Cotton Catchment Communities CRC

FINAL REPORT

Part 1 - Summary Details

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Part 3 – Final Report

The first part of this report is structured with a section on each of the four objectives covering background, methods, results and outcomes.

Objective 1: To identify at-risk weeds for evolving glyphosate resistance and species shift.

Background

Weed management practices in the Australian cotton industry have changed from systems based around tillage, to minimum or zero-tillage systems based on frequent use of glyphosate and permanent beds in irrigated systems. Even before the introduction of glyphosate-tolerant varieties, glyphosate was becoming commonly used for pre-plant knockdown applications, and shielded applications within the crop. Glyphosate use in fallow has largely replaced tillage, particularly in dryland systems.

Previous surveys conducted in cotton-based farming systems had already shown some shift towards glyphosate-tolerant, small seeded species favoured by frequent glyphosate use and little or no tillage. The introduction of glyphosate-tolerant cotton in 2000 created an even greater reliance on glyphosate.

This objective was developed to determine what changes there had been, and identify weeds and practices at risk of evolving glyphosate resistance and species shift.

Methodology

Information on the weed species present and management practices was gained from the range of surveys that had been conducted in Australian cotton systems. The surveys reviewed were:

- surveys of irrigated fields conducted by NSW DPI from 1992 to 2001 (Charles et al 2004);
- surveys conducted by QDPI&F in 2001 (Walker et al. 2005); and
- weed management audits from Roundup Ready/Flex crops from 2003-2007 (provided by Monsanto).

The first two surveys were conducted prior to the introduction of glyphosate-tolerant cotton, although glyphosate was widely used in other phases of the rotations.

Fifty fields were selected that had been previously surveyed in dryland cropping systems in 2001 and irrigated cotton fields surveyed in 1992, 1996 and 2001. Four new surveys were done in the 2008-09 and 2010-11 seasons. Surveys were conducted at the start of the summer cropping season (November-December) and the second at the end of the same season (March-April). Surveys were done at these times to gain an understanding of what weed species were present at the time early season herbicides are applied, and to identify weeds that either germinated later in the season, or were not controlled.

A glyphosate resistance risk assessment was conducted by examining species characteristics and management practices. The major species characteristics that contribute to resistance evolution are high seed production and a high proportion of the seed bank present at the time of spraying. Other characteristics that contribute, but are not considered as important, are mating and reproductive methods and the potential number of generations in a year. The second part of the glyphosate resistance risk assessment involved management practices. The main factors affecting the intensity of selection for resistance evolution are the number of glyphosate applications, the control of survivors of glyphosate applications and the use of alternatives to glyphosate. Competition from crops was also considered. Information was gained from 50 cotton growers. The species characteristics and management practices were rated for relative importance and given weightings to reflect this.

<u>Results</u>

Bladder ketmia, peachvine and barnyard grass rated in the top 10 in all surveys. Nutgrass rated highly in both irrigated fields and RR/Flex fields. In the case of fleabane, it was rated 14th in dryland fields and 20th in irrigated fields in 1996. However in the audit of RR/Flex fields its rating increased from 7th in 2003 to 2nd in 2007, indicating that it is becoming more of a problem due to its tolerance to glyphosate based weed management.

The weed audits in RR/Flex fields do not show which species were present at the time of spraying, rather what has survived since the last glyphosate spray, and any new possible germinations. This information can, however, be matched to the last season surveys of residual weeds in dryland fields. Fleabane, barnyard grass, peachvine and pigweed were poorly controlled in fallow and cotton crops in the dryland survey, and this was also the case in the RR/Flex audits. Fleabane and peachvine are tolerant to glyphosate, and barnyard grass, pigweed and fleabane are also favoured by reduced tillage. Detailed information is included in the technical report under "Review of existing data on weed management and practices in Australian cotton systems" (pages 10 - 16).

The major change in weed species presence found in the field surveys was the increase in fleabane. In the dryland cotton surveys in 2001 it was ranked 14th compared to 2nd in 2008 and then 1st in 2010. Fleabane did not rank in the top 20 in surveys of irrigated cotton in 1992 – 2001, but was also ranked 1st in 2010. Fleabane is particularly adapted to no-till systems based on glyphosate. It has long been considered tolerant, and more recently was confirmed resistant to glyphosate.

Sowthistle was ranked 13th in the survey of irrigated cotton in 1992 – 2001, but increased to 3rd in 2008 and then 2nd in 2010. It was also ranked highly in the survey of dryland cotton systems in 2001. Like fleabane, sowthistle is a small seeded asteraceae that is favoured by no-till cropping systems as it virtually only germinates from the soil surface. Bladder ketmia and peachvine have also maintained their prevalence; both have strong dormancy, can remain viable in the soil for many years and will emerge almost year round when moisture conditions are right. In the 2010-11 survey, a slight increase in prevalence in some annual summer grasses was observed. These include button grass, native millet, summer grass and feathertop Rhodes grass. Prevalence of feathertop Rhodes grass was similar to that in the 2008-09 survey. It is a problem weed in central Queensland, and appears to be on the increase in the survey region as well. Detailed information is included in the technical report under "Collection of current information on weed species changes in cotton cropping systems" (pages 17 - 27).

When the weed species present in the industry were assessed for their resistance risk based on their biological characteristics, those with the highest ratings were:

- sweet summer grass
- fleabane
- liverseed grass
- feathertop Rhodes grass
- sowthistle
- barnyard grass.

When the management practices are viewed with respect to risk species for resistance risk the situations that stand out are as follows:

- Resistance and species shift
    - Fleabane in winter and summer fallows, RF cotton, other winter crops, and sorghum
    - Sowthistle in winter and summer fallows, non-irrigated RF cotton and other winter crops
    - Barnyard grass in non-irrigated and irrigated RF cotton, summer fallow, and sorghum
    - Feathertop Rhodes grass in non-irrigated and irrigated RF cotton, summer fallow and sorghum
- Resistance
    - Sweet summer grass in non-irrigated and irrigated RF cotton, summer fallow and sorghum in Central Queensland
    - Paradoxa grass, barley grass and annual ryegrass in winter fallow and other winter crops
- Species shift
    - Australian bindweed, peachvine, annual verbine, caustic weed and dwarf amaranth in non-irrigated and irrigated RF cotton, summer fallow and sorghum.

Detailed information is included in the technical report under "Determining the glyphosate resistance risk in cotton and grains systems" (pages 28 - 36).

Outcomes

We now have a clear understanding of weed species present in the cotton cropping systems (dryland and irrigated) that are at risk of evolving glyphosate resistance. Identification of weed species that are surviving current practices and are still present at the end of the season posing a risk for species shift to an increasing number of glyphosate tolerant weeds. The situations above describe very real risks to glyphosate-dominated farming systems, with fleabane a prime example. Growers are strongly encouraged to monitor these weed species that are high risk, and target and refine their weed management so that glyphosate is used sustainably in conjunction with alternatives to so minimise these risks.

Objective 2: To devise management tactics for indentified glyphosate resistant and tolerant weeds

<u>Background</u>

Glyphosate resistant barnyard grass populations were detected in grain cropping systems in 2007 and in a cotton farm in 2009 following a long rotation of summer fallows and RR cotton. In this project, research was undertaken to develop control options for glyphosate resistant barnyard grass in a cotton crop, which complements research undertaken in a GRDC-funded project (DAQ00136), which is investigating control options for this problem weed in summer fallows, most of which is applicable also to cotton farming systems.

In recent years fleabane has become a major problem weed of grain and cotton systems in southern Queensland and northern NSW (as noted in Objective 1). Early in 2011 eight populations of this weed were confirmed as glyphosate resistant. These populations were from no-till grain farms in southern Queensland and northern NSW. In this project, research was undertaken to develop control options for fleabane in a cotton crop, which complements research undertaken in a GRDC-funded project (DAQ00137), which is investigating control options for this problem weed in fallows, wheat and sorghum, most of which is also applicable to cotton farming systems.

<u>Methods (barnyard grass)</u>

The level of glyphosate resistance was quantified in two dose response experiments (pot and field). In the pot experiment, survival of the resistant population was compared with a known susceptible population to seven rates of glyphosate. Similarly, the survival of the natural infestation of resistant population was measured following treatment with seven rates of glyphosate applied to two weed ages (seedling and mid-tillering).

The efficacy of six residual herbicides was determined in two field and two glasshouse experiments. Assessment continued for 2-5 months to determine the length of residual control. In the grains project, pot and field experiments investigated the efficacy of double knock tactics, residuals and knockdown alternatives to glyphosate, as well as research on the weed's ecology and seed-bank dynamics.

<u>Methods (fleabane)</u>

Two pot and one field experiment investigated the efficacy and length of control with five or six residual herbicides. In the GRDC project, 21 pot and field experiments investigated:

- Impact of weed age and moisture stress on efficacy of knockdowns, glyphosate mixes, double knock, and wheat selective herbicides
- Options for controlling larger weeds

- Efficacy of residual herbicides
- Fine-tuning of the double knock tactic
- Fence-line control
- Importance of crop competition
- Levels of glyphosate resistance.

<u>Results (barnyard grass)</u>

The cotton glyphosate resistant population had approximately 3-fold resistance level, which is similar to that measured for the other populations from grain farms. Under ideal growing conditions in the field, the glyphosate resistant population was controlled adequately when glyphosate was applied at the maximum registered rate irrespective of weed size. However, control was poor when glyphosate was applied at the normally used field rates, particularly on tillering weeds.

Across all four experiments, pendimethalin consistently gave the best and longest control (up to 5 months). Metolachlor also provided excellent residual control initially (up to 2 months) but this product was not as persistent as pendimethalin. Norflurazon also showed some promise and may be worth further investigation. Trifluralin gave excellent control in the pot experiments where the chemical was well incorporated into the soil following application. For more information, see “Experiments on glyphosate resistant barnyard grass:” in the Technical Report (pages 37 - 47).

<u>Results (fleabane)</u>

Several cotton residual herbicides - metolachlor, norflurazon, prometryn and convoy - provided good to excellent control for up to two months. For more information, see “Experiments on fleabane” in the Technical Report (pages 48 – 51).

Some key points for effective control in grain systems are:

- Monitor paddocks for new flushes especially in autumn and spring
- In fallows, spray small weeds (<5cm diameter rosettes) with glyphosate mix (such as Tordon 75D) or non-glyphosate knockdown (such as Amitrole)
- Knockdown efficacy drops markedly on older and larger weeds
- For dense infestations or larger rosettes, use the double knock tactic by spraying paraquat products (such as Sprayseed or Alliance) approximately 7 days after the glyphosate mix
- Consider adding a residual to the double knock for season-long control
- Follow-up sprayed survivors with robust rates of knockdowns (such as Sprayseed, Amitrole, Alliance) using weed detector sprayer as outlined in the new Weedseeker permit (PER11163)
- Grow a competitive winter cereal with row spacing ≤30cm
- Spray small weeds with Group I products in winter cereal.

Outcomes

Unfortunately, the number of glyphosate resistant populations of barnyard grass and fleabane are likely to increase in cotton farming systems in the near future. Thus, it is important to have available a range of effective tactics for the different parts of the rotation. This project, in collaboration with the GRDC projects, has successfully developed a number of alternatives to glyphosate for highly effective control in both the summer fallow and cotton crop. These include a number of residual herbicides that provide several months of control, knockdowns and double knock. Discussions are in progress with chemical companies for modifying herbicide labels to include these weeds where applicable.

Objective 3: To predict the impact of current management practices on glyphosate resistance evolution

Background

The largest driver for resistance evolution is management practices. Using one herbicide continuously has been consistently shown to be the major cause of resistance, regardless of species. It is therefore critical that growers adopt management practices that do not promote glyphosate resistance. Robust IWM programs will successfully prevent and manage resistant populations. However, growers need to tailor them to their weed species present and crop rotations for them to be cost effective as well.

In this region, farming systems are highly variable, with a wide range of crops and management practices used. As a result the industry-wide glyphosate resistance risk is likely to be quite different from a grower's individual risk. In order to identify and predict the impact of current management practices on glyphosate resistance evolution, we undertook the development of an online tool that can:

1. Enable a grower to assess his own individual glyphosate resistance risk
2. Enable a grower to identify what changes to management practices can be made to reduce that risk
3. Obtain information from the industry as a whole on high risk situations.

In addition, the barnyard glyphosate resistance model developed in the previous GRDC project will be expanded to include cotton and additional weed species. This will enable further prediction of management practices to prevent and manage glyphosate resistance evolution.

Methods

RAT development

A glyphosate resistance risk framework was developed as part of Objective 1 by identifying the biological characteristics and management practices that contribute to resistance evolution in different weed species. For more information see the "Determining the glyphosate resistance risk in cotton and grains systems" section in the Technical Report (pages 28 - 36). This framework formed the basis of the risk assessment tool.

The risk assessment tool (RAT) was developed in conjunction with the DEEDI Strategic Communication and Marketing (SC&M) team in Brisbane as a Flash package for online delivery. The tool was designed to also send an automated email with each user's selections and scores to us, which we then used to build a database of responses. Initial tool prototypes were reviewed by researchers and extension team members in CRDC, Cotton CRC, Monsanto and DEEDI. For more information on how the RAT was developed see the "Construction of the Risk Assessment Tool (RAT)" section in the Technical Report (pages 52 - 63).

Addition of Cotton and Weed Modules to glyphosate resistance model

APSIM's existing module for cotton (*ozcot*) was modified to simulate herbicide tolerant varieties. A substantial amount of programming work was done to simulate irrigated and dryland cotton rotations, agronomy, and a suite of weed control methods including glyphosate and non-glyphosate knockdowns, residual herbicides, and tillage options. With these additions, the model can be used to simulate continuous cotton cropping or mixed cotton and grains rotations. For more information see the section on "Adding cotton to DEEDI's glyphosate resistance model" in the Technical Report (pages 70 - 74).

New modules for several key weed species were developed in conjunction with a GRDC project on herbicide resistance in the northern region. New modules were created and parameter values developed for sowthistle, liverseed grass, sweet summer grass, and fleabane. In addition, the existing barnyard grass module was overhauled. The new weed modules include improved treatment of multiple cohorts and the ability to simulate the production of more than one generation per year. The modules for sowthistle and barnyard grass were used in simulations for this project to investigate the effectiveness of resistance-prevention measures on two different classes of weeds. For more information, see the section "Adding new weed species to DEEDI's glyphosate resistance model" in the Technical Report (pages 76 - 80).

<u>Results</u>

Risk Assessment Tool publication

The Online Glyphosate Resistance Toolkit, comprising the risk assessment tool, the resistance quiz, and a small package of useful information, was published on the DEEDI website in May 2010. It is available at http://www.dpi.qld.gov.au/26_16653.htm and is freely accessible to all.

Use of modules in simulations

As noted in the Methods and Outcomes sections for Objective 4 below, the new weed and crop modules were used to run simulations on almost 100 different scenarios. See the section "Simulations" in the Technical Report (pages 80 - 92).

<u>Outcomes</u>

To date, the Risk Assessment Tool has been used 38 times by growers and agronomists running 'live' scenarios (either their current real practices or modified systems to test the effects of possible practice change) as well as a number of times by users who submitted no data and who we judged were merely checking out how the tool works. As far as we are able to judge, most of the 'real' runs have been by different users. We have also used the tool to test and teach resistance risks in workshops with growers in Dirranbandi and St George, and in individual sessions with several growers.

We used the online toolkit to generate a database of risk scores and management practices and analysed the responses. Glyphosate resistance risks were found to be highest on average in fallows and dryland glyphosate-resistant cotton crops, and averages for all users turned out lower than expected. However, risks and practices were found to vary substantially within and between common crops and fallows (see Table 1), with some growers returning extremely high risk scores in almost all phases. So, while the results suggest that industry should regard summer fallows and dryland glyphosate-resistant cotton crops as being relatively high-risk phases of any rotation, individuals' own resistance risks are likely to be significantly different from the average. Therefore, results strongly support the idea that growers should assess and respond to their resistance risk individually, rather than relying on whole-industry assessments of risk and generic resistance management strategies. With the toolkit as it stands, growers and agronomists have a useful tool for investigating the value of a range of different practices that they view as having potential for their situation.

Table 1. Risk score means and ranges for all phases reported in the online tool

Phase	Mean risk score	Risk score range
Summer fallow	1.5	0 - 5.0
Dryland GR cotton	1.4	0 - 2.9
Irrigated GR cotton	1.1	0 - 2.8
Winter fallows	0.9	0 - 4.0
Other winter crops	0.5	0 - 3.0
Sorghum	0.4	0 - 3.9
Other summer crops	0.2	0 - 0.9
Barley	0.2	0 - 1.6
Wheat	0.1	0 - 1.8
Irrigated conventional cotton	0*	0
Summer average	*0.86*	*0 - 3.9*
Winter average	*0.34*	*0 - 2.1*

*Only one user reported growing conventional irrigated cotton. No users reported growing dryland conventional cotton.

The resistance quiz has been completed around 60 times and again we believe most of these uses are by different users. Table 2 shows that average scores are quite high, indicating a surprisingly good level of knowledge, at least among those who elected to seek out and use the quiz. Should the quiz be applied more widely (and not in a self-selecting process) it is likely that the average score would be lower. The largest category of respondents was those who identified themselves as consultants (14 users).

Table 2. Scores (expressed as a percentage of questions correct) obtained by users of the online resistance quiz

User category	Mean score	Score range
Cotton growers*	84	74-89
Grain growers	86	80-91
Agronomists	81	49-100
Others**	61	31-100

*Users' responses form part of the average for more than one category if they identified themselves as belonging to more than one industry sector.

**"Others" includes students, researchers, and unspecified industry participants

Objective 4: To devise and deliver management strategies for farming systems with herbicide tolerant cotton that will minimise glyphosate resistance evolution and species shift to glyphosate tolerant weeds

Background

The project team has delivered management strategies for minimising glyphosate resistance evolution in a number of ways. Throughout the life of the project, team members have presented findings at the Cotton Conference, GRDC Updates, IWM workshops, GLYCOM and other venues. These are listed in the "Publications" section of this report.

In addition, the DEEDI weeds team, in partnership with the Cotton Extension Team, developed a framework for "Herbicide Resistance" workshops that can be delivered by extension members and industry.

The expanded glyphosate resistance model was used to identify the long-term benefits of preventative tactics in reducing the risk of glyphosate resistance. The results from these simulations were interpreted and used in the development and refinement of strategies.

Methods

Herbicide Resistance Workshops

A meeting was held with the project team and the cotton extension team to discuss how a series of herbicide resistance workshops could be delivered to growers. The group decided, in conjunction with CRDC, that the project team would develop a framework by which these workshops could be delivered by either the extension team or industry, with the aid of the relevant researcher. The DEEDI weeds team, as part of the previous GRDC weeds project, had developed a number of herbicide resistance workshops for grain growers. The reference material for these workshops was then adapted to be more relevant to farming systems with cotton.

The framework consisted of producing a training manual with all relevant information included. This could then be adapted as a workshop manual that consisted of relevant material for the particular growers attending the workshop and their knowledge level. This provides the workshop facilitator and presenters with all the material they needed to run the workshops.

Simulation plan for GR model

The project team put together a simulations plan to test the impact of over 90 scenarios on the rate of resistance evolution and weed seed bank increase (or decline) in three broad categories:

1. Crop rotations (tested rotations that included conventional cotton, sorghum, and wheat in rotation with glyphosate-resistant cotton at different frequencies)

2. Controlling glyphosate survivors (tested different frequencies and efficacies of controlling survivors of glyphosate sprays)

3. Preventative effects of IWM measures (tested the preventative and management benefits of tillage, pre-plant residuals and layby residuals in different combinations and at different frequencies)

In all scenarios, an irrigated cropping system with one crop every year (and no summer fallows) with a dryland system with one cotton crop every two years with three different kinds of weed management in the summer fallows:

A. glyphosate alone

B. glyphosate plus the non-glyphosate tactics used in-crop

C. IWM fallow including a residual herbicide and a double knock of glyphosate followed by paraquat.

The full simulations plan can be reviewed in the section 'Simulations' in the Technical Report (pages 80 - 92).

Results

Herbicide Resistance Workshops

The training manual has been completed and consists of the following modules:

1. Principles of herbicide resistance
2. Understanding the enemy
3. Weed management tactics – the toolbox
4. Developing an IWM plan (putting it all together)
5. Testing for resistance (what to do if glyphosate resistance is suspected)
6. Case studies
7. Group Activities.

The manual also contains number of supporting factsheets, brochures and other documents relevant to herbicide resistance. A copy of the manual is included as an attachment to this report.

Simulation results

The differences and similarities in the responses of the two species demonstrate the importance of finding and using the right IWM tactics if glyphosate's useful lifespan is to be maximised.

Sowthistle was generally found to take longer to reach 100% resistance than barnyard grass. In dryland continuous cotton systems where only glyphosate is used (the highest-risk cotton simulations), barnyard grass was predicted to develop resistance after 13 years, and sowthistle after 18 years. Conversely, slowing or preventing resistance was found to be more feasible in barnyard grass.

Irrigated continuous cotton systems were predicted to have substantial resistance advantages over dryland cropping, especially for barnyard grass. Resistance can be prevented in barnyard grass for more than 30 years in irrigated systems with one to two non-glyphosate actions in every crop under irrigation. Resistance was not predicted to be entirely preventable in dryland cropping, except where all survivors are controlled vigorously (99.9% survivors controlled on all cohorts in crop) or two non-glyphosate actions occur in both crop and fallow each year.

Long-term seed bank management in both species is predicted to be possible where modest but well-targeted IWM actions are implemented in both crop and fallow, even after resistance begins to evolve. It is useful to note that the scenarios with prevented or slowed resistance are largely the same scenarios, in which seed banks can be controlled in the long term, so strategies are likely to be similar for both aims.

Summary tables and detailed analysis of results can be found in the section 'Simulations' in the Technical Report. Graphs of all simulations are presented as an appendix to the Technical Report.

<u>Outcomes</u>

Herbicide Resistance Workshops

Two resistance workshops have been held, at St George and Dirranbandi. However due to changes in the extension team, no further workshops occurred.

Simulations

The results from the simulations have been analysed and incorporated into industry-wide strategies for preventing, slowing, and managing glyphosate resistance.

1. Controlling survivors of in-crop glyphosate sprays is the most effective way to prevent or slow resistance. In dryland systems this must be accompanied by at least one non-glyphosate action in every fallow for reliable prevention and long-term seed bank control.
2. For barnyard grass, attempting to control glyphosate survivors in every cohort in GR cotton was more beneficial than getting very high efficacy on survivors in only one cohort, while the reverse was true for sowthistle. Controlling less than one cohort in-crop per year was not an effective strategy for either species.
3. In dryland systems, summer fallows must contain one or more non-glyphosate actions if any preventative or management strategy is to be effective. A relatively low-cost IWM fallow with one double knock and one residual is predicted to slow resistance and provide long-term seed bank control provided at least one robust non-glyphosate control tactic is applied in-crop.

4. Difficulties with obtaining very high efficacies with residual herbicides mean they should not be used as the sole non-glyphosate method in a resistance-prevention or management strategy. A pre-plant residual or a layby alone was not predicted to provide useful long-term prevention of resistance or management of resistant barnyard grass populations except in irrigated systems. However, a pre-plant residual plus layby plus one inter-row tillage was predicted to be very effective in all systems, especially when one or two non-glyphosate actions were also taken in dryland summer fallows. While residuals may control members of more than one cohort, tillage can be more effectively timed to control particular cohorts. So, using both tactics in crop has useful synergies.
5. Plant biology and ecology are important. Sowthistle was predicted to be slower to evolve glyphosate resistance than barnyard grass, but less effectively controlled by a range of IWM strategies in the longer term. The strategies most effective for prevention and management of resistance differed between the two species to some extent.

Most effective strategies for **slowing or preventing resistance** in **barnyard grass**:

- In irrigated systems:
    - Controlling survivors of all cohorts using inter-row tillage and/or chipping
    - Two to three of the following options used together in every crop (or every second crop providing one of the options is well-timed tillage):
        - Inter-row tillage
        - Pre-plant residual
        - Layby
- In dryland systems:
    - Controlling survivors of all cohorts with tillage followed up by chipping (or some other means of getting 99.9% control), further improved if one to two non-glyphosate options are also used in fallows
    - Two inter-row tillage in crop and one to two strategic tillage in fallows
    - Two to three of the following options used together in every crop AND summer fallow:
        - Tillage (inter-row in crop, full disturbance in fallow)
        - Broad acre residual (pre-plant in crop)
        - Layby

Effective strategies for long-term **seed bank management** of **barnyard grass**, including on resistant populations:

- In irrigated systems:
    - Controlling survivors of glyphosate sprays either:

        - On every cohort; or
        - At very high efficacy (99.9%); or both
    - Pre-plant residual plus layby, or inter-row tillage with or without a residual, every crop or every second crop
- In dryland systems:
    - Controlling survivors of glyphosate sprays with very high efficacy
    - Two or more IWM actions in summer fallows plus
        - Inter-row tillage plus layby or pre-plant residual every crop or every second crop

Most effective strategies for **slowing or preventing resistance** in **sowthistle**:

- In irrigated systems:
    - Controlling glyphosate survivors on all in-crop cohorts with inter-row tillage followed up by chipping
- In dryland systems:
    - With one to two non-glyphosate options in summer fallows AND a selective (group I) in winter AND a pre-plant residual plus one or both of a layby or inter-row tillage in crop
        - Pre-plant residual plus two inter-row tillage in crop, with summer fallows containing strategic tillage and a residual, was the most effective combination

Effective strategies for long-term **seed bank management** of **sowthistle**, including on resistant populations:

- In irrigated systems:
    - Control survivors of glyphosate sprays in one or more cohorts annually, with very high efficacy
    - Two inter-row tillage operations in crop (improved with the addition of pre-plant residual)
- In dryland systems:
    - Residual plus double knock in summer fallows plus:
        - Pre-plant residual, layby and tillage in conventional cotton
        - One to two non-glyphosate actions in RRFlex crops
    - Strategic tillage in fallows plus inter-row tillage in crop either:
        - Twice per crop or;
        - Once per crop with an added residual

The frequency at which these strategies are employed will determine their success, particularly in terms of slowing or preventing resistance.

Conclusions

Glyphosate resistance is now a reality for the Australian cotton industry. The case of resistance barnyard grass is the first confirmed of possibly more suspected and future glyphosate resistance cases. The reliance of cotton and grains systems on glyphosate has resulted in both glyphosate resistance, and species shift. Field surveys recorded the rise of fleabane, the "ultimate" weed in glyphosate based farming. Fleabane ranks high on both species shift and herbicide resistance risk assessments. In fact, populations of fleabane have been confirmed glyphosate resistant in NSW and Queensland grains systems. Other weed species such as liverseed grass, feathertop Rhodes, sowthistle and barnyard grass also were determined to have high risk ratings for developing glyphosate resistance. The continued reliance on glyphosate also contributed to the continued prevalence of peachvine, Australian bindweed, annual verbine in both non-irrigated and irrigated cotton farming systems.

When the management practices used in crop and fallow were investigated, it was found the summer fallows had the highest reliance on glyphosate, and therefore the highest risk. This was followed by non-irrigated Roundup Flex® and then conventional cotton. Species and crop phases at risk are highlighted in Table 3.

Field and glasshouse experiments concentrated on awnless barnyard grass and fleabane. The glyphosate-resistant barnyard population was confirmed to have a 3-4 fold resistance to glyphosate. Dose response experiments in the field showed that this population could still be controlled with a full label rate of Roundup Ready herbicide when plants were small and conditions were good. Residual herbicides, registered for barnyard grass control, were still effective on this population. This showed that resistant populations are able to be effectively managed in glyphosate-tolerant cotton systems.

A number of experiments were conducted on fleabane. In addition to diuron, a prometryn, Convoy® (prometryn+Fluometuron) and Norflurazon were effective in reducing fleabane emergences. Additional double knock trials conducted in the GRDC project again showed that controlling small weeds is important. The addition of Tordon 75-D improves control over 2,4-D however has limited use in a cotton system. Managing fleabane in a cotton system still remains a challenge as a number of effective herbicides have considerable plant backs to cotton. The in-crop options are limited besides layby residuals, and shielded paraquat product applications.

An online risk assessment tool (RAT) was developed for the following purposes:

1. Allows growers to assess the risk of glyphosate resistance developing with the practices they use
2. Allows growers to predict/determine ways they can reduce their risk by changing practices
3. Provides researchers with information on weed species present and practices used across the industry.

Table 3. Highest risk species for glyphosate resistance (GR) and species shift (SS) in relation to current management practices in 2010 surveys.

	Dryland GR cotton	Irrigated GR cotton	Summer fallow	Sorghum	Winter crops	Winter fallow
Fleabane	GR, SS	GR, SS	GR, SS	GR, SS	GR, SS	GR, SS
Sowthistle	GR, SS		GR, SS	GR, SS	GR, SS	GR, SS
Awnless barnyard grass	GR, SS	GR, SS	GR, SS	GR, SS		
Feathertop Rhodes grass	SS	SS	SS	SS		
Sweet summer grass	GR	GR	GR	GR		
Paradoxa grass					GR	GR
Barley grass					GR	GR
Annual ryegrass					GR	GR
Australian bindweed	SS	SS	SS	SS		
Peachvine	SS	SS	SS	SS		
Emu-foot	SS	SS	SS	SS		
Caustic weed	SS	SS	SS	SS		
Dwarf amaranth	SS	SS	SS	SS		

The RAT is a major achievement for the project, has been received well by the industry and the team is keen to see it used further. There are some improvements in terms of data capture and to distinguish between grasses and broadleaves, which will be undertaken in the next project.

Simulations from the enhanced glyphosate resistance model have shown that resistance can be prevented by a combination of three main tactics:

1. Control of survivors of glyphosate applications
2. Effective use of glyphosate alternatives in the fallows
3. Combining effective glyphosate alternatives in-crop.

Irrigated cotton systems, without summer fallows, generally used less high risk practices, and therefore had substantial advantages of dryland systems. This was particularly the case for barnyard grass.

Long-term management of the seed bank, which is just as important as resistance prevention, was predicted to be possible where well-targeted IWM actions were used in both crop and fallow. The simulations clearly showed that resistance prevention strategies need to employ effective non-glyphosate tactics over all phases of the rotation.

Extension Opportunities

1. Detail a plan for the activities or other steps that may be taken:

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

A new research project has been funded that will use this project technology to further improve control and management of identified risk species in transgenic cotton systems. The risk assessment tool will be further improved to differentiate between grasses and broadleaves, and allow same screen comparisons of the effects of potential management changes to resistance risks.

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

- Additions to Weedpak on key species will be made
- Presentation will be made relevant conferences
- Three articles have been drafted from project outcomes to be published in Cottongrower magazine
- Three papers are scheduled this year for submission to scientific journals
- Discussions and plans are underway with the new funded weeds extension specialist to extend these research outputs.

   (c) for future research.

The ability of genetic material (seed and pollen) of resistant plants to move across fields, farms and catchments needs to be researched. On farm resistance prevention strategies may be hampered by the addition of resistant material from outside. It is important that the pathways, potential distances and possible prevention strategies for movement of genetic material are investigated.

Further research on the ecology of identified risk species is also required. This will enable the identification of gaps in knowledge of the characteristics that allow these species to remain problem weeds in cotton systems.

Publications

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Walker S (2009) 'Latest research on fleabane' at the Annual meeting of Australian Glyphosate Sustainable Working Group, Moree

Werth J (2009) 'Protecting glyphosate in summer fallows – mixes with pre-emergent herbicides and double knocking trials' at GRDC Update, Goondiwindi

Walker S (2009) 'Herbicide resistance' to ChemCert Training Queensland, Dalby

Walker S (2009) 'The latest on fleabane control' at the CRT workshop, Toowoomba

Werth J (2009) 'Fleabane management' at CSD dryland cotton field day, Warra

Werth J, Widderick M, Boucher B and Walker S (2009) 'Protecting glyphosate in summer fallows – mixes with pre-emergent herbicides and double knocking trials' in Proceedings of GRDC Update, Goondiwindi

Werth J (2009) 'Preparing for summer – Double knock, residuals and resistance' at Cotton Trade Show, Moree

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<u>Grower Magazines and Articles</u>

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Steve Walker (2010) 'Fleabane problem needs all out attack' in Toowoomba Rural Weekly (p 9)

Steve Walker (2010) 'Hit fleabane young for control' in Oakey Champion (p 11)

Steve Walker (2011) 'Fleabane stands defiant' in Queensland Country Life (p 11-12)

Steve Walker (2011) 'Tough weeds unearthed locally' in Western Star (p 10)

On-line resources

"Glyphosate Resistance Toolkit" http://www.dpi.qld.gov.au/26_16653.htm

- Resistance knowledge quiz
- Risk Assessment tool

"Testing for glyphosate resistance" http://www.dpi.qld.gov.au/26_14562.htm

Part 4 – Final Report Executive Summary

The introduction of glyphosate tolerant cotton has significantly improved the flexibility and management of a number of problem weeds in cotton systems. However, reliance on glyphosate poses risks to the industry in term of glyphosate resistance and species shift. The aims of this project were to identify these risks, and determine strategies to prevent and mitigate the potential for resistance evolution.

Field surveys identified fleabane as the most common weed now in both irrigated and dryland system. Sowthistle has also increased in prevalence, and bladder ketmia and peachvine remained common. The continued reliance on glyphosate has favoured small seeded, and glyphosate tolerant species. Fleabane is both of these, with populations confirmed resistant in grains systems in Queensland and NSW.

When species were assessed for their resistance risk, fleabane, liverseed grass, feathertop Rhodes grass, sowthistle and barnyard grass were determined to have high risk ratings. Management practices were also determined to rely heavily on glyphosate and therefore be high risk in summer fallows, and dryland glyphosate tolerant and conventional cotton. Situations were these high risk species are present in high risk cropping phases need particular attention.

The confirmation of a glyphosate resistance barnyard grass population in a dryland glyphosate tolerant cotton system means resistance is now a reality for the cotton industry. However, experiments have shown that resistant populations can be managed with other herbicide options currently available. However, the options for fleabane management in cotton are still limited. Although some selective residual herbicides are showing promise, the majority of fleabane control tactics can only be used in other phases of the cotton rotation.

An online glyphosate resistance tool has been developed. This tool allows growers to assess their individual glyphosate resistance risks, and how they can adjust their practices to reduce their risks. It also provides researchers with current information on weed species present and practices used across the industry. This tool will be extremely useful in tailoring future research and extension efforts.

Simulations from the expanded glyphosate resistance model have shown that glyphosate resistance can be prevented and managed in glyphosate-tolerant cotton farming systems. However, for strategies to be successful, some effort is required. Simulations have shown the importance of controlling survivors of glyphosate applications, using effective glyphosate alternatives in fallows, and combining several effective glyphosate alternatives in crop, and these are the key to the prevention and management of glyphosate resistance.

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