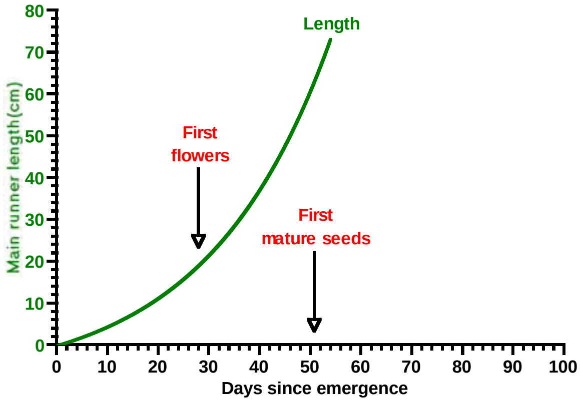
Annual N	
Frost sensitive N	
Emergence	Spring - autumn
Days to emerge	3 - 7
Typical emergence	5%
Depth of emergence	
First flowers	30 days
Mature seed pods	45 days
Seeds per pod	2 - 3
Seeds per medium plant	1000 - 12 000
Mature plant height	1.4 m
An introduced weed N	

Wild gooseberry (*Physalis minima*)



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

Yellow vine (*Tribulus micrococcus*)



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

Information extracted from the:

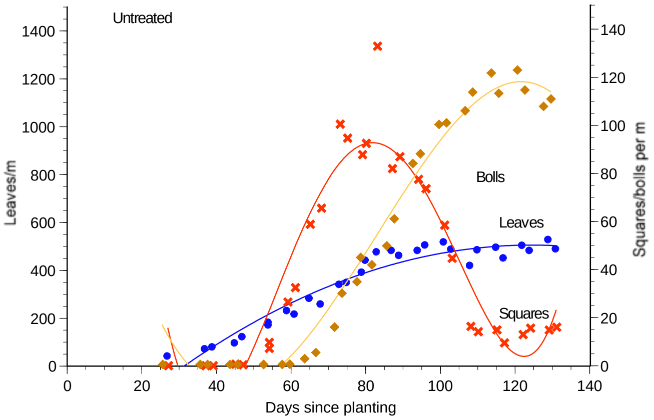
Herbicide damage guide for cotton

Available on the Cotton CRC website

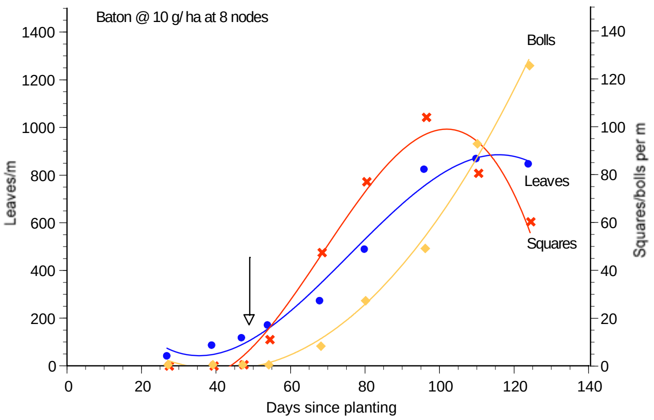
Contact: Graham Charles

NSW DPI, ACRI

02 6799 1524

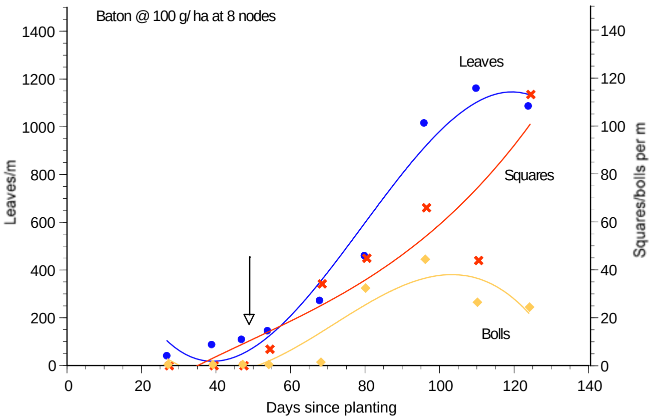


Equivalent to Amicide 625 @ 13 ml/ha
Exposed at 8 nodes



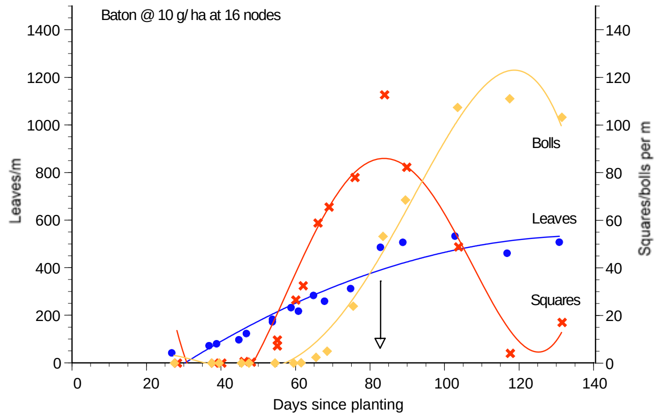
Final plant count data		
	Untreated	**2,4-D**
Nodes/plant	21.5	25.3
Leaves/m	502	844
Light interception	87%	91%
Leaf area (cm²/m)	22921	17210
Bolls/m	114	125
Boll weight (g/boll)	4.4	1.9
Days to 50% open	154	-
% Open bolls at picking	82%	36%
Lint yield/ha	1649	1383

Equivalent to Amicide 625 @ 128 ml/ha
Exposed at 8 nodes



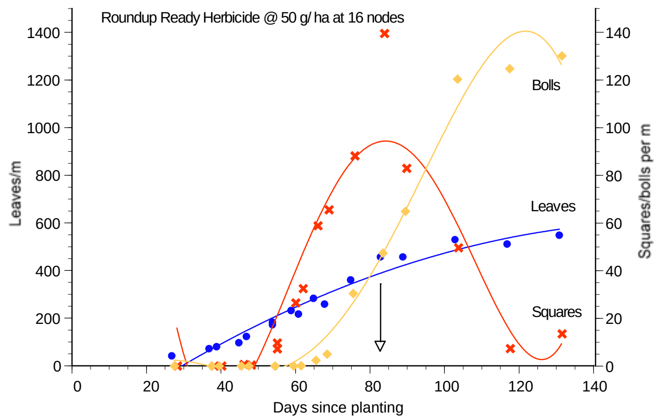
Final plant count data		
	Untreated	**2,4-D**
Nodes/plant	21.5	24.6
Leaves/m	502	1084
Light interception	87%	79%
Leaf area (cm²/m)	22921	14693
Bolls/m	114	24
Boll weight (g/boll)	4.4	0.4
Days to 50% open	154	-
% Open bolls at picking	82%	8%
Lint yield/ha	1649	277

Equivalent to Amicide 625 @ 13 ml/ha
Exposed at 16 nodes



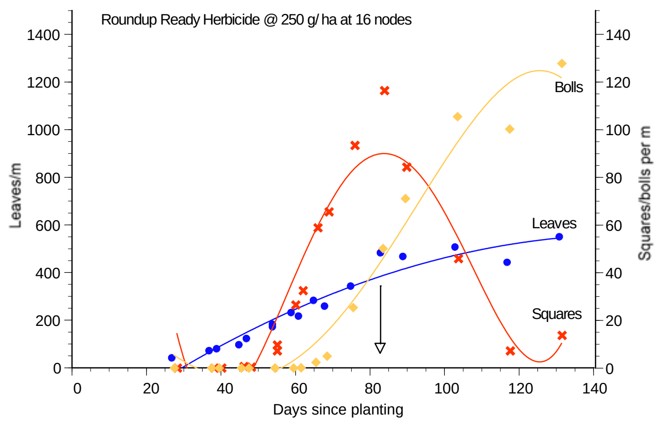
Final plant count data		
	Untreated	2,4-D
Nodes/plant	21.5	20.9
Leaves/m	502	504
Light interception	87%	86%
Leaf area (cm²/m)	22921	16692
Bolls/m	114	103
Boll weight (g/boll)	4.4	4.9
Days to 50% open	154	172
% Open bolls at picking	82%	74%
Lint yield/ha	1649	1504

Equivalent to Glyphosate CT @ 64 ml/ha
Exposed at 16 nodes



Final plant count data		
	Untreated	glyphosat
Nodes/plant	21.5	21.6
Leaves/m	502	545
Light interception	87%	83%
Leaf area (cm²/m)	22921	19966
Bolls/m	114	130
Boll weight (g/boll)	4.4	4.0
Days to 50% open	154	170
% Open bolls at picking	82%	65%
Lint yield/ha	1649	1649

Equivalent to Glyphosate CT @ 320 ml/ha
Exposed at 16 nodes



Final plant count data		
	Untreated	glyphosat
Nodes/plant	21.5	22.4
Leaves/m	502	547
Light interception	87%	84%
Leaf area (cm²/m)	22921	17681
Bolls/m	114	127
Boll weight (g/boll)	4.4	4.4
Days to 50% open	154	180
% Open bolls at picking	82%	68%
Lint yield/ha	1649	1606

Herbicide: 2,4-D amine
Rate: 80 g a.i./ha
% of typical field rate 10%
Date of exposure: 4th Jan (7½ weeks post-emergence)
Growth stage at exposure: 12 nodes

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: I
Translocation: readily moves to the plant growth points
Mode of action: An auxin-type (phenoxy) herbicide. 2,4-D affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause abnormal increases in RNA, DNA & protein biosynthesis, resulting in uncontrolled cell division & growth.
Residual activity: limited
Soil half-life: 10 days in moist soil

Cotton plants at 12 nodes at the time of herbicide exposure.

1 day after exposure.

The 2,4-D exposure initially caused bending and twisting of the petioles (leaf stems), giving a wilted appearance.

2 days after exposure.

The bending and twisting of the petioles (leaf stems), has largely disappeared.

5 days after exposure.

The most apparent sign of damage at this stage is reddening of the petioles.

15 days after exposure.

The petioles are still very red.

The signs of damage to emerging leaves are becoming apparent. The margins of expanding leaves are crinkled, and smaller leaves are distorted.

21 days after exposure.

All emerging leaves are distorted and cupped.

28 days after exposure.

The sign of 2,4-D damage are readily apparent. New leaves on the damaged branches are short, narrow, cupped, twisted and distorted.

28 days after exposure the 2,4-D damage is easily seen by looking down the rows.

37 days after exposure.

42 days after exposure.

49 days after exposure.

63 days after exposure.

79 days after exposure.

Herbicide:	**2,4-D amine**	
Rate:	**8 g a.i./ha**	
% of typical field rate	**1%**	
Date of exposure:	**4th Jan** (7½ weeks post-emergence)	
Growth stage at exposure:	**12 nodes**	

Damage key:	
Leaf loss	
Leaf distortion	**x**
Petiole distortion	**x**
Plant stunting	
Square shedding	**x**
Boll shedding	**x**

Herbicidal action

Herbicide group: **I**

Translocation: readily moves to the plant growth points

Mode of action: An auxin-type (phenoxy) herbicide. 2,4-D affects cell wall plasticity & nucleic acid metabolism. Low concentrations cause abnormal increases in RNA, DNA & protein biosynthesis, resulting in uncontrolled cell division & growth.

Residual activity: limited

Soil half-life: 10 days in moist soil

Cotton plants at 12 nodes at the time of herbicide exposure.

1 day after exposure.

No strong symptoms of the 2,4-D damage are apparent at this stage.

2 days after exposure.

The petioles are beginning to redden.

15 days after exposure.

The petioles are very red.

The signs of damage to emerging leaves are becoming apparent. The margins of expanding leaves are crinkled, and smaller leaves are distorted.

21 days after exposure.

All emerging leaves are distorted and cupped.

28 days after exposure.

The sign of 2,4-D damage are readily apparent. New leaves on the damaged branches are short, narrow, cupped, twisted and distorted.

28 days after exposure the 2,4-D damage is easily seen by looking down the rows.

37 days after exposure.

49 days after exposure.

63 days after exposure.

79 days after exposure.

Herbicide:	**gyphosate**	
Rate:	**173 g a.i./ha**	
% of typical field rate	**17%**	
Date of exposure:	**4th Jan** (7½ weeks post-emergence)	
Growth stage at exposure:	**12 nodes**	

Damage key:	
Leaf loss	
Leaf distortion	x
Petiole distortion	x
Plant stunting	
Square shedding	x
Boll shedding	x

Herbicidal action

Herbicide group: M
Translocation: moves throughout the plant to growth points
Mode of action: Inhibits EPSP synthase, leading to the depletion of some amino acids, preventing protein synthesis.
Residual activity: none
Soil half-life: 47 days in moist soil

Cotton plants at 12 nodes at the time of herbicide exposure.

1 day after exposure.

2 days after exposure.

At no stage were any symptoms of glyphosate damage apparent on this crop.

5 days after exposure.

15 days after exposure.

21 days after exposure.

28 days after exposure.

37 days after exposure.

49 days after exposure.

63 days after exposure.

79 days after exposure.